한국환경농학회지 제19권 제5호(2000)
Korean Journal of Environmental Agriculture
Vol. 19, No. 5, pp. 433~441

Feasibility Study of Agronomic Application of Treated Sewage for Paddy Rice Culture

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ABSTRACT : A feasibility study was performed to examine the agronomic application of treated sewage on paddy rice culture by field experiment for two consecutive years. The domestic sewage was treated by the constructed wetland system which was in subsurface flow type and consisted of sand and macrophyte. The effluent of the wetland system was used for irrigation water. The effluent was diluted to maintain the total nitrogen concentration below $26mg \cdot L^{-1}$ in the first year and used without dilution in the second year experiment. Growth components and yields were compared against the CONTROL plot where conventional method was applied. And also, soil characteristics of the plots before and after reclaimed sewage irrigation were analyzed. Generally, addition of the treated sewage to the irrigation water showed no adverse effects on paddy rice culture, and even enhancement was noticed in both growth and yield. Irrigation of treated sewage after concentration adjusted with conventional fertilization showed the better result, and the yield exceeded that of CONTROL case where clean water was irrigated. Soil characteristics changed after irrigation, and significant EC increasing was observed for the reclaimed sewage irrigation plots. From this study, it appears that reuse of treated sewage, as supplemental irrigation water could be a feasible and practical alternative. For full-scale application, further study is recommended on the specific guideline of major water quality components in treated sewage for irrigation and public health.

Key words : Paddy rice, Constructed wetland system, Grain yield, Soil characteristics, Total nitrogen, Total phosphorous,

INTRODUCTION

Water constitutes a crucial element for all the life on earth, and its availability has governed the development of economic activities. It becomes more difficult to keep water resources in desirable quantity and quality due to rapid urbanization and environmental pollution from industrialization, therefore, efficient water use is a growing interest. It is especially true in the area of water-shortage, and Korea belongs to a country of water-shortage (Kwun, 1997).

Utilization of sewage water for agriculture has been practiced for centuries in many part of the world. With the advent of sewerage systems in the nineteenth century, sewage was used at sewage farms, and by 1900 there were numerous sewage farms in Europe and Unite States (Sterritt and Lester, 1988). Irrigation with sewage effluent has been successfully operated since 1897 at the Werribee farm, located near Melbourne, Australia (MvPherson, 1979). Although these sewage farms were used primarily for waste disposal, incidental water use was made for crop production or other beneficial uses. The US Water Resources Council estimated in 1970 that only 3% of the reclaimed municipal wastewater was reused for planned purposes, and the use of sewage effluent in 1982 in Australia was about 11% of total annual flow (Storm, 1984). The recent increase, however, in water conservation awareness has increased water reuse effort, and sewage effluent reuse has become a fundamental tenet of most reclamation projects. A number of planned wastewater reclamation and reuse projects have been developed as a matter of necessity to meet growing water needs in irrigation and other uses (Asano, 1994). In Israel, about 67% of the potential quantity of effluents are used for irrigation or reclaimed by recharge the aquifer (Eitan, 1989).

Irrigation with treated sewage has some advantages which include increasing water use efficiency, beneficial use of water and nutrients in effluent, and water quality protection by ultimate disposal of effluent instead of discharge to water bodies. But, treated sewage effluent as a source of irrigation water may differ from the regular water supply in several aspects. The effluent may contain organic and inorganic components which can affect plant growth, different levels of macronutrients, especially nitrogen and phosphorus, should be taken account into consideration for plant nutrients, trace elements may be present in excessive levels, and residual pathogenic microorganisms can cause public health problems. Therefore, special care should be practiced in addition to other considerations to all irrigation water.

In Korea, agricultural water usage is the largest and it takes about 53% of the total water usage. Most arable farmland is used for paddy rice culture that requires large amount of irrigation water. Therefore, efficient irrigation water use is a critical issue in water resources management nationwide. In the past, the waste was disposed of in the easiest way available without environmental concerns in rural area. Sewage has been discharged directly to the streams and lakes, or spread on land, relying on natural purification. However, this is not the case any more. Increasing sewage discharge rate due to increasing population density, enhancement of toilet system, and more water consumption threatens water quality of receiving water bodies. Although legislation on the effluent water quality and forcing sewage treatment systems to meet water quality standards, final disposal method has not been changed significantly and only a very small portion of the effluent is presently reused.

Scattered housing pattern in rural area makes the large scale centralized wastewater treatment systems not practical because of high cost for sewage collection and system operation. Small sewage treatment with low technology system is preferred in rural area, and one of the promising alternatives for small sewage treatment systems in rural area is a wetland system. Wetland systems become widely accepted for wastewater treatment, and attractive basic function of them are physical entrapment of pollutant through filtration and sorption in the soil and organic matter, utilization and transformation of elements by microorganisms, and low energy and maintenance requirements to attain consistent treatment levels (USEPA, 1988). They can transform many of the common pollutants in conventional wastewater into harmless byproducts or essential nutrients for additional biological activities, and are one of the least expensive treatment systems (Kadlec and Knight, 1996). However, the treatment performance may not be conveniently controlled compared to the conventional treatment systems, and the effluent might exceed water quality standards under certain circumstances. It would be great if the effluent of the wetland system can be reused as supplemental irrigation water for agriculture without causing adverse effects on crop growth. Which can make ultimate disposal of sewage effluent in more safe way and water quality problems in receiving water less concerned.

In this study, feasibility on the agronomic application of treated sewage from constructed wetland system was examined by paddy rice culture for two years. The growth rate, yield, and soil characteristics were analyzed to investigate possible effects of the treated sewage irrigation.

MATERIALS AND METHODS

Experimental Facilities

The treated sewage used for experiment was the effluent of the constructed wetland system installed at Konkuk University in Seoul, Korea, and schematic of the system is shown in Figure 1. The sewage came from school building and was collected to the septic tank. It was pumped from the last compartment of the tank to the storage tank, then flew into the wetland system. The wetland system was in subsurface type and filled with sand, where reeds were transplanted. Theoretical hydraulic retention time of the system were 3.46 days. The treated sewage by the wetland system was used to the irrigation water for paddy rice culture.

In the first year experiment, concentrations of the treated sewage for irrigation was controlled by dilution to keep T-N concentration was below 25 mg·L^{-1}. In the second year, the treated sewage was irrigated with less dilution. T-N was the most concern because rice is sensitive to the nitrogen concentration. The current agricultural water quality standard

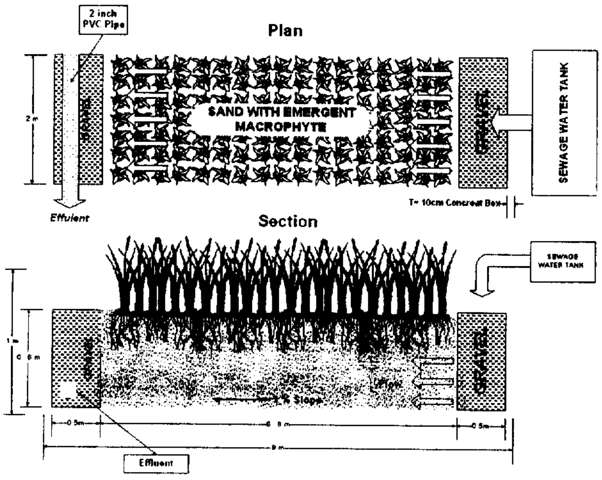

Fig. 1. Schematics of the constructed wetland for sewage treatment

for T-N is 1 $mg \cdot L^{-1}$. Most of T-N was in NH_3^--N, and NO_3^--N was about 1 $mg \cdot L^{-1}$ and NO_2^--N was almost not detectable. About half of the T-P was in PO_4^{3-}-P. The adjusted average concentration for COD, SS, T-N, and T-P was about 20 $mg \cdot L^{-1}$, 8 $mg \cdot L^{-1}$, 25 $mg \cdot L^{-1}$, and 2 $mg \cdot L^{-1}$, respectively.

Section and general view of experimental plot is shown in Figure 2 and Figure 3, respectively. The material of the plot was PVC, and the size was 90cm wide × 110cm long × 70cm high with surface area of about $1m^2$. Bottom 10cm was filled with gravel, filter cloth covered the gravel, and paddy soil was put atop and leave 10cm space for irrigation water. The drainpipe was installed at the bottom of the plot to control water percolation rate. The plot exterior was insulated by soil to prevent possible temperature effect on the crop growth and mimic the natural condition. Drain pipe with valve was provided at bottom of each plot for proper drain through the soil.

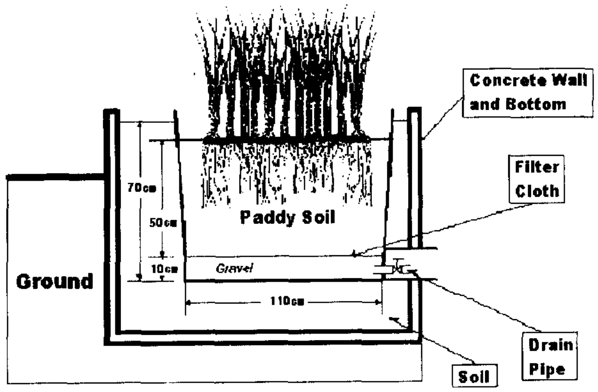

Fig. 2. Section of experimental plot for rice cultivation

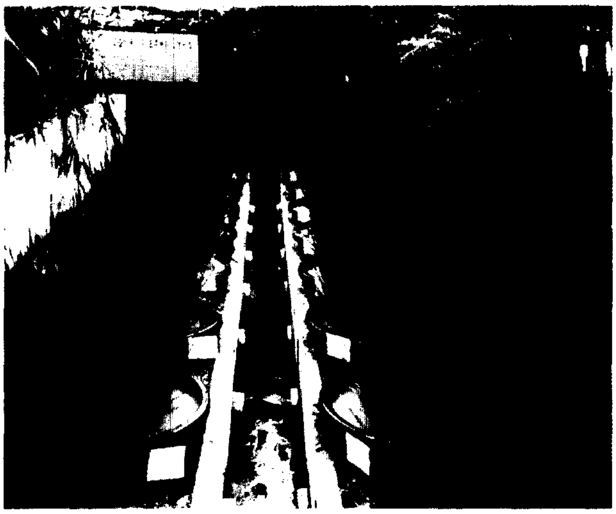

Fig. 3. General view of experimental system for rice cultivation

First Year Experiment

As a testing material, Illpumbyeo was planted at rate of one plant per hill and 22hills per plot on May 25, 1998. Paddy rice plots were laid out in four treatments and one control, and they were replicated three times. Fertilization application for the control was at rate of 110-70-80$kg \cdot ha^{-1}$(N-P_2O_5-K_2O), and fertilization for treatment plots were applied at the rates explained earlier. Conventional management methods of the local district were used in other practices.

Four treatments were examined with a control plot. Treatments include: (1) irrigation of treated sewage after concentration adjusted and conventional fertilization (TWCF), (2) irrigation of treated sewage after concentration adjusted and half of the conventional fertilization (TWHF), (3) irrigation of treated sewage after concentration adjusted and no fertilization (TWNF), and (4) irrigation of treated sewage as it was and no fertilization (SWNF). The control plot was irrigated with clean water and conventional fertilization was applied (CONTROL).

Total water requirement of irrigated rice through the growing season is from $500L \cdot m^2$ to $2,000L \cdot m^2$. The irrigation water was applied at rate of 20L each time and 15times, thus the amount of irrigated water through the crop season is 300L. Considering the amount of precipitation, the total water provided during the growing period was sufficient to the requirement. Samples to evaluate established plant were collected five times with 7-day interval starting from August 10, with three replications. Plant height, leaf area, and tiller number were measured at each stage by standard methods designed by Rural Development Administration in Korean Government. Leaf areas of rice plant were measured with Leaf area meter(AAM-8, Hayashi Denkoh Co. Japan). Plant samples were dried at 60℃ in the oven for one week, and panicle length and culm length were measured.

The paddy rice was harvested on October 21, and yield components were measured by the standard methods designed by RDA. The yield was calculated by yield components and corrected to 14% moisture. All measurements above were same in the second year.

Second Year Experiment

The same material of Ilpumbyeo was transplanted at rate of one plant per hill and 19hills per plot on May 24, 1999, and treated sewage was irrigated with less dilution. Treatments include: (1) continuous irrigation of treated sewage and no fertilization (CSWNF), (2) irrigation of treated sewage with dilution and conventional fertilization (TWCF), (3) irrigation of treated sewage and half of the conventional fertilization (SWHF), and (4) irrigation of treated sewage and conventional fertilization (SWCF). The control plot was irrigated with clean water and conventional fertilization was applied (CONTROL).

In the CSWNF, treated sewage was irrigated total 540 L at rate of 10 L everyday except wet day. This treatment was included to investigate effects of high nutrient lodging. For other plots, total 430 L, irrigation was provided at the same rate of 10 L everyday and water depth in plot was controlled not to overflow. The average concentration of irrigation water is shown in Table 1, where water quality was analyzed by Standard Methods (APHA, 1995).

Soil samples from each plot were collected after crop harvested and compared with the initial condition before the experiment. Three samples were taken from each plot and mixed thoroughly before analysis. Soil samples were analyzed by Methods of Soil Analysis (ASA and SSSA, 1982).

RESULTS AND DISCUSSION

Growth characteristics

To investigate growth characteristics of rice plant, plant height, leaf area, tiller number, dry weight were measured with three replications with 7-day interval from 8-3-'98 to 8-30-'98 in the first year and 8-10-'99 to 9-7-'99 in the second year.

Plant heights used as a scale of crop growth are presented in Figure 4. In comparison of plant height with treatments, the increasing rate of height was similar for the TWCF, TWHF, and CONTROL treatments, whereas those of treatments without fertilization (TWNF, SWNF) were smaller than the former in the first year. In the second year, the plots that received treated sewage without dilution showed high values where fertilization affected less. This explain that the nutrients in treated sewage was utilized positively to the plant growth rather than harming.

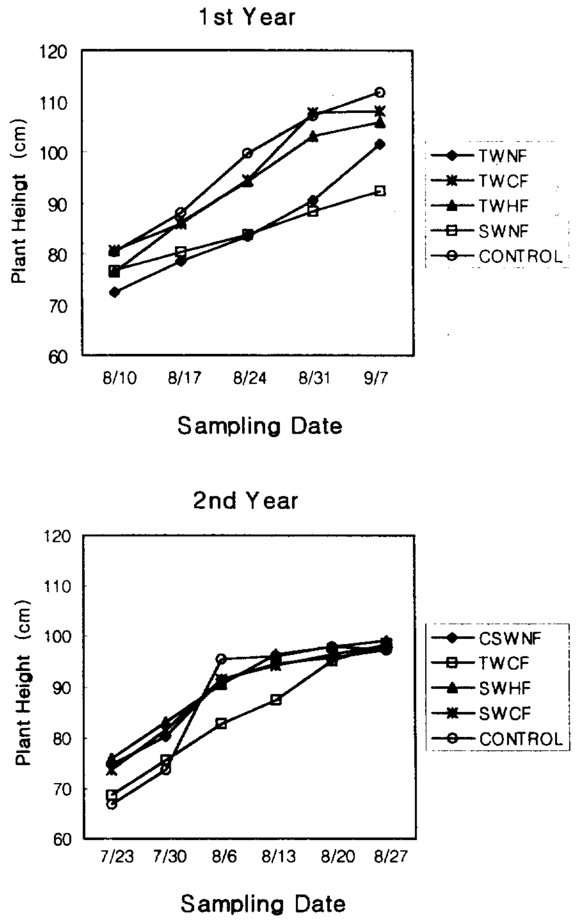

Fig. 4. Comparison of plant height with treatment

Table 1. Average concentration and loading of irrigation water

Year	Treated sewage		COD	SS	TN	TP
1st year (1998)	No Dilution	Concentration ($\mathrm{mg \cdot L^{-1}}$)	65.92	18.56	67.39	6.3
		Loading (g)	19.78	5.57	20.22	1.89
	With Dilution	Concentration ($\mathrm{mg \cdot L^{-1}}$)	22.38	6.54	25.95	2.27
		Loading (g)	6.71	1.96	7.79	0.68
2nd year (1999)	No Dilution	Concentration ($\mathrm{mg \cdot L^{-1}}$)	41.24	9.40	90.18	6.71
		Loading (g)	17.73	4.04	38.78	2.89
	With Dilution	Concentration ($\mathrm{mg \cdot L^{-1}}$)	8.14	1.88	18.06	1.34
		Loading (g)	3.50	0.81	7.77	0.58

Tillering capacity affects the grain yield of a paddy rice. However, too many tillers induce low yield because of decreasing filling rate. High tillering habits can be either advantageous or disadvantageous for the yield. Generally, tillering may start when the main culm develops the fifth leaf. In the first year, the CONTROL represents the most tiller number as in Figure 5. Like comparison of plant height, tiller number of SWNF and TWNF also were lower than those of other treatments. In the second year, tillering was brisker than the first year and more nutrient concentration in the irrigation was thought to affect tillering. The SWCF and SWHF were higher than others, and the CONTROL was lowest in the second year.

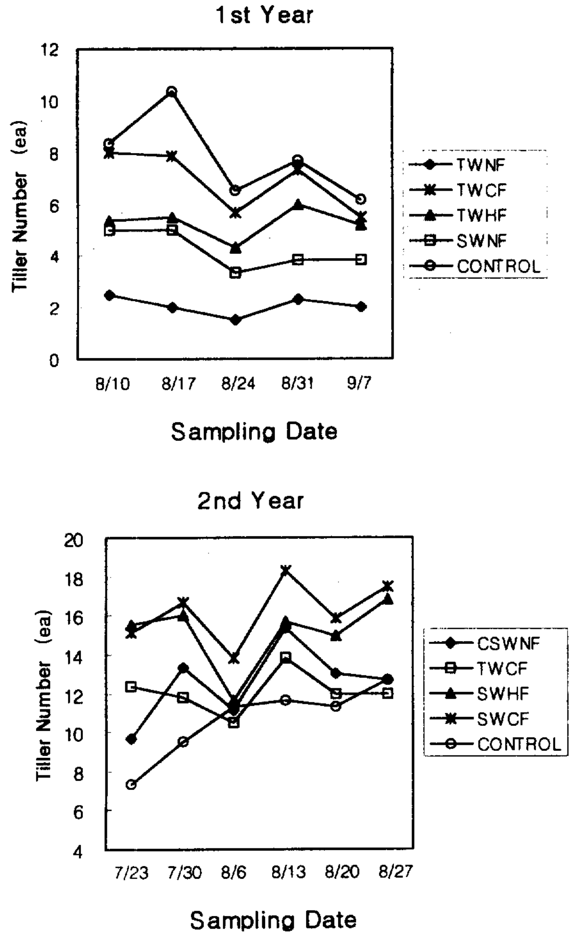

Fig. 5. Comparison of tiller number with treatment

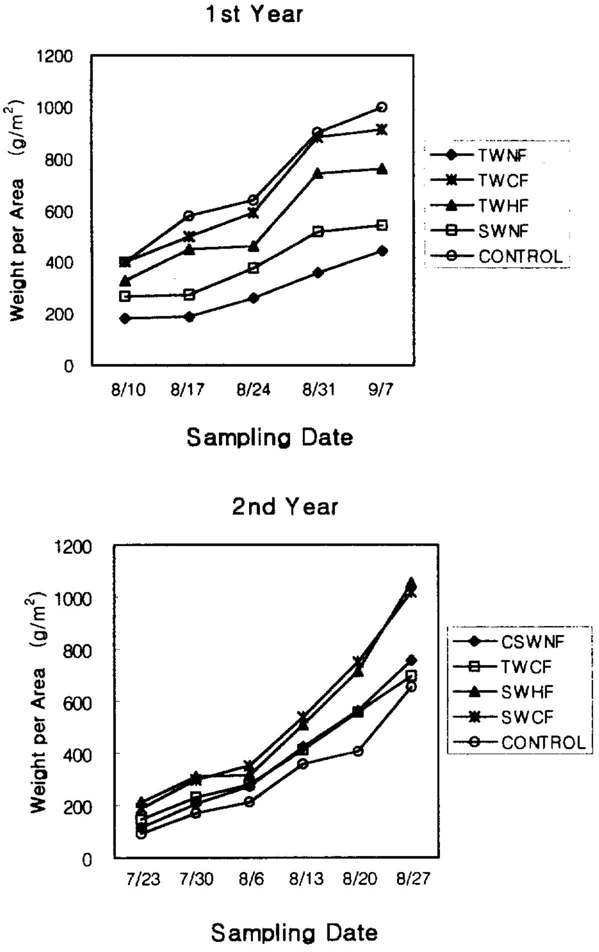

Fig. 6. Comparison of total dry weight with treatment

Figure 6 shows dry, where the CONTROL and TWCF increased in similar trend for the first year. Although increasing pattern of TWHF was similar to the CONTROL and TWCF, dry weight of TWHF was lower than those of CONTROL and TWCF. Dry weight of SWNF and TWNF increased significantly lower compared to other treatments and resulted in grain yield reduction. In the second year, CSWNF and SWCF were the highest similar to the tiller number case. These two plots were irrigated with treated sewage without dilution and fertilization, and eventually resulted in more grain yield.

Biomass of crop depends on assimilation and respiration of a crop, which are closely related with leaf area, assimilatory capacity per unit, and light interception efficiency. Amount of assimilation increases when plant has large leaf area and most of the leaves are exposed to direct sunlight. For crops using solar radiation, most of the radiation must be absorbed by leaves and leaf area is an important index of crop growth. As shown in Figure 7, leaf areas of SWNF and TWNF were significantly low compared to those of others in the first year. Although leaf area of TWHF was smaller compared to those of CONTROL and TWCF from August 10 to 31, it became similar to them at last. In the second year, leaf area of treatments were greater than the CONTROL which implies that irrigation water with high nutrients affected positively to the leaf area of rice plant.

Leaf area index (LAI) is the ratio of the leaf area of the crop per unit ground area and shown in Figure 8. LAI is a rough measure of leaf area per unit of available solar radiation. It can be calculated as leaf area divided by ground area. The more leaf area, the more biomass produced. But as the crop grows and LAI increases, more and more leaves become shaded and a decrease in net assimilation can occur. As shown in Figure 8, LAIs of CONTROL, TWCF and TWHF are greater than that of SWNF and TWNF in the first year and generally more LAIs were obtained in the second year.

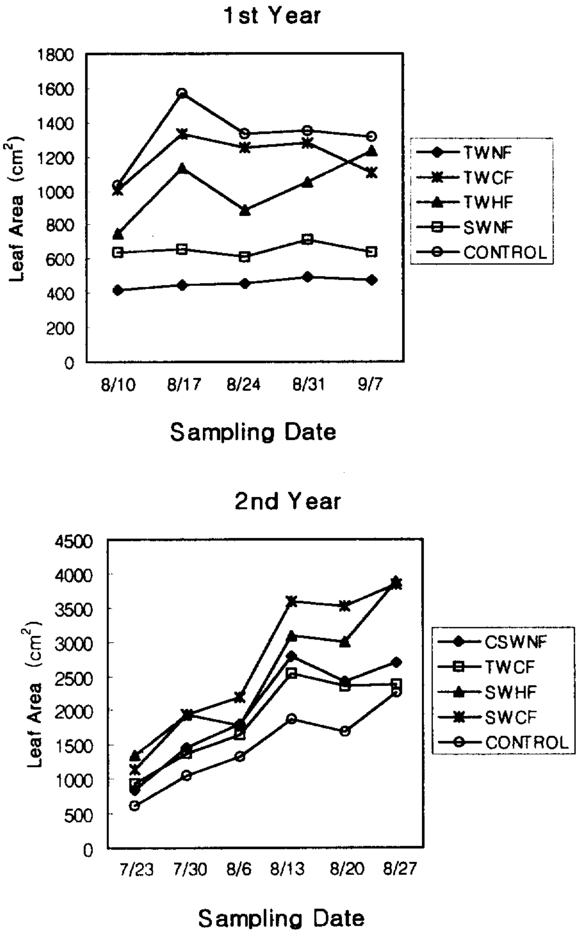

Fig. 7. Comparison of leaf area with treatment

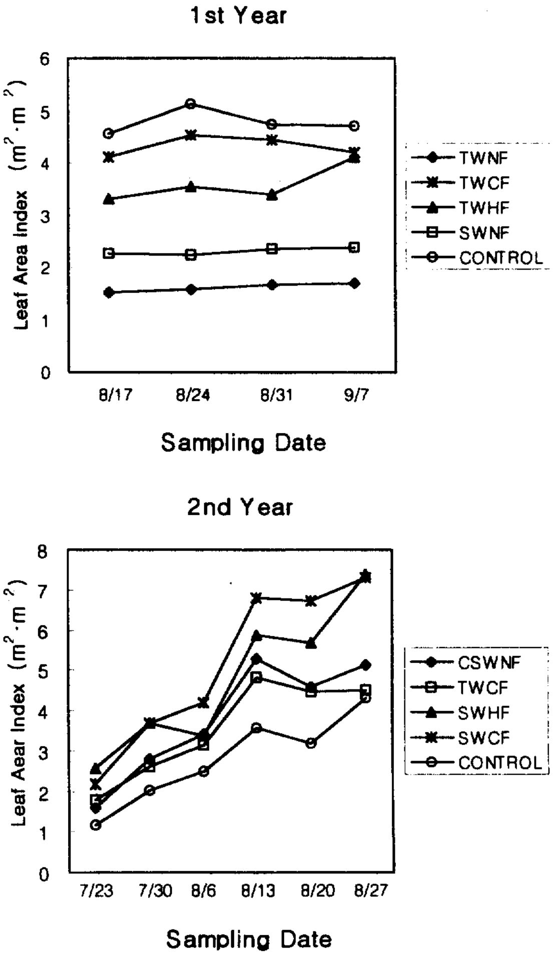

Fig. 8. Comparison of leaf area index with treatment

Yield

Comparison of yields per unit area is summarized in Figure 9. In the first year, fertilization was an important factor and reduced fertilization resulted in less yield. Against the general belief that high nutrient irrigation water might cause reduced yield, treated sewage with dilution and conventional fertilization demonstrated more yield than the CONTROL. Which implies that current irrigation water quality standard and general belief could be wrong. The yield of TWCF was even about 10% more than that of CONTROL, 573.4 kg·10a^{-1} versus 525.2 kg·10a^{-1}. The yield of TWHF which used half the conventional fertilization was 30% less than that of CONTROL with 364.5 kg·10a^{-1}. The yield of TWNF and SWNF were 258.9 kg·10a^{-1} and 239.2 kg·10a^{-1}, respectively, which were less than 50% of the CONTROL.

In the second year, the SWCF and SWHF were the highest, which received treated sewage without dilution. It implies that high nutrients in the irrigation water was beneficial to the yield of rice as a whole. Generally, yields increased more than the first year because soil conditions were improved than the first experimental year. not proper to initial rice culture yet.

The yield of paddy rice was not affected adversely by treated sewage addition to irrigation water, and encouragingly even more yield was observed. The important factor significantly affected the rice yield was an amount of fertilization rather than addition of irrigation water quality.

Soil characteristics

Soil characteristics of the plot are summarized in Table 3. The pH, OM, and TN increased slightly while EC and available-P decreased significantly after harvest in the first year. Reasons for the increase might be higher pH and organics in irrigation water, and excessive nitrogen supply from fertilization and treated sewage. And addition of ionic compounds by treated sewage and plant uptake of phosphorus might cause decrease in EC and available-P.

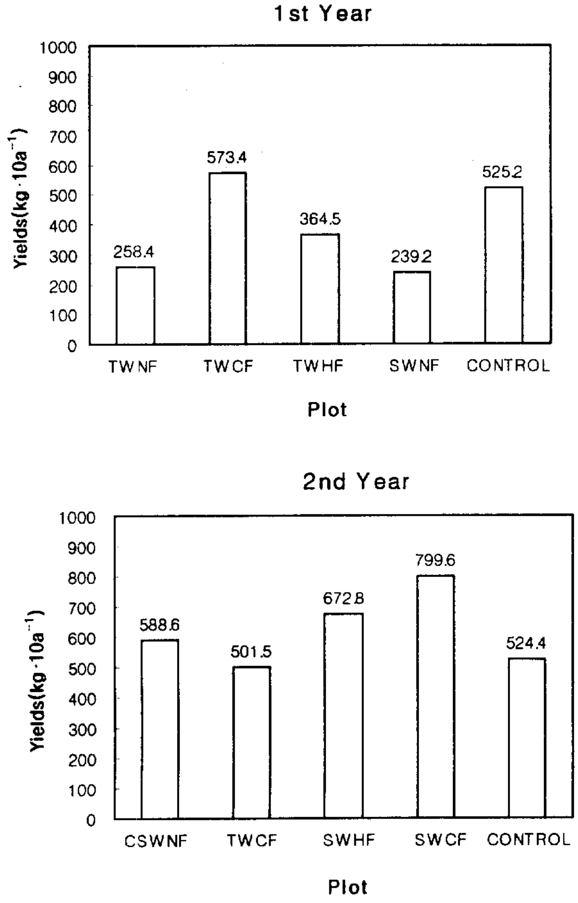

Fig. 9. Comparison of yields per unit area(kg·10a^{-1})

In the second year, there was no significant change in pH even with treated sewage irrigation without dilution, which might be caused by soil buffer capacity for pH cahnge. However, EC was markedly increased for the plots after irrigation of high nutrients compared to the CONTROL. This implies that the salts accumulation in the soil by treated sewage could be a more significant problem in paddy rice culture rather than lodging by excessive nitrogen concentration. In fact, T-N concentration of about 20mg/L was irrigated to the rice culture and no lodging was observed during the study period while agricultural water quality standard for T-N is 1mg/L.

Changes in OM, CEC, and T-N were not apparent and the reason might be a large buffering capacity of paddy soil. T-P concentration in the second year was generally higher than the first year, which implies that phosphorus accumulation in the substrate can happen if loading exceeds the consumption. Available phosphorus after harvest showed much lower than the one before transplanting, which implies that plant uptake by rice was significant that adequate supply of phosphorus might be necessary for proper rice culture.

Other concerns

Potential drawbacks of the wetland system include mosquito control. Mosquito transmitted diseases have become relatively rare in many of the developed parts of the world, and actual

Table 3 Characteristics of paddy soil

Treatment*		pH (1:5)	EC ($\mu S \cdot cm^{-1}$)	OM (%)	CEC ($cmol^{+} \cdot kg^{-1}$)	TN (%)	TP ($mg \cdot kg^{-1}$)	$Av.P_2O_5$ ($mg \cdot kg^{-1}$)
First Year (1998)								
Initial Soil Condition		5.47	54.8	0.790	8.7	0.023	472.9	541.93
TWNF A.H		6.02	20.7	0.890	9.1	0.027	417.0	261.11
TWCF A.H		6.31	17.7	0.991	11.2	0.025	502.5	280.05
TWHF A.H		6.34	18.7	0.840	10.6	0.023	483.4	268.10
SWNF A.H		6.14	18.9	0.974	12.3	0.025	409.3	303.03
CONTROL A.H		6.32	20.1	1.008	11.8	0.030	493.0	283.17
Second Year (1999)								
CSWNF	B.T.	6.58	31.6	0.705	9.5	0.049	652.6	280.34
	A.H.	7.58	125.7	0.840	13.3	0.050	662.1	101.32
TWCF	B.T.	6.50	26.9	0.806	15.0	0.060	742.9	283.55
	A.H.	7.64	110.0	0.806	13.6	0.050	674.1	94.19
SWHF	B.T.	6.59	22.3	0.739	15.5	0.049	693.7	304.37
	A.H.	7.41	83.7	0.873	12.8	0.046	672.0	134.42
SWCF	B.T.	6.56	20.7	0.672	13.0	0.041	664.4	325.80
	A.H.	7.88	149.0	0.974	14.5	0.053	722.5	94.59
CONTROL	B.T.	6.45	31.2	0.605	12.0	0.048	703.7	304.11
	A.H.	6.48	25.0	0.840	10.5	0.046	638.5	152.68

* B.T. : Before Transplanting ** A.H. : After Harvest

incidence of mosquito-related problems with wetland systems is rare. The wetland system used in the study was in subsurface type and most wetland surface was kept not ponding, therefore, generally mosquito nuisance was not observed. Only the inlet part of the system sometimes flooded and limited larvae development was experienced. Among the several mosquito control measures, changing hydrologic condition was applied. The system stopped influent feeding for a while then it became dry soon because it was a subsurface system, which eliminated larvae development problem. In large field application, intermittent application of sewage might avoid mosquito problems in wetland systems.

Risks of pathogen transmission and infecting workers on paddy fields could be another concern in agronomic application of treated sewage water to rice culture. But, many of the processes to reduce pathogen populations in natural systems are equally or even more effective in wetland treatment systems (Kadlec and Knight, 1996). In this study, total coliform was used as an indicator organism and its concentration of the irrigated sewage water varied in the range from hundreds to few thousands MPN/100 mL. Microorganisms would be removed in paddy field relatively soon and removal mechanism might include natural die-off, predation, and exposure to ultraviolet light. Furthermore, most of farming practices in the paddy field are mechanized and water contact is minimal. Therefore, risks of pathogen and disease problem were thought to be low.

Although chances of above-mentioned problems are low, regular monitoring on the larvae population in the wetland system and careful washing after water contact in the paddy field are recommended.

CONCLUSIONS

A feasibility study was performed to examine the agronomic application of treated sewage on paddy rice culture by field experiment for two consecutive years. The domestic sewage was treated by the constructed wetland system and its effluent was fed into paddy rice as irrigation water. The result can be summarized as below.

1. Irrigation with treated sewage would not adversely affect paddy rice culture in both growth and yields. With identical fertilization, plots with treated sewage irrigation demonstrated even better growth and yields than the control plot. It implies that addition of treated sewage can be beneficial rather than instead of being harmful to the rice culture.
2. From the soil characteristics analysis, EC increased markedly in the plots with irrigation of treated sewage irrigation without dilution and it implies salt accumulation might be a problem in treated sewage irrigation rather than nutrient concentration like nitrogen for rice culture eventually. T-N and T-P increased slightly in the second year and its proper management might be necessary for continuous operation.
3. The overall results showed that treated sewage could be used as a supplemental irrigation water for paddy rice culture without causing adverse effect. This is encouraging because paddy rice culture requires large quantity of irrigation water and sewage effluent is one of the main pollutant sources to water quality problem in Korea. Therefore, it is thought that the treated sewage can be disposed of ultimately to the paddy field in stead of receiving water body.
4. For full-scale application, however, further studies on specific guidelines to the irrigation water quality and optimum fertilization on paddy rice culture, and distribution of small sewage treatment systems in rural area are recommended.

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