Summary of Doctoral Thesis

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UGAS Specialty: Biotic Environment Science
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Title	Development of treated wastewater reuse system to cultivate rice for animal feeding toward sustainable water and nutrient circulation

Introduction and objectives

One of the biggest challenges facing the world today is feeding the continuously growing population in the scene of climate change and water pollution. Serving as a stable food source for more than half of the world's population, rice is cultivated in at least 95 countries across the globe and consumes around 50% of the worldwide irrigation water. Recently, municipal wastewater for rice irrigation has been adopted as an effective measure in many countries for recycling nutrients and water resources and avoiding the discharge of pollutants from sewage effluents to surface water bodies.

The objective of this study was to develop a proper cultivating system of rice for animal feed with continuous irrigation of treated municipal wastewater (TWW). Firstly, the study has evaluated nitrogen (N) removal from TWW, rice yield and grain quality, and accumulation of heavy metals in paddy soil and rice grains. Secondly, the capacity of generating electricity from the paddy field irrigated with TWW has been assessed by installing a microbial fuel cell (MFC) system which utilized the organic matter source in TWW. Thirdly, the need of phosphorous (P)-fertilizer for the rice cultivation under TWW irrigation was also evaluated in two seasons. In addition, the emission fluxes of two major greenhouse gases, namely methane (CH_4) and nitrous oxide (N_2O), were also evaluated.

Materials and methods

The experiments were conducted in three farming seasons from 2015 to 2017, using a bench-scale apparatus which consist of a simulated paddy field with an area of 0.18 m^2 and influent and effluent tanks. Bekoaoba, a large-grain-type high-yield rice variety was selected to transplant in six treatments (called runs) in 2015 and 2016 seasons, and in four treatments in 2017 season with different cultivation conditions. Among these, one run was used as the control, in which the paddy soil was supplemented with N-P-K composite fertilizers and irrigated with tap water as seen in normal paddy fields. The other runs were served continuously with TWW taken from a municipal wastewater treatment plant in Tsuruoka, Yamagata, Japan, which employs the standard activated sludge process followed by chlorine disinfection. Two types of TWW irrigation at different directions were applied. One was bottom-to-top irrigation, in which TWW was supplied from the underdrain pipe at the bottom of the field, infiltrated the paddy soil layer upward and then flowed into the effluent tank. The other was top-to-top irrigation, in which TWW was pumped to the surface of the rice field and discharged from the top at the other side of the field. The MFC system was constructed using electrodes (0.6 m x 0.3 m) made of carbon graphite felt. The electrodes were connected to a circuit using copper cables and the voltage generated from the MFC system was recorded every 10 min using a logger.

During the experiments, the qualities of the irrigation water in the influent and effluent tanks, relevant to total nitrogen (TN) and N-components, total organic carbon (TOC), dissolved oxygen (DO), pH, electrical conductivity (EC), temperature, and oxidation-reduction potential (ORP), were monitored routinely. The growth of rice plants, the whole plant dry biomass, and grain yield were also examined using the standard methods. The quality of rice was evaluated based on the protein content of grains. In addition, the contents of TN and total phosphorous (TP) in the soil before and after the experiment were evaluated. As harmful substances primarily concerned in TWW irrigation, the concentrations of heavy metals (Cr, Mn, Ni, Zn, Cu, Mo, Cd, and Pb) in water, rice and soil were analyzed using an inductively coupled plasma mass spectrometer (ICP-MS). Furthermore, CH_4 and N_2O gases samples were collected once a week with the manual static chamber and then analyzed using gas chromatography.

Results

The results of the experiments indicated that bottom-to-top irrigation had improved the performance of rice cultivation with the grain yield of 14.1 t/ha, the dry mass of 16.2 t/ha, and the protein content in the brown rice of 14.6 %, which were markedly higher than those achieved in top-to-top irrigation. Throughout the 3-season experiments, N removal efficiencies in bottom-to-top irrigation (ranging from 79 to 93%) have been found to be much greater than those obtained in the treatments using top-to-top irrigation (42-63%). No accumulation of the harmful metals in the paddy soil was found after three growing seasons under TWW irrigation, except for an increase of Cu in the experimental soil in 2015 season. This was probably resulted from the oxidation of the copper wire used for MFC system rather than the effect of TWW irrigation. Those metals' content levels in the harvested rice grains were also lower than the permissible limits of the international standards. The electric output from the MFC system in 2015 season was much lower than that reported in normal paddy fields, probably due to the poor connection between the cables and the electrodes. However, it remained to be low in 2016 season even when the connection was modified using graphite rods instead of the copper cables. CH_4 emission was not found in 2015 season, probably due to the inhibitory effect of Cu in the experimental soil. This gas was detected in the following two seasons from all the runs but the fluxes were much lower than those observed in normal paddy fields. The first measurement of N_2O in 2017 season revealed it was emitted in all runs, and that the emission fluxes from the runs applied with TWW irrigation were significantly higher than the run using tap water irrigation. The combined global warming potential (GWP) was found to be significantly increased in the treatments of TWW application using top-to-top irrigation, while decreased in the runs using bottom-to-top irrigation, as compared with that in the tap-water-irrigation treatment.

Conclusions and recommendations

This study implied that bottom-to-top irrigation enhanced N removal efficiency from TWW. High yield and quality of brown rice could be achieved under continuous irrigation of TWW from bottom-to-top without application of any chemical fertilizer. TWW irrigation decreased CH_4 emission but increased N_2O emission from the paddy fields, resulting in increased combined GWP. No accumulation of the harmful metals was found in the harvested grains and the experimental soils after the three-cropping seasons under the continuous irrigation of TWW. Electric output from the MFC system under the continuous irrigation of TWW was lower than that previously reported from normal paddy fields as well as the paddy fields under circulated irrigation of TWW. From all mentioned results, the bottom-to-top irrigation of TWW could be recommended to be applied to the real paddy fields. Although there was no building up of the heavy metals in the experimental soils and brown rice through the three-farming seasons, continuous monitoring of heavy metals in the soil and brown rice in every season is highly recommended to avoid long-term accumulation or accidental contamination. Beside the cultivation of rice for animal feed, further studies should be conducted to cultivate rice for other beneficial purposes. The content of P in the soil would be decreased after a long-term TWW irrigation without P-fertilization, which consequently could decrease the rice yield and quality. Thus, P content in the soil should be evaluated after harvesting in each season. In addition, further studies on the efficiency of power generation of the MFC system utilizing C source in TWW are highly recommended. With a high removal efficiency of N from TWW revealed in this study, paddy fields would be considered a step in a wastewater treatment process. To avoid the adverse effect of hazardous materials in raw wastewater, paddy fields should be established as an advanced treatment after normal treatment processes such as activated sludge process.