Research Paper

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# Study of a Slurry Irrigation System by Methane Fermentation Digestion for Wet Rice Cultivation

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## Abstract

We investigated difference in effects between periodic and one-time application of digested slurry (PDS and 1DS, respectively) to wet rice fields by a slurry irrigation system using controlled pot cultivation and actual wet rice field tests. Fertilizer application rates were 120 kgN/ha for PDS and 220 kgN/ha for 1DS. Both experiments gave similar results for growth duration and nitrogen (N) use efficiency. During the tillering stage, plants after PDS had lower stem number and SPAD values (chlorophyll content of leaves) than plants after 1DS, but the values increased during the panicle initial stage and were higher than 1DS during the ripening stage. PDS exhibited significantly higher levels of N uptake, agronomic efficiency, and fertilizer N recovery efficiency than 1DS.

[Keywords] rice cultivation, digested slurry, methane fermentation, N use efficiency, slurry irrigation system, N uptake

## I Introduction

Methane fermentation is an effective technology for treatment of livestock manure, sewage sludge, and waste biomass. Methane fermentation converts degradable organic compounds by anaerobic digestion, hydrolysis, acid formation, and methane production (Kaspar and Wuhrmann, 1978) to biogas which is an energy resource, and digested slurry (DS), which is used as a liquid fertilizer for plants (Haga *et al.*, 1979) because of its high ammonium nitrogen ($NH_4$-N) content, an important nutrient for plant growth (Carballa *et al.*, 2009, Hou *et al.*, 2007). The type of raw material is related to the potential productivity of methane fermentation (Wong *et al.*, 2008). Hou *et al.* (2007) reported that the total nitrogen (TN) in DS was 3850 mg/l when the material used was dairy cattle waste, while Furukawa *et al.* (2009) reported TN of 1600–2200 mg/l when the material used was a mixture of raw garbage, livestock manure, and sewage sludge. The main characteristics of slurry digested by mesophilic fermentation were 1400–1600 mg/l of $NH_4$-N, 1600–2200 mg/l of TN, pH of 8.5, 2000–3000 mg/l of suspended solids, 8000–10000 mg/l of chemical oxygen demand, and 1000–1500 mg/l of biochemical oxygen demand (Furukawa *et al.*, 2009). This indicates that the constitutes of DS as well as their concentrations must be considered and adjusted to provide optimal conditions for target plants when DS is applied as a fertilizer for cultivation.

DS is used as a liquid fertilizer in various types of farmlands worldwide. European countries and US use DS for grasslands, while Asian countries use it for rice cultivation (Hopkins, 2009, Hou *et al.*, 2007). Many studies have been conducted to compare DS and chemical fertilizer (CF) applications.

Li *et al.* (2003) reported that no significant differences existed between DS and CFs for plant length, number of tillers, and leaf area indices. However, the same study found that grain and biomass yields of rice with the same N application rate (50–70 kgN/ha) and recovery rate (RE) as well as agronomic efficiency (AE) for N from DS were higher than those from CFs, although not significantly. These results corresponded with reports by Liu *et al.* (2002) and Jeyabal and Kuppuswamy (2001) that grain and straw yields increased on using DS. These results indicate that even when the application volume of DS is decreased, it can still produce the same yields as CF and that the total area of rice fields will be expanded when DS at the same application rate as CF is used. Furthermore, when comparing equal outputs from DS and CF, the environmental load of DS is less than CFs because of the difference in energy consumed during their production.

If a farmer decides to use DS, a large amount of it has to be transported to the field and applied within a limited time to correspond with plant growth. Therefore, distribution methods of DS to agricultural fields are important. Many techniques are used for the application of DS to crop fields in European countries and US, especially for grasslands (The Asia-Pacific Economic Cooperation: Virtual Center for Environmental Technology Exchange, 2010). The techniques include sprinklers and drip irrigation systems known as "fertigation" (Cassman, 2008, Fangueiro *et al.*, 2008). In Asian countries, especially in Japan, DS is

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transported as a liquid fertilizer to agricultureal fields in vacuum trucks containing several tons of the fertilizer. DS is applied to rice fields by two methods. One is the spray crawler method and the other is the slurry irrigation method, in which DS is mixed with irrigation water, which is then used to irrigate the fields.

In the spray crawler method DS is spread before tilling. During spraying, vacuum trucks bring DS from the facility to the target field and transfer the slurry to the spray crawler. The land is tilled to mix the soil and fertilizer well, and the field is irrigated for rice transplantation (Iwashita and Iwata, 2010). In Japan, a town in Chikujyou developed a spray crawler with a 2.5-ton tank that could spread 5 tons of DS to 1000 $m^2$ within 18 min with two transshipments from vacuum trucks. Thus, in 1 h, this system can spread 16.5 tons of DS to fields and treat approximately 0.33 ha. However, until the required volume for one rice field is reached, this process would have to be repeated many times because of the limited capacity of the vehicle, and fuel consumption in transportation would be a concern.

When a mixture of irrigation water and DS is used, vacuum trucks are used to bring and mix the two near the rice fields. This method can be used after irrigation and transplantation as well as during rice growth as a topdressing. In that case, the truck operator should continue to supply a constant volume of DS to water during the entire irrigation time in order to maintain a uniformly mixing of the fertilizer constituents in the irrigation water for application to the rice field (Iwashita and Iwata, 2010). Consequently, vacuum trucks are occupied during these operations for a longer time period than the spray crawler.

A common limitation to both of these application methods is the long time for completion. Development of a pipeline system to supply DS to fields is assumed to improve this limitation. If pipelines from the facility would directly delivery DS to the rice fields, farmers could control the open system and estimate the volume of DS using a flow meter on a discharge line.

In the case of liquid fertilizers and CF, basal and/or panicle fertilizers are generally applied at one time to the rice field. However, the required periods for fertilizer spreading are approximately the same for farmers cultivating wet rice. In other words, DS usage by farmers is concentrated during the same period. Therefore, a large amount of DS has to be transshipped and distributed over wide areas during a limited time period. Such conditions cause two problems: a difficulty in satisfying all requests from farmers who want to use DS and a decline in the fertilizer utilization ratio caused by the effect of nitrification, denitrification, and runoff from fields. If a farmer decides to use DS at variable intervals and if these intervals become longer than they are at present, then these is a possibility for improvement of these two problems. In addition, Sasahara and Itoh (1989) reported that split application of a fertilizer improved growth conditions for rice and increased yields. The slurry irrigation method may potentially allow frequent or continuous application of DS to a rice field.

To acquire the basic data for the development of a pipeline system, this study focused on differences in the effects of periodic and one-time supplication of DS (PDS and 1DS, respectively). Our main objective was to investigate the effects of continuous application of slurry digested by methane fermentation to a wet rice field as a topdressing with irrigation water and identify the absorption ability of plants for the fertilizer applied as basal and topdressing, and estimate the amount of biomass yield achieved.

This study was divided into two parts. First, we studied the effects of the application methods of DS on rice cultivation from the viewpoint of growth duration and N use efficiency through controlled pot cultivation tests. Second, we conducted rice cultivation tests on actual wet rice fields in Yamaga City to confirm the results of the pot cultivation tests.

## II Materials and Methods

### 1. DS from methane fermentation

DS in this experiment was obtained from the Yamaga Biomass Center in Yamaga City, Kumamoto Prefecture. Products generated at this center include biogas, DS from methane fermentation, and solid fertilizer from compost. Raw materials used are waste biomasses, such as manure and food waste.

### 2. Controlled pot cultivation tests

The objective of this experiment was to investigate the effects of continuous application of DS to a wet rice field as a topdressing with irrigation water.

The experiment was performed in an experimental greenhouse at Saga University, Japan, from July 9 to October 14, 2009. The area of the greenhouse was 105 $m^2$ and the roof was covered with transparent plastic sheets. For ventilation and insect screening, the four sides of the greenhouse were covered with window screens and transparent plastic sheets. The rice cultivar used was ‘Morinokumasan’. This is a commended variety bred by Kumamoto Prefecture Agricultural Research Center. The cultivars were transplanted 0.05 $m^2$ from the soil surface and stood 0.30 m, tall. Wagner pots were made by Kiya Seisakusho, Ltd, and poor sandy soil with 0.1 mgN/kg. TN, $NH_4$-N, nitrate ($NO_x$-N), and total phosphorus (TP) in DS was 1800, 1540, 12, and 26 mg/l, respectively.