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Resource-Recycling System for Domestic Wastewater Treatment Using Biogeofilter Ditches Planted with Useful Plants

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Abstract

It is necessary to develop an energy-saving and resource-recycling system for water purification in rural and mountainous areas. This paper outlines the development of a resource-recycling system for water purification. The purification system consisted of a combination of an anaerobic/aerobic treatment plant and biogeofilter (BGF) ditches filled with zeolite and Kanuma soil as bed filter materials. The BGF ditches were planted with useful aquatic and terrestrial plants. The average rates of total nitrogen (T-N) and total phosphorus (T-P) removal by the aquatic plants were 1.34 g m^{-2} d^{-1} and 0.34 g m^{-2} d^{-1}, respectively. The water purification system decreased the average T-N concentration to 0.31 mg L^{-1} and average T-P concentration to 0.22 mg L^{-1} from domestic wastewater in summer. The useful plants planted in the BGF ditches grew vigorously and were more productive indicating that the secondary effluent of the domestic wastewater contains essential nutrient elements. Thus, the use of this effluent for water culture of useful plants enables to purify the domestic wastewater and is also an effective means of nutrient recycling.

Discipline: Agricultural environment/Horticulture
Additional key words: domestic wastewater purification, nitrogen, phosphorus

Introduction

The nitrogen (N) and phosphorus (P) contained in domestic wastewater have recently been the major causes of water pollution in semi-closed water bodies such as Kasumigaura Lake. Until about 1955, human feces and urine were mostly returned to farmlands and used as valuable manure sources[8]. As a result, the water of rivers and lakes remained clear and a large number of species of organisms were able to live there, while children were provided with areas to observe nature, play, fish, and engage in other recreational activities.

Based on previous basic studies[3,5-7,12,13], the researchers of the Water Quality Control Laboratory constructed on an experimental basis biogeofilter (BGF) ditches filled with filtering materials and planted with useful plants[1,2,9-11]. These ditches can effectively use the adsorbing and filtering function of filtering materials, nutrient-absorbing function of plants, and water-purifying function of microorganisms. Using BGF ditches, the Laboratory has developed a resource-recycling water purification system for rural and mountainous areas. This BGF ditch is not costly and functions as an energy-saving wastewater treatment system suited to rural areas.

Characteristics and operation of BGF ditches

The resource-recycling water purification system consisted of a combination of an anaerobic/aerobic treatment plant and 2 BGF ditches 0.4×19.5 ×0.4^{H} m in size. The BGF ditches were filled with zeolite and Kanuma soil as bed filter materials. The Kanuma soil is one of the volcanic ash soils rich in allophane. The packing height of the filtering materials in the ditch could be adjusted according to the moisture tolerance of plants (Fig. 1). In this way, vegetables, and other useful terrestrial plants could be used for water purification purposes. As an example, in the ditch where some terrestrial plants were planted, the filtering material was packed up to a height of about 10 cm above the water level.

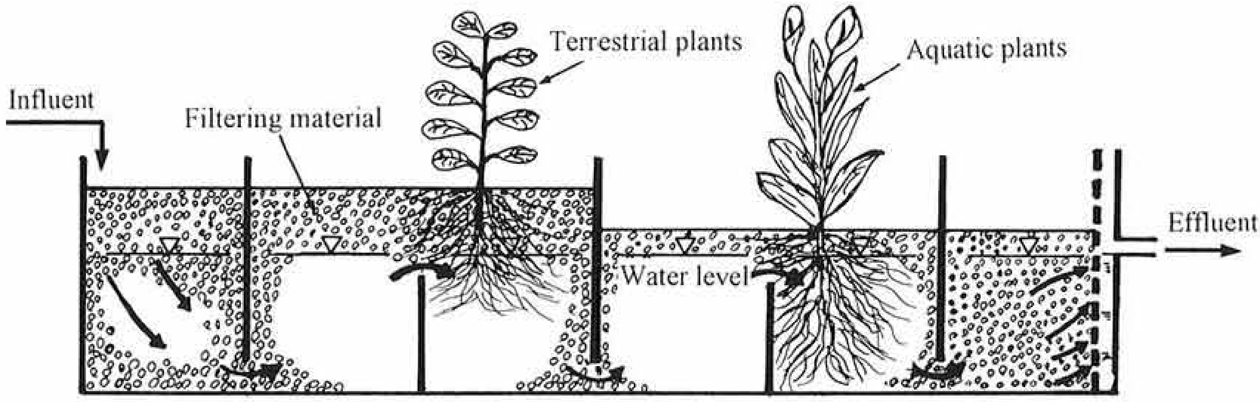

Fig. 1. Biogeofilter ditch with filtering materials

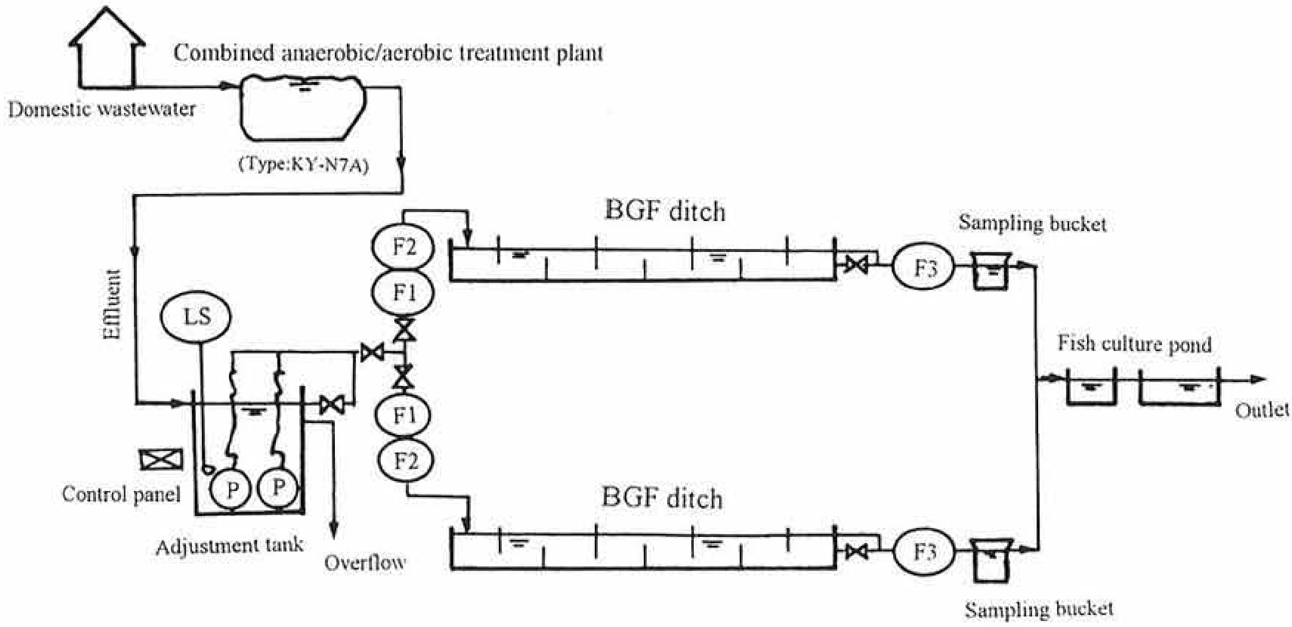

Fig. 2. Resource-recycling system for wastewater purification combining a treatment plant and BGF ditches
P: Pump, LS: Level switch, F1: Instantaneous flowmeter, F2: Integrated flowmeter, F3: Tipping-water flowmeter.

The water purification experiment was initiated in October 1993 using the domestic wastewater effluent from a family of five. The amount of wastewater was about 1 m^3 per day with 40 to 60 mg L^{-1} total N (T-N) and 4.5 to 7.0 mg L^{-1} total P (T-P). The domestic wastewater was treated in the combined anaerobic/aerobic treatment plant (Kirin Machinery Corp. Type KY-N7A) and introduced into the adjustment tank. Then the treated water was pumped to the BGF ditches at a rate of 30 to 45 L h^{-1}, which was measured by an instantaneous and integrating flowmeter. The amount of water flowing out of the ditches was measured by using tipping-water flowmeters (Fig. 2). Influent, water running in the ditch and effluent were sampled at least once a week and analyzed to evaluate the changes in the water purification function. The useful plants were replaced with new ones when they almost lost their nutrient-absorbing function after they had flowered and fruited.

Comparison of water purification function between a ditch with terrestrial plants and a ditch with aquatic plants

Fig. 3 shows the results of the water purification experiment in which terrestrial plants were grown in the first ditch (H ditch) while aquatic plants were grown in the second ditch (M ditch) in August 1996. In the M ditch planted with swamp

H ditch	Tomato	White jute	Basil	Mint	Lavender	Kenaf	Mint
M ditch	Swamp cabbage	Arrowhead	Rice		Lemongrass	Papyrus	

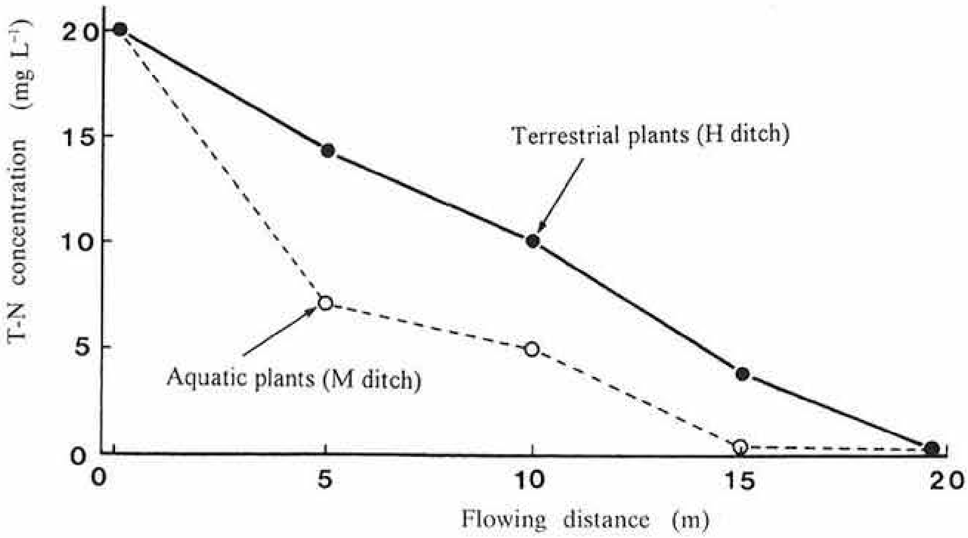

Fig. 3. Changes in total nitrogen concentration of wastewater effluent at varying flowing distances (August 1996)

Fig. 4. Growth conditions of useful plants in BGF ditches (August 1996)

cabbage (*Ipomoea aquatica* Forsk) and Chinese arrowhead (*Sagittaria sagittifolia* L.), the average reduction of the T-N concentration in the water was 12.7 mg L^{-1}. On the other hand, in the section of papyrus (*Cyperus papyrus* L.), the average decrease in the T-N concentration was 5.2 mg L^{-1} while only 1.9 mg L^{-1} in the section of rice (*Oryza sativa* L.). As a result, the average T-N concentration of effluents was 0.46 mg L^{-1}. In the H ditch, the concentration decreased roughly at the same rate when the water ran down to the end of the ditch. The T-N level of the effluents was reduced to 0.80 mg L^{-1}. The roots of the terrestrial plants reached only an area of about 10 cm below the water surface while the roots of papyrus, swamp cabbage and other aquatic plants reached the ditch bottom and displayed a much higher water purification function.

Fig. 5. Growth conditions of papyrus in the last section of M ditch

Fig. 4. shows the growth conditions of the plants cultivated in the BGF ditches. Tomato (*Lycopersicum esculentum* M.) plants produced more fruits while swamp cabbage, Chinese arrowhead grew very well. Kenaf (*Hibiscus cannabinus* L.) and papyrus planted in the rear of the ditches grew to a height of more than 2.5 m high. Fig. 5 shows the growth stages of papyrus planted in the last section of the 7.3 m long M ditch. The height of papyrus was 2.5 m in the upper part of the section but only about 1.2 to 1.5 m in the lower part. The plant growth decreased further when the growth of swamp cabbage and Chinese arrowhead planted in the upper ditch increased from mid-July to mid-September. This trend indicates that the papyrus in the upper part might have absorbed most of the nutrients from the influents. As shown in Fig. 3, the T-N concentration of the water in the lower part of the section was 0.2 to 0.3 mg L^{-1}, probably corresponding to the plants' critical purification function.

Simultaneous removal of T-N and T-P using zeolite and Kanuma soil

The changes in the T-N concentration of the effluent in the M ditch, in which zeolite and Kanuma soil were used as bed filter materials, and in the H ditch, in which only zeolite was used, are shown in Fig. 6. Transplanting was performed from April 20 to May 20. Aquatic plants such as

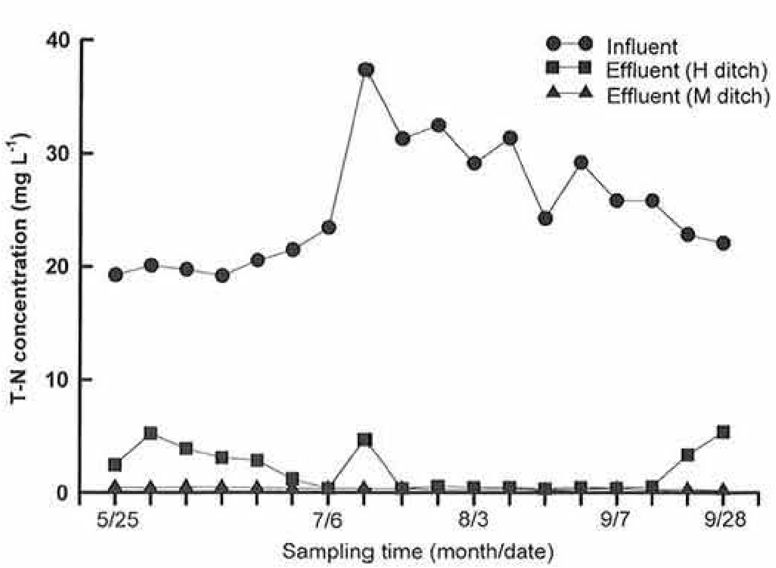

Fig. 6. Nitrogen purification of BGF ditches planted with useful plants in the summer of 1997

swamp cabbage, Chinese arrowhead, taro (*Colocasia esculenta* S.C.) and papyrus were planted in the M ditch while terrrestrial plants such as tomato, basil (*Ocymum basilicum* L.), mint (*Mentha* spp.) and kenaf were planted in the H ditch. The initial 5 mg L^{-1} T-N concentration of the effluent from the H ditch decreased to 0.4 mg L^{-1} when the growth rate of the terrestrial plants increased markedly at 6 weeks after planting. On the other hand, T-N concentrations of the effluent from the M ditch ranged from 0.21 to 0.54 mg L^{-1}.

The T-P concentration of the effluent from the H ditch ranged from 1.10 to 4.69 mg L^{-1} while in the M ditch, from 0.01 to 1.63 mg L^{-1} (Fig. 7). Tables 1 and 2 indicate the total N and P contents of the effluents from the M ditch in summer. From August to September, the total N and P concentrations were lower than those corresponding to the environmental water quality standards (T-N ≤0.4 mg L^{-1}, T-P ≤0.03 mg L^{-1}) in Kasumigaura Lake[4]. Swamp cabbage, taro, tomato and garland chrysanthemum (*Chrysanthemum coronarium* L.) planted in the Kanuma soil showed similar growth rates to those when planted in zeolite. Moreover, no evidence of micronutrient deficiency symptoms was observed. Especially, the height of the taro plants was 2.3 m and the yield was 22 kg m^{-2} (Fig. 8).

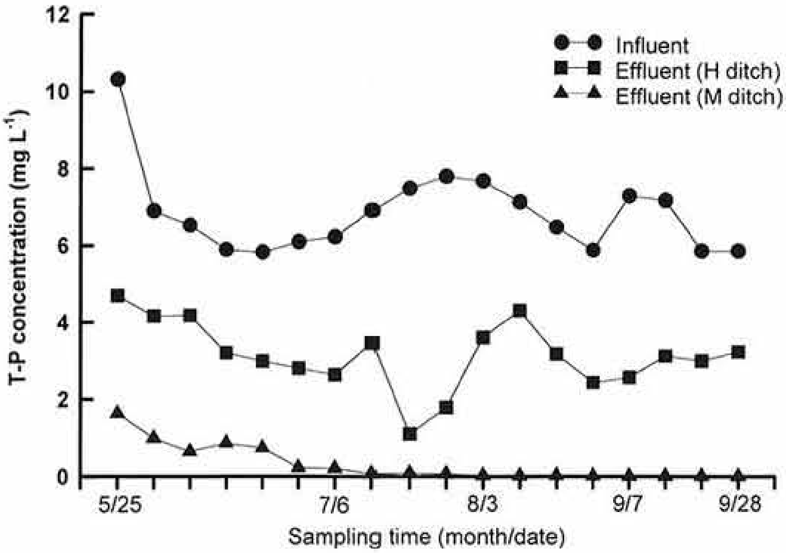

Fig. 7. Phosphorus purification of BGF ditches planted with useful plants in the summer of 1997

Table 1. Total nitrogen purification from domestic wastewater effluent by BGF ditch planted with aquatic plants in the summer of 1997

Date	Influent			Effluent			Removal rate ($g\ m^{-2}\ d^{-1}$)
	Flow rate ($L\ d^{-1}$)	Concentration ($mg\ L^{-1}$)	Loading rate ($g\ m^{-2}\ d^{-1}$)	Flow rate ($L\ d^{-1}$)	Concentration ($mg\ L^{-1}$)	Removal (%)	
June	372	20.22	0.96	271	0.38	99.0	0.95
July	419	30.73	1.65	252	0.31	99.4	1.64
August	425	28.51	1.55	283	0.26	99.4	1.54
September	394	24.17	1.22	308	0.29	99.2	1.21
Mean	403	25.90	1.35	279	0.31	99.3	1.34

Note: 1) Bed filter materials; Kanuma soil and zeolite.
2) Transplanting of aquatic plants was terminated on May 20, 1997.
3) Transplanting of winter plants started on October 1, 1997.

Table 2. Total phosphorus purification from domestic wastewater effluent by BGF ditch planted with aquatic plants in the summer of 1997

Date	Influent			Effluent			Removal rate ($g\ m^{-2}\ d^{-1}$)
	Flow rate ($L\ d^{-1}$)	Concentration ($mg\ L^{-1}$)	Loading rate ($g\ m^{-2}\ d^{-1}$)	Flow rate ($L\ d^{-1}$)	Concentration ($mg\ L^{-1}$)	Removal (%)	
June	372	6.25	0.30	271	0.70	99.3	0.28
July	419	6.88	0.37	252	0.12	99.0	0.37
August	425	6.78	0.37	283	0.03	99.7	0.37
September	394	6.55	0.33	308	0.01	99.9	0.33
Mean	403	6.62	0.34	279	0.22	98.0	0.34

Note: 1) Bed filter materials; Kanuma soil and zeolite.
2) Transplanting of aquatic plants was terminated on May 20, 1997.
3) Transplanting of winter plants started on October 1, 1997.

Fig. 8. Taro grown in BGF ditch (November 4, 1997)

Fig. 9. Tomato harvested in BGF ditch (August 1996)

Applications of the BGF ditch system

The members of the family who evaluated the resource recycling system using BGF ditches, reassessed their previous lifestyle and paid much attention to the cycle of resources. Since they voluntarily stopped using chemical pollutants such as bleach and synthetic detergents, the water from their BGF ditches became very clear and odorless. In the fish culture pond to which the water was discharged, fishes like killifish, loach and goldfish started breeding and dragonfly larvae and frogs built their habitat, creating an ecosystem similar to that of a natural pond.

The family ate tomato (Fig. 9), taro, swamp cabbage, garland chrysanthemum, radish (*Raphanus sativus* L.), and other crops grown in the ditch. The family also enjoyed a bath using the herbs harvested from the ditches. Moreover, in their papermaking classes, the pupils of the elementary schools in Tsukuba, Ibaraki Prefecture, became interested and tried to make paper out of the papyrus cultivated by the BGF ditch system.

In addition to the water purification function, the BGF system could supply the following functions:

1. Domestic waste water facilities for rural communities to provide parks with water amenities and areas to enjoy the waterside;
2. Facilities for islands and arid areas to recycle

water resources and essential nutrient elements;

3. Horticultural facilities to efficiently use fertilizer resources and provide people with places for enjoying recreational and other activities;
4. Facilities for households to use home gardens, flower beds, and hedges;
5. Facilities for schools, nurseries, and similar establishments to provide children with areas for environmental education and nature observation; and
6. Facilities for hospitals, schools for handicapped children, homes for senior citizens and for providing patients and others with areas for horticultural therapy.

Conclusion

This study showed that domestic wastewater treated in a combined anaerobic/aerobic treatment plant became an excellent liquid fertilizer with a balanced nutrient composition. Consequently, by using this liquid for water culture of vegetables and useful plants, the natural cycle of resources and water purification could be achieved simultaneously.

The rapid population growth and increase in human activities today generate environmental issues. Population problems are not only due to food and agriculture production but also to the person's lifestyle including eating habits. For nature and human beings to coexist in a harmoniou community, it is necessary to change the way of life into a more eco-friendly one.

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