WATER MANAGEMENT FOR INCREASING FEED RICE YIELD AND FOR ENVIRONMENTAL CONSERVATION:
AN EXPERIMENTAL STUDY

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ABSTRACT

Feed rice was planted in 80,000 ha of paddy fields in Japan in 2015. Feed rice production is predicted to increase because the Japanese government has recommended the cultivation of feed rice for securing food safety and increasing the food self-sufficiency ratio. In general, because feed rice farmers place importance on rice yield and not rice taste and quality, it is possible to increase irrigation and fertilizer more than for rice cultivated for human consumption. In this study, we first determined water balance and runoff load (nitrogen and phosphorus, chemical oxygen demand [COD]) for paddy fields with feed rice (Oryza sativa L) cultivation in Goshogawara City in the northern part of Japan from May to October 2015. The amount of water and the quality of the water were analyzed from irrigation canals, drainage pipes, the surface of paddy fields, and rainfall each day. Secondly, we conducted cultivation studies under conditions of flooding and intermittent irrigation. As the results, the paddy fields of feed rice were of the drainage type, in which much outflow was drained from the drainage. Water balance for the irrigation period was as follows: total irrigation was 2,513 mm, total rainfall was 273 mm, total drainage was 1,672 mm, total evapotranspiration was 620 mm, and total percolation was 552 mm. The runoff load for the irrigation period was high as follows: T-N was 42.1 (kg ha⁻¹); T-P was 12.8 (kg ha⁻¹); COD was 326.9 (kg ha⁻¹). Concerning pot cultivation studies, differences in irrigation management affected yield. The average yields of flooding treatments (1112 kg per 10a) were higher than that of intermittent treatments (732 kg per 10a). The total runoff load of T-N in flooding treatment was 9.3 (Kg ha⁻¹), in intermittent irrigation treatment was 29 (Kg ha⁻¹). In terms of environmental conservation and yields, it is thought that flooding is a beneficial method of water management.

Keywords: Feed rice, water balance, Runoff Load, Water Management, Flooding, environmental conservation.

1. INTRODUCTION

Feed rice was planted in 80,000 ha of paddy fields in Japan in 2015. Feed rice is a new variety developed for feeding only to domestic livestock. It produces larger quantities of biomass and can be made into whole crop silage. Feed rice production is predicted to increase because the Japanese government has recommended the cultivation of feed rice for securing food safety and increasing the food self-sufficiency ratio. In general, because feed rice farmers place importance on rice yield and not rice taste and quality, it is possible to increase irrigation and fertilizer more than for rice cultivated for human consumption. Therefore, it is important to balance yield and the environment loads around the paddy fields.

In 1970s, the paddy field was one of the major non-point source of loads in Japan. Average nitrogen load from paddy field was 32.7 (kg ha⁻¹) from 1970s to 1980s (Haruta et al., 2015). Although the reduction of fertilization and the cultivation method

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of environmental conservation type had been promoted, the National Agriculture and Food Research Organization (2015) recommends fertilization at 1.6 to 2.0 times that used for rice cultivated for human consumption. Generally, the normal level of fertilization for rice for human consumption is less than 10 g N m\(^{-2}\). For example, Gusmini (2015) recommended that the application of 14 g N m\(^{-2}\) was considered effective for high production of Tachisuzuka forage rice and useful for the reduction of N loading in the environment.

Case studies regarding water balance and outflow loads for the paddy fields cultivating feed rice are rare. Yoshida (2014) reported the estimated nitrogen load from paddy fields was 36 kg ha\(^{-1}\) for feed rice cultivation in Japan. But, it is not clarified the present condition of runoff loads from feed rice paddy field. In this study, we first determined water balance and runoff load (nitrogen and phosphorus, chemical oxygen demand [COD]) for paddy fields with feed rice (Oryza sativa L ‘Minayutaka’) cultivation in Goshogawara City in the northern part of Japan from May to October 2015. The amount of water and the quality of the water were analyzed from irrigation canals, drainage pipes, the surface of paddy fields, and rainfall each day. Secondly, we conducted cultivation studies under conditions of flooding and intermittent irrigation.

2. MATERIALS AND METHOD

2.1 Paddy field experiment

The investigation of the feed rice paddy in Goshogawara City was performed from June 2 to October 6, 2015. The cultivar of feed rice used was Minayutaka. Ono et al. (2009) reported that it is resistant to cold and is expected to have large yields. To determine the water and load balance for the cultivation of feed rice, management of water and fertilizer were performed by the farmer. The paddy field area was 0.5 ha, ground fertilizer was 11 kg N 10 a\(^{-1}\), and additional fertilizer was 3 kg N 10 a\(^{-1}\). Water balance is described below, and inflow and outflow were measured by a Parshall flume set up in the irrigation and drainage canals. Water requirement rate was measured with a water requirement rate meter set up near the center of the paddy field. Evaporation was determined by an evaporation gauge near the rice paddy. Evaporation was measured by pan evaporation every week. One-day evaporation was calculated by the amount distributed proportionally based on one-day evaporation measured at Hirosaki University. Rice transpiration was calculated as evaporation-evapotranspiration rate once a mouth. Rainfall was measured with a rain gauge near the paddy field. The amount of percolation was calculated by subtracting evapotranspiration from water requirement rate. To determine the runoff load, water samples were taken and water quality analyses were performed. An automatic water-sampling machine was installed in the irrigation canal and drainage outlet of the paddy field, and water sampling was performed at a fixed time once a day. Sampling of culvert water was performed at a culvert spout on each investigation day. Rainfall was also sampled. Water quality analysis was performed at the laboratory at Hirosaki University. Six parameters were analyzed, including chemical oxygen demand (COD), total nitrogen (T-N), total phosphorus (T-P), dissolved oxygen (DO), hydrogen-ion exponent (pH), and turbidity.

2.2 Pot Cultivation Studies

Parallel to paddy field investigations, the feed rice cultivation studies were conducted in the field at the Hirosaki University. A cultivation experiment performed from June 17 to October 8, 2015. Rice was planted on June 17, the mid-summer drainage was two weeks from July 10, and the harvest was October 8. The cultivation studies were conducted under eight treatments (Table 1). Three pots were instituted in each experimental plot, for a total of 24 pots. Irrigation methods were flooding and
intermittent irrigation to compare differences in yield based on irrigation. The intermittent irrigation was performed to prevent lodging by supplying oxygen to the roots and for growth of the stooling stage. The basal fertilizer treatment was 10 kg N 10 a⁻¹ and the high fertilizer treatment was 15 kg N 10 a⁻¹ to compare differences in yield based on fertilizer. The fertilizer was “PURAIMU KOUDO” (N: 14% P: 14% K: 14%). The additional fertilizer was applied after the mid-summer drainage, and both treatments were fertilized with 10 kg N 10 a⁻¹. With lodging prevention and cyclic agriculture in mind, organic matter was derived from bamboo (elution among: N: 4.1 mg P: 3.4 mg K: 33.8 mg) fertilized with 5 g. The flooding treatment was irrigated to a depth of 2–5 cm from the rice planting during the mid-summer drainage. After the mid-summer drainage, intermittent irrigation was performed twice to prevent water stress to rice. After that, it was irrigated to a water depth of 2–5 cm, and waterfall was performed before the harvest. The intermittent irrigation treatment was irrigated to a water depth of 2–5 cm from the rice planting during the mid-summer drainage. After the mid-summer drainage, flooding and waterfall were decided based on the oxidation-reduction potential (ORP). Intermittent irrigation was performed four times: July 27–August 3, August 6–August 11, August 19–August 27, and August 31–September 9. After that, irrigation to a depth of 2–5 cm was performed and there was a waterfall before the harvest.

**Table 2-1. Treatment of cultivation study (n=3)**

<table>
<thead>
<tr>
<th>Fertilizer</th>
<th>Water management</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flooding</td>
<td>Intermittent Irrigation</td>
</tr>
<tr>
<td>Basal Fertilizer</td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>Basal Fertilizer + Organic</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>High Fertilizer</td>
<td>(5)</td>
<td>(6)</td>
</tr>
<tr>
<td>High Fertilizer + Organic</td>
<td>(7)</td>
<td>(8)</td>
</tr>
</tbody>
</table>

2.3 Growth and Yield Investigation

We measured the number of the stooling stage and leaf length in each treatment for rice once a week from June 17 to October 8, 2015. Leaf length was measured in three plants at the stooling stage. Measurements included full length, rod length, panicles length, number of panicles, total weight, total weight of panicles for each treatment, total number of paddies for each treatment, weight of gross paddies, coarse grain weight, total number of paddies ripening, total number of paddies with poor ripening, total weight of gross brown rice per unit area, total weight of brown rice per unit area, total number of brown rice grain per unit area, total weight of poorly ripened rice per unit area, total weight of straw. In addition, total weight of ear per effective panicle, number of paddies per effective panicle, number rate of ripening paddies to total paddies and 1,000 grain weight of brown rice were calculated from measurements.

3. RESULTS AND DISCUSSION

3.1 Water balance in rice paddy field

The total inflow and outflow for the irrigation period were calculated as follows:

- The total inflow = total irrigation + total rainfall
- The total outflow = total drainage + total evapotranspiration + total percolation
Water balance for the irrigation period was as follows: total irrigation: 2,513 mm, total rainfall: 273 mm, total drainage: 1,672 mm, total evapotranspiration: 620 mm, and total percolation: 552 mm. The total inflow was 2,786 mm, total outflow was 2,801 mm, and total outflow subtracted from the total inflow left 15 mm. It was found that this rice paddy field was an outflow-type field in 2015. Figure 3-1 shows water balance of the paddy field in each week. Almost all inflow was irrigated from irrigation canals because there was not much precipitation in 2015. There was substantial irrigation in June of the paddling and beginning period of growth and in July after the mid-summer drainage. The inflow was more than the outflow, except during the mid-summer drainage period. Concerning outflow, most of the drainage occurred just after the mid-summer drainage because water continued flowing into the paddy field to prevent oxygen insufficiency of rice by irrigation after mid-summer drainage. Approximately 60% of the drainage water flowed from the surface water of the paddy. It is assumed this paddy field is a surface drainage type. Water balance of the rice paddy field for the irrigation period was studied by Matsuura et al. (2010), and the total inflow was 2,199 mm, total outflow was 2,195 mm, and total inflow and outflow of feed rice paddy fields exceeded that of rice paddy fields. It is assumed that feed rice paddy fields were irrigated with more water to increase yield.

![Water balance of paddy field each week](image)

**Figure 3-1.** Water balance of paddy field each week

### 3.2 Runoff load in rice paddy fields

Figure 3-2 and 3-3 shows the load balance of T-N and T-P at the paddy field each week. The runoff load for the irrigation period was as follows: for T-N, the total inflow load was 41.5 (kg ha\(^{-1}\)) and total runoff load was 42.1 (kg ha\(^{-1}\)); for T-P, the total inflow load was 6.7 (kg ha\(^{-1}\)) and total runoff load was 12.8 (kg ha\(^{-1}\)); for COD, the total inflow load was 132.3 (kg ha\(^{-1}\)) and total runoff load was 326.9 (kg ha\(^{-1}\)). It was found that the total runoff load was more than total inflow load for every variable measured. The total runoff load of T-N studied by Tabuchi and Takamura (1985) was 46.1 (kg ha\(^{-1}\)) at the period the farmer didn’t consider environmental conservation, was equal to this paddy field. Tabuchi et al.(1998) reported that runoff load of T-N at the year were about 10-60 (kg ha\(^{-1}\)), runoff loads of T-N at this paddy field showed a close value. Because our studies were performed after pudding, it is thought total runoff loads were more lager than this studies. In recent years, rice cultivation of agriculture of environmental conservation type is performed to reduce the runoff load, Kurosawa
*et al.* (2007) suggested that it could reduce about 23\% of the runoff load of T-N to change agriculture of environmental conservation type from conventional agriculture. Kanagi *et al.* (2006) reported the total runoff load of T-N at environmental conservation type rice cultivation for human after pudding was about 10 (Kg ha\(^{-1}\)). Haruta *et al.* (2015) reported the total runoff load of T-N in some region at 2000s was 15.1 (kg ha\(^{-1}\)) (average; n=22). From the above, it was found this feed rice paddy field was high non-point source of runoff load of T-N. In all variables, larger loads flowed in the drainage just before mid-summer drainage, runoff of T-N also followed just after mid-summer drainage. Because, high concentration of T-N was drained with drainage water when the additional fertilizer applied after the mid-summer drainage. The paddy field was a surface drainage type in which runoff loads occur from rainfall, mid-summer drainage, and the pudding period (Maruyama and Hashimoto, 2005, Kudo *et al.* 2006). The total runoff loads from the surface at this feed rice paddy field of T-N and T-P were 70\% of total runoff loads. In the irrigation period, runoff loads were measured for the mid-summer drainage. The total runoff loads for the mid-summer drainage at this feed rice paddy field were 46\% of T-N and 53\% of T-P.

**Figure 3-2.** Load balance of T-N at paddy field each week

**Figure 3-3.** Load balance of T-P at paddy field each week
3.3 Results of yield investigation

Table 3.1 shows results of yield investigation for each treatment. The number of grains per effective panicle for flooding treatments was greater than intermittent irrigation treatments. In addition, 1,000 grain weight of brown rice were approximately 20 g in each treatment, the basal fertilizer + flooding was the greatest at 22.3 g, high fertilizer + intermittent irrigation treatment was the least at 19.6 g. There was a tendency for flooding conditions to produce more than intermittent irrigation conditions. Intermittent irrigation was thought to produce young panicles, but the available water was insufficient for optimal growth.

We determined the total weight of ground parts, paddies, and straw. The total weight of straw did not differ among treatments. For total weight of paddies and total weight of ground part, the high fertilizer + flooding + organic treatment was the greatest, and flooding conditions produced more weight than intermittent irrigation conditions overall. Based on these factors, water conditions are believed to affect the formation of paddies. The yield in response to the high fertilizer + organic +flooding treatment was the greatest at 1,213.3 kg per 10a. The high fertilizer + flooding treatment was second at 1,165.3 kg per 10a. The high fertilizer + intermittent irrigation treatment produced the smallest yield of 648.7 kg per 10a. Average yield of flooding condition was 1112 kg per 10a, intermittent condition was 732 kg per 10a. As a whole, flooding produced more yield than did intermittent irrigation. It is believed that fertilizer under intermittent irrigation conditions was removed with water during the several drainages. Because of the yield investigation, we conclude that flooding led to greater yield in terms of water management. The total runoff load of T-N in flooding treatment was 9.3 (Kg ha⁻¹), in intermittent irrigation treatment was 29 (Kg ha⁻¹), it was found that the runoff load of flooding treatment is small. From the above, water management of the flooding is suited to agriculture of environmental conservation type, and get more a yield.

Table 3-1. Results of yield investigation for each treatment (n = 3)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Number of paddies per effective panicle (number)</th>
<th>1,000 grain weight of brown rice (g)</th>
<th>Total weight of ground part (kg/10a)</th>
<th>Total weight of brown rice (kg/10a)</th>
<th>Total weight of straw (kg/10a)</th>
<th>Total weight of paddies (kg/10a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basal fertilizer flooding</td>
<td>63.0</td>
<td>22.3</td>
<td>1064.7</td>
<td>1033.3</td>
<td>898.0</td>
<td>1315.3</td>
</tr>
<tr>
<td>Basal fertilizer intermittent irrigation</td>
<td>54.5</td>
<td>21.8</td>
<td>762.7</td>
<td>730.0</td>
<td>616.7</td>
<td>947.3</td>
</tr>
<tr>
<td>Basal fertilizer + organic flooding</td>
<td>65.8</td>
<td>22.1</td>
<td>1090.7</td>
<td>1037.3</td>
<td>882.0</td>
<td>1336.0</td>
</tr>
<tr>
<td>Basal fertilizer + organic intermittent irrigation flooding</td>
<td>57.4</td>
<td>22.6</td>
<td>820.7</td>
<td>778.7</td>
<td>757.3</td>
<td>1012.7</td>
</tr>
<tr>
<td>Much fertilizer flooding</td>
<td>70.3</td>
<td>22.1</td>
<td>1218.7</td>
<td>1165.3</td>
<td>1050.7</td>
<td>1495.3</td>
</tr>
<tr>
<td>Much fertilizer intermittent irrigation</td>
<td>50.2</td>
<td>19.6</td>
<td>761.3</td>
<td>645.7</td>
<td>902.7</td>
<td>955.3</td>
</tr>
<tr>
<td>Much fertilizer + organic flooding</td>
<td>70.6</td>
<td>21.9</td>
<td>1274.0</td>
<td>1213.3</td>
<td>1055.3</td>
<td>1556.3</td>
</tr>
<tr>
<td>Much fertilizer + organic intermittent irrigation</td>
<td>53.5</td>
<td>20.6</td>
<td>829.3</td>
<td>769.3</td>
<td>1043.3</td>
<td>1043.3</td>
</tr>
</tbody>
</table>

4. CONCLUSIONS

In this investigation, paddy fields of feed rice in Goshogawara City were of the drainage type, in which much outflow was drained from the drainage canal. The outflow increased just before the mid-summer drainage and following the irrigation with free flowing water just after mid-summer drainage, but during other periods, the inflow exceeded the outflow. A considerable amount of inflow was taken from the
irrigation canal. This paddy field had little drainage water in 2015 because there was little rain in that year, and therefore, irrigation water was not drained, and it collected in the paddy field. Concerning load balances, runoff loads of all variables were greater than inflow loads. Each concentration in runoff at this paddy field was comparatively high. In recent years, rice cultivation of agriculture of environmental conservation type is performed to reduce the runoff load. From this, the total runoff load of T-N in 2000s was 15.1 (Kg ha⁻¹), compared to rice cultivation of agriculture of environmental conservation type, it is found that the runoff load of the feed rice paddy field is high. But this paddy field had little drainage water in 2015. Thus, it has possibility to increase the environmental load from this feed rice paddy field.

Concerning pot cultivation studies, differences in irrigation management affected yield. Waterfall and irrigation were planned in periods that were determined based on the ORP of the soil. However, as a result, the yields of flooding treatments were higher than that of intermittent treatments. It believed that intermittent irrigation immediately after application of additional fertilizer drained each load of nitrogen and phosphorus reduced nutrients for young panicle formation. The average yields of flooding treatments (1112 kg per 10a) were higher than that of intermittent treatments (732 kg per 10a). The total runoff load of T-N in flooding treatment was 9.3 (Kg ha⁻¹), in intermittent irrigation treatment was 29 (Kg ha⁻¹). In terms of environmental conservation and yields, it is thought that flooding is a beneficial method of water management.

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