Effects of Planting Time and Nitrogen Application on Dry Matter Yield of the Forage Rice Cultivar Tachiaoba in Southwestern Japan

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Abstract: We examined the effects of planting time on the dry matter (DM) yield of the forage rice cultivar Tachiaoba in southwestern Japan. DM yield was much higher with early planting than with normal planting. Dry weight (DW) per tiller was much higher with early planting than with normal planting. Thus, early planting is effective to obtain high DM yield. DM yield was closely related to the DW increase from transplanting to the full-heading stage (DW increase before heading) and DW per tiller. These results suggest that early planting leads to an increase in DW at the full-heading stage through an increase in DW per tiller and gives a high DM yield at the yellow-ripe stage. We also examined the effects of nitrogen (N) application rate and method on DM yield at the yellow-ripe stage. DM yield was higher with application of 22.5 g N m\(^{-2}\) than with 15.0 g N m\(^{-2}\). Although DW per tiller was slightly lower with application of 22.5 g N m\(^{-2}\) than with 15.0 g N m\(^{-2}\), the number of tillers per square meter was much higher with application of 22.5 g N m\(^{-2}\) than with 15.0 g N m\(^{-2}\). DM yield was the highest with N application method 1 that was applied more N early, followed by methods 2 that was applied more N evenly over time and 3 that was applied more N later. The number of tillers per square meter was much higher with method 1 than with method 2 or 3. Thus, application of 22.5 g N m\(^{-2}\) by method 1 is effective to obtain high DM yield. With both early and normal plantings, DM yield was closely related to the DW increase before heading and the number of tillers per square meter. These results suggest that application of 22.5 g N m\(^{-2}\) by method 1 lead to an increase in DW at the full-heading stage through an increase in the number of tillers per square meter resulting in a high DM yield at the yellow-ripe stage.

Key words: Dry matter yield, Forage rice, Nitrogen application method, Nitrogen application rate, *Oryza sativa* L., Planting time, Tachiaoba.

Production of forage rice (*Oryza sativa* L.) is increasing in Japan because of improved control of rice grain production and increasing demand for domestic forage (Sakai et al., 2003). In 2006, forage rice was grown on 5000 ha, and half of which was in southwestern Japan, where there is a prosperous livestock industry. Forage rice is generally harvested at the yellow-ripe stage, because although harvesting at the full-stage gives a higher dry matter (DM) yield, harvesting at the yellow-ripe stage gives a higher nutrient yield, fermentative quality, and voluntary intake by beef cattle, as well as a lower proportion of grain undigested by beef cattle (Nakui et al., 1988). These qualities make it important to maximize the DM yield at the yellow-ripe stage in forage rice.

There are four main cropping systems for forage rice in southwestern Japan: forage rice single-cropping (very early planting); forage rice – Italian ryegrass (*Lolium multiflorum* Lam.) cropping (early planting); forage rice – wheat (*Triticum aestivum* L.) or – barley (*Hordeum vulgare* L.) cropping (normal planting); and forage rice – tobacco (*Nicotiana tabacum* L.) cropping. We previously reported that twice harvesting (i.e., ratoon cropping) of the rice cultivar Taporuri, which is transplanted very early, gives a very high total DM yield in southwestern Japan (Nakano and Morita, 2007; 2008; Nakano et al., 2009). However, twice harvesting is not feasible for early and normal plantings because it requires a long growth duration. Recently, the new rice cultivars Tachiaoba and Nishiaoba, which perform acceptably as forage rices in southwestern Japan, were developed by the National Agricultural Research Center for Kyushu Okinawa Region (Sakai et al., 2007; Tamura et al., 2007). We previously examined the effects of planting time (early or normal planting) and cultivar (Tachiaoba, Nishiaoba, or Hinoihikari) on the DM yield and found that it is effective to plant Tachiaoba early to obtain a high DM yield at the yellow-ripe stage (Nakano et al., 2008).

Although much information is available about planting time, nitrogen (N) application rate, and N application method for obtaining high grain yields at the full-stage, few studies have examined the effects of these factors on DM yield at the yellow-ripe stage in forage rice in southwestern Japan. Firm field demonstrations have not supported the high
DM production potential of forage rice. DM yield of forage rice generally increase with increasing N application amount (Nakayama et al., 1987; Baba et al., 2002). However, N application above the optimum level causes lodging that reduces the grain yield of rice as a result of self-shading and a reduction in canopy photosynthesis (Setter et al., 1997). In general, N application at transplanting and active tillering promotes the growth of tiller bud and N application at booting promotes the growth of panicle.

We examined the effects of planting time, N application rate, and N application method on the DM yield of Tachiaoba at the yellow-ripe stage in southwestern Japan. Our aim was to optimize these factors to obtain a high DM yield of Tachiaoba at the yellow-ripe stage in southwestern Japan.

**Materials and Methods**

The study was conducted on a Grey Lowland soil at the National Agricultural Research Center for Kyushu Okinawa Region (33° 12′ N lat., 130° 30′ E long., 10 m a.s.l.), Chikugo, Fukuoka, Japan, in 2004 and 2005. The previous crop grown in the field was rice, and the same field was used for the experiments in both years of the study. The experiment had a 2 (planting time) × 2 (N application rate) × 3 (N application method) factorial design arranged in a randomized complete block with three replicates. The planting times were early and normal. To test the effects of N application rate and method, plants received either 22.5 or 15.0 g N m⁻² by three N application protocols: (method 1) 60% applied at transplanting, 20% at active tillering, and 10% at 20 d before heading; (method 2) 40%, 20%, 20%, and 20%, respectively; and (method 3) 20%, 30%, 30%, and 30%, respectively. We used the rice cultivar Tachiaoba, which has a higher DM production potential of forage rice. DM yield with the increase in N application rate was higher with early planting than with normal planting in both years. It was significantly (P < 0.05) higher with N application method 1 than with method 2 or 3 in both years. There was a significant (P < 0.05) interaction between planting time and N application rate for DM yield in 2005 (Table 2). The increase in DM yield with the increase in N application rate was greater with early planting than with normal planting.

We tested the differences among treatments by analysis of variance (ANOVA). When an F-test gave P < 0.05, treatment effects were compared by using the least significant difference (LSD).

**Results**

1. **DM yield and its components**

   DM yield was significantly (P < 0.05) higher with early planting than with normal planting in both years (Tables 1, 2). It was significantly (P < 0.05) higher with application of 22.5 g N m⁻² than with 15.0 g N m⁻² in both years. It was also significantly (P < 0.05) higher with N application method 1 than with method 2 or 3 in both years. There was a significant (P < 0.05) interaction between planting time and N application rate for DM yield in 2005 (Table 2). The increase in DM yield with the increase in N application rate was greater with early planting than with normal planting.

   There was a significant (P < 0.05) interaction between planting time and N application method for DM yield in 2005. With early planting, DM yield was significantly (P < 0.05) higher with N application method 1 than with method 2 or 3. With normal planting, it was significantly (P < 0.05) higher with N methods 1 and 2 than with method 3. There was a significant (P < 0.05) interaction between N application rate and method for DM yield in 2005. With N application methods 1 and 2, DM yield was significantly (P < 0.05) higher with application of 22.5 g N m⁻² than with 15.0 g N m⁻². With N application method 3, it did not differ significantly (P > 0.05) between N application rates. With application of 22.5 g N m⁻², DM yield was significantly (P < 0.05) higher with N application method 1 than with method 2 or 3, and with method 2 than with method 3. With application of 15.0 g N m⁻², it was significantly (P < 0.05) higher with N application method 1 than with method 2 or 3.

   The number of tillers per square meter was significantly (P < 0.05) lower with early planting than with normal planting in both years (Tables 1, 2). It was significantly (P < 0.05) higher with application of 22.5 g N m⁻² than with 15.0 g N m⁻² in both years. It was also significantly (P < 0.05) higher with N application method 1 than with method 2 or 3 in both years. There was a significant (P < 0.01) interaction between planting time and N application method for the number of tillers per square meter in 2005 (Table
With N application methods 1 and 2, the number of tillers per meter was significantly (P < 0.05) lower with early planting than with normal planting. With N application method 3, it did not differ significantly (P > 0.05) between planting times. With early planting, the number of tillers per meter was significantly (P < 0.05) higher with N application method 1 than with method 2 or 3, and with method 2 than with method 3. With application of 15.0 g N m⁻², it was significantly (P < 0.05) higher with N application method 1 than with method 2. DW per tiller was significantly (P < 0.05) higher with early planting than with normal planting in both years (Tables 1, 2). It was significantly (P < 0.05) lower with application of 22.5 g N m⁻² than with 15.0 g N m⁻² in both years. It was also significantly (P < 0.05) lower with N application method 1 than with method 2 or 3. There was a significant (P < 0.05) interaction between planting time and N application method for DW per tiller in both years (Tables 1, 2). With N application method 1 and 2 in both years, DW per tiller was significantly

### Table 1. Effects of planting time, N application rate, and N application method on DM yield, DM yield components, DW increase, vegetative growth duration, and plant height in the forage rice cultivar Tachiaoba in 2004.

<table>
<thead>
<tr>
<th>Planting time (A)</th>
<th>DM yield (g m⁻²)</th>
<th>Tillers per square meter (tillers m⁻²)</th>
<th>DW per tiller (g tiller⁻¹)</th>
<th>DW increase before heading (g m⁻²)</th>
<th>DW increase after heading (g m⁻²)</th>
<th>Panicle DW (g m⁻²)</th>
<th>Panicle DW ratio (%)</th>
<th>Vegetative growth (days)</th>
<th>Plant height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early</td>
<td>1776 a</td>
<td>276 b</td>
<td>6.47 a</td>
<td>1537 a</td>
<td>239 a</td>
<td>656 a</td>
<td>37.0 b</td>
<td>98.3 a</td>
<td>129 a</td>
</tr>
<tr>
<td>Normal</td>
<td>1479 b</td>
<td>301 a</td>
<td>4.96 b</td>
<td>1251 b</td>
<td>227 a</td>
<td>612 b</td>
<td>41.5 a</td>
<td>80.5 b</td>
<td>122 b</td>
</tr>
<tr>
<td>N application rate (g N m⁻²) (B)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22.5</td>
<td>1681 a</td>
<td>309 a</td>
<td>5.51 b</td>
<td>1449 a</td>
<td>232 a</td>
<td>630 a</td>
<td>37.8 b</td>
<td>90.0 a</td>
<td>130 a</td>
</tr>
<tr>
<td>15.0</td>
<td>1574 b</td>
<td>267 b</td>
<td>5.92 a</td>
<td>1359 b</td>
<td>235 a</td>
<td>638 a</td>
<td>40.8 a</td>
<td>88.8 b</td>
<td>121 b</td>
</tr>
<tr>
<td>N application method (C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1670 a</td>
<td>311 a</td>
<td>5.46 b</td>
<td>1453 a</td>
<td>217 a</td>
<td>602 c</td>
<td>36.3 c</td>
<td>89.8 a</td>
<td>127 a</td>
</tr>
<tr>
<td>2</td>
<td>1623 b</td>
<td>284 b</td>
<td>5.78 a</td>
<td>1403 b</td>
<td>220 a</td>
<td>635 b</td>
<td>39.5 b</td>
<td>89.2 b</td>
<td>125 b</td>
</tr>
<tr>
<td>3</td>
<td>1589 b</td>
<td>270 c</td>
<td>5.91 a</td>
<td>1326 b</td>
<td>263 a</td>
<td>665 a</td>
<td>42.1 a</td>
<td>89.3 b</td>
<td>125 b</td>
</tr>
</tbody>
</table>

**ANOVA**

- ** and * are significant at P < 0.01 and P < 0.05 levels, respectively. Early planting: seedlings were transplanted to the paddy field by hand in mid-May. Normal planting: seedlings were transplanted to the paddy field by hand in late June. N application method 1: 60% applied at transplanting, 20% at active tillering, 10% at 20 d before heading, and 10% at 10 d before heading. N application method 2: 40% applied at transplanting, 20% at active tillering, 20% at 20 d before heading, and 20% at 10 d before heading. N application method 3: 20% applied at transplanting, 20% at active tillering, 30% at 20 d before heading, and 30% at 10 d before heading. DW increase before heading: change in DW from transplanting to the full-heading stage. DW increase after heading: change in DW from full-heading to the yellow-ripe stage. Panicle DW ratio is the ratio of panicle to total DW. Vegetative growth duration is the number of days from transplanting to the heading.
(P<0.05) lower with application of 22.5 g N m⁻² than with 15.0 g N m⁻². With N application method 3, it did not differ significantly (P > 0.05) between N application rates. With application of 25.0 g N m⁻² in both years, DW per tiller was significantly (P<0.05) higher with N application methods 3 and 2 than with method 1. With application of 15.0 g N m⁻², it did not differ significantly (P > 0.05) among N application methods.

2. DW increase from transplanting to the full-heading stage and from full-heading to the yellow-ripe stage

DW increase from transplanting to the full-heading stage (DW increase before heading) was significantly (P<0.05) lower with early planting than with normal planting in 2005 (Table 2). It was significantly (P<0.05) higher with N application method 1 than with method 2 or 3 in 2005. There was a significant (P<0.05) interaction between planting time and N application method for DW increase after heading in 2005. With early planting, DW increase after heading was significantly (P<0.05) higher with N application method 1 than with method 2 or 3. With normal planting, it was significantly (P<0.05) higher with N application methods 1 and 2 than with method 3. There was a significant (P<0.05) interaction between N application rate and method for DW increase after heading in 2005. With application of 22.5 g N m⁻², DW increase after heading was significantly (P<0.05) higher with N application method 1 than with method 2 or 3. With application of 15.0 g N m⁻², it did not differ significantly (P > 0.05) among N application methods.
3. Panicle DW and its ratio to total DW

Panicle DW was significantly (P < 0.05) higher with early planting than with normal planting in 2004 (Table 1), but was significantly (P < 0.05) lower with early planting than with normal planting in 2005 (Table 2). It was significantly (P < 0.05) higher with application of 22.5 g N m\(^{-2}\) than with 15.0 g N m\(^{-2}\) in 2005. It was also significantly (P < 0.05) lower with N application method 1 than method 2 or 3, and with method 2 than with method 3, in 2004 (Table 1). There was a significant (P < 0.05) interaction between planting time and N application method for panicle DW in 2005 (Table 2). With early planting, panicle DW was significantly (P < 0.05) higher with application of 22.5 g N m\(^{-2}\) than with 15.0 g N m\(^{-2}\). With normal planting, it did not differ significantly (P > 0.05) between N application rates.

Panicle DW ratio to total DW (panicle DW ratio) was significantly (P < 0.05) lower with early planting than with normal planting in both years (Tables 1, 2). It was significantly (P < 0.05) lower with application of 22.5 g N m\(^{-2}\) than with 15.0 g N m\(^{-2}\) in 2004 (Table 1). It was also significantly (P < 0.05) lower with N application method 1 than with method 2 or 3, and with method 2 than with method 3, in both years (Tables 1, 2). There was a significant (P < 0.05) interaction between planting time and N application rate for panicle DW ratio in 2005 (Table 2). With early planting, panicle DW ratio did not differ significantly (P > 0.05) between N application rates. With application of 22.5 g N m\(^{-2}\), panicle DW ratio was significantly (P < 0.05) lower with N application method 1 than method 2 or 3, and with method 2 than method 3. With application of 15.0 g N m\(^{-2}\), it was significantly (P < 0.05) lower with N application method 1 than with 2 or 3.

4. Vegetative growth, plant height, and lodging

Vegetative growth duration was significantly (P < 0.05) longer with early planting than with normal planting in both years (Tables 1, 2). It was significantly (P < 0.05) longer with application of 22.5 g N m\(^{-2}\) than with 15.0 g N m\(^{-2}\) in both years. It was also significantly (P < 0.05) longer with N application method 1 than with method 2 or 3 in 2004 (Table 1).

Plant height was significantly (P < 0.05) higher with early planting than with normal planting in both years (Tables 1, 2). It was significantly (P < 0.05) higher with application of 22.5 g N m\(^{-2}\) than with 15.0 g N m\(^{-2}\) in both years. It was also significantly (P < 0.05) higher with N application method 3 than with method 2 or 1 in both years.

Lodging was not observed in any treatments (data not shown).

5. Relationships between DM yield and its related traits

DM yield was significantly and positively correlated with DW increase before heading (P < 0.001), plant height (P < 0.001), vegetative growth duration (P < 0.001), and DW per tiller (P < 0.01 in 2004, P < 0.1 in 2005). It was significantly and negatively correlated with panicle DW ratio in both years (P < 0.001) (Table 3).

With early planting, DM yield was significantly and positively correlated with the number of tillers per square meter in both years (P < 0.001 in 2004, P < 0.01 in 2005), plant height in both years (P < 0.05 in 2004, P < 0.01 in 2005), DW increase before heading in both

<table>
<thead>
<tr>
<th>DM yield related traits</th>
<th>2004</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tillers per square meter</td>
<td>-0.011</td>
<td>0.193</td>
</tr>
<tr>
<td>DW per tiller</td>
<td>0.712 **</td>
<td>0.688 *</td>
</tr>
<tr>
<td>DW increase before heading</td>
<td>0.987 ***</td>
<td>0.937 ***</td>
</tr>
<tr>
<td>DW increase after heading</td>
<td>0.068</td>
<td>-0.436</td>
</tr>
<tr>
<td>Panicle DW</td>
<td>0.363</td>
<td>-0.307</td>
</tr>
<tr>
<td>Panicle DW ratio</td>
<td>-0.834 ***</td>
<td>-0.935 ***</td>
</tr>
<tr>
<td>Vegetative growth</td>
<td>0.937 ***</td>
<td>0.875 ***</td>
</tr>
<tr>
<td>Plant height</td>
<td>0.870 ***</td>
<td>0.967 ***</td>
</tr>
</tbody>
</table>

***, **, and * are significant at P < 0.001, P < 0.01, and P < 0.05 levels, respectively.

DW increase before heading: change in DW from transplanting to the full-heading stage. DW increase after heading: change in DW from full-heading to the yellow-ripe stage. Panicle DW ratio is the ratio of panicle to total DW. Vegetative growth duration is the number of days from transplanting to the heading.
years (P<0.01 in 2004, P<0.1 in 2005), and vegetative growth duration in both years (P<0.1 in 2004, P<0.05 in 2005). It was significantly and negatively correlated with DW per tiller in 2004 (P<0.01) and panicle dry weight ratio in 2004 (P<0.01) (Table 4). With normal planting, DM yield was significantly and positively correlated with the number of tillers per square meter in both years (P<0.01), plant height in both years (P<0.01), vegetative growth duration in both years (P<0.01 in 2004, P<0.1 in 2005), DW increase before heading in 2004 (P<0.01), and panicle DW in 2005 (P<0.05). It was significantly and negatively correlated with panicle DW ratio in both years (P<0.1 in 2004, P<0.01 in 2005) and DW per tiller in both years (P<0.05 in 2005, P<0.1 in 2004).

**Discussion**

We examined the effects of planting time on DM yield of the forage rice cultivar Tachiaoba in southwestern Japan. DM yield was higher with early planting than with normal planting (Tables 1, 2). Although the number of tillers per square meter was slightly lower with early planting than with normal planting, DW per tiller was much higher with early planting than with normal planting. DM yield is generally higher in rice plants with a longer vegetative growth duration (e.g., Saitoh et al., 2000; Nakano and Morita, 2007; Nakano et al., 2008). In the present study, vegetative growth duration was longer with early planting than with normal planting (Tables 1, 2). Thus, early planting is effective to obtain a high DM yield. DW increase before heading was higher with early planting than with normal planting. DM yield was strongly related to the DW increase before heading and DW per tiller (Table 3). These results suggest that early planting leads to an increase in DW at the full-heading stage through an increase in DW per tiller and gives a high DM yield at the yellow-ripe stage.

Although there are many studies on the effects of N application rate and method on grain yield at the full-ripe stage (Yoshida, 1981), few have examined the effects of N application rate and method on DM yield at the yellow-ripe stage. Therefore, we also examined the effects of N application rate and method on DM yield at the yellow-ripe stage (Tables 1, 2). DM yield was higher with application of 22.5 g N m⁻² than with 15.0 g N m⁻². Although DW per tiller was slightly lower with application of 22.5 g N m⁻² than with 15.0 g N,...
m², the number of tillers per square meter was much higher with application of 22.5 g N m⁻² than with 15.0 g N m⁻². In southwestern Japan, the food rice cultivar Akisayaka, which heads on almost the same day as Tachiaoba, is generally transplanted in late June (i.e., normal planting). In the present study, panicle DW was lower with early planting than with normal planting in 2005, but was higher with early planting than with normal planting in 2004. The low panicle DW in normal planting in 2004 may be due to the effect of typhoon 16 and 18 that passed over southwestern Japan at the booting and heading stages, respectively. Akisayaka is generally supplied with N fertilizer for the promotion of high grain yield by a standard method: 50% applied at transplanting, 30% at 20 d before heading, and 20% at 13 d before heading. N application from the panicle formation stage to heading increases grain yield because it increases the number of grains per panicle (Shiga and Miyazaki, 1977). Similarly, in the present study in 2004, panicle DW was the highest with N application method 3, followed by methods 2 and 1 (Table 1). In 2005, it did not differ among N application methods. This might be because plants supplied with N by method 1 in 2005 had a lower DW were less luxuriant at full-heading stage, and had more adequate light-intercepting characteristics at the ripening period and a higher panicle DW than those in 2004. However, DM yield was the highest with N application method 1, followed by methods 2 and 3 (Tables 1, 2). Although DW per tiller was slightly lower with N application method 1 than with method 2 or 3, the number of tillers per square meter was much higher with N application method 1 than with method 2 or 3. Thus, application of 22.5 g N m⁻² by method 1 is effective to obtain a high DM yield. The best N application method for high DM yield is different from that for high grain yield. With both early and normal plantings, DM yield was closely related to the DW increase before heading and the number of tillers per square meter (Table 4). These results suggest that application of 22.5 g N m⁻² by method 1 lead to an increase in DW at the full-heading stage through an increase in the number of tillers per square meter resulting in a high DM yield at the yellow-ripe stage. Although combine harvesters have been developed to harvest forage rice (Urakawa and Yoshimura, 2003; Hattori et al., 2006), they drop many grains. The grain is often not digested by beef cattle, because it is covered with a hull (Nakui et al., 1988). Therefore, rice cultivars with a low panicle DW ratio are expected to be useful as forage rices (Yoshinaga et al., 2005).

In the present study, DM yield was higher with early planting than with normal planting and panicle DW ratio was lower with early planting than with normal planting (Tables 1, 2). DM yield was the highest with N application method 1, followed by methods 2 and 3 and panicle DW ratio was the lowest with N application method 1, followed by methods 2 and 3. Thus, the differences in DM yield caused by the difference in N application method might be larger when harvested by a combine harvester than by hand. Depending on the leaf and stem instead of the panicle for DW might compensate for the loss of dry weight harvested by a combine harvester and digested by dairy cattle and beef cattle.

Forage rice is generally used as fodder after fermentation. Lodging decreases forage rice quality (Noda et al., 1975), due to contamination with clostridia, which causes defective fermentation of silage (McDonald et al., 1991). Lodging, which often occurs in tall plant, reduces grain yield as a result of self-shading and reduction in canopy photosynthesis (Setter et al., 1997). Although the early planted plants supplied with 22.5 g N m⁻² by method 1 had the highest DM yield, and had the highest plant height in all treatments, they did not lodge. This might be because cultivar Tachiaoba has resistance to lodging because of the fat shape of its root (Sakai et al., 2007). Thus, it may be possible to increase DM yield of Tachiaoba through the application of cattle manure, which is a by-product of the prosperous livestock industry in southwestern Japan.

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References


* In Japanese with English abstract.
** In Japanese with English summary.
*** In Japanese with English synopsis.
**** In Japanese with English title.