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Dry Matter Yield Response to Seeding Rate and Row Spacing in Direct-seeded and Double-harvested Forage Rice

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Abstract

Forage rice (*Oryza sativa* L.) must be cost competitive with other fodders, and thus an important goal is increasing its dry matter (DM) and total digestible nutrient (TDN) yields, while reducing labor and costs. Although the direct seeding of rice does not have higher yield stability than transplanting, it has the potential to reduce labor and costs. The objective of this study was to determine the effects of seeding rate (2, 4, or 6 g m^{-2}) and row spacing (10 or 30 cm) on DM and TDN yields in direct-seeded and double-harvested forage rice in a well-drained paddy field. The seeding rate did not affect the total DM and TDN yields of the first and second crops, although those total yields were higher at 10 cm row spacing than at 30 cm row spacing. The DM yield and tiller number of the first crop increased with increasing seeding rate. Both were higher at 10 cm row spacing than at 30 cm row spacing. The seeding rate did not affect the DM and TDN yields of the second crop harvested at heading, although those yields were higher at 10 cm row spacing than at 30 cm row spacing. Neither seeding rate nor row spacing affected the DM and TDN yields of the second crop harvested at dough ripe. Thus, increasing the seeding rate is effective for increasing the DM and TDN yields of the first crop and reducing row spacing is effective for increasing total DM and TDN yields of the first and second crops. This cultivation method is expected to facilitate forage rice production by reducing labor and costs in temperate regions.

Discipline: Crop Science
Additional key words: ratooning, Ruriaoba, total digestible nutrient

Introduction

Rice (*Oryza sativa* L.) is one of the world's most important crops and is widely grown in paddy fields in both tropical and temperate regions. Forage rice for whole crop silage (WCS) has been suggested as a potential crop to increase Japan's self-sufficiency (Sakai et al. 2003; Kato 2008). Forage rice must be cost competitive with other fodders, and thus an important production goal is increasing its dry matter (DM) and total digestible nutrient (TDN) yields, the latter of which is among the most useful feeding standards. In southwestern Japan, double harvesting (by ratooning) that results in very high DM and TDN yields is currently being practiced using the forage rice cultivar "Ruriaoba" (Sakai et al. 2013). The effects of harvest time of the first crop, nitrogen (N) management, cutting height of the first crop, and equipment traffic treatment of the first crop on DM yield and TDN concentration have been examined in the double harvesting of Ruriaoba, and a new cultivation method for increasing DM and TDN yields has been developed (Nakano & Morita 2008; Nakano et al. 2009; Nakano et al. 2010; Nakano et al. 2011). Moreover, a new cultivation method for the seed production of Ruriaoba has recently been proposed (Nakano et al. 2014).

In 98% of the total rice planted area in Japan, rice seeds are sown in nursery boxes, and then the seedlings are transplanted into paddy fields (Ministry of Agriculture, Forestry and Fisheries). This means that direct seeding is only extended to 2% of Japan's total rice planted area. Although the direct seeding of rice does not have higher yield stability than transplanting, it has the potential to reduce labor and costs. Rice is seeded by drilling, broadcast, or hilling into a paddy field. Several studies have shown that rice plants seeded by broadcast into well-drained paddy fields produce higher or approximately the same grain yields than those seeded by drilling (Koyama et al. 1965; Yamane et al. 1970; Nonaka et al. 1973; Nagamine et al. 1984; Nakano & Tsuchiya 2012). Nevertheless, Japanese farmers tend to try hilling or drilling plants

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that resemble those of transplanting, but not broadcast. During vegetative growth, broadcast-seeded rice plants show a higher crop growth rate than drill-seeded plants (Nagamine et al. 1984) due to lower competition among individual plants. However, broadcast-seeded rice plants have lower root density below hills and exhibit higher lodging scores than drill-seeded plants (Koyama et al. 1965; Yamane et al. 1970; Nagoshi & Tanabe 2001). The growth of rice plants seeded by drilling with extremely reduced row spacing entails lower competition among individual plants in rows, and is considered to be similar to the growth of those seeded by broadcast. In order to evaluate the adaptability of plants with a higher crop growth rate during vegetative growth to direct seeding and double harvesting, it is important to compare plants seeded by drilling with different row spacings. Because the first crop is generally harvested at heading to avoid lodging in the double harvesting of Ruriaoba, broadcast seeding should be introduced to reduce labor and costs associated with forage rice production.

In broadcast-seeded rice plants, a suitable seeding density for high grain yield is estimated to be 100-150 m^{-2} (Yamane et al. 1970; Sakai & Ito 1973; Sakai et al. 1976). However, in broadcast-seeded Ruriaoba, this estimation may vary owing to its vigorous early growth. In addition, although weed growth is generally promoted in well-drained paddy fields, Ruriaoba suppresses weed growth with its vigorous early growth (Koarai et al. 2011). The present study aimed to determine the effects of seeding rate and row spacing on the DM and TDN yields in direct-seeded and double-harvested forage rice in a well-drained paddy field, in order to develop a suitable cultivation method for temperate regions.

Materials and methods

1. Experimental design and crop management

The study was conducted in 2010 on a fine-loamy, thermic Typic Endoaquept (a Lowland Paddy soil in the Japanese soil classification system) at the NARO Kyushu Okinawa Agricultural Research Center (33°12′N, 130°30′ E), Chikugo, Fukuoka, Japan. Rice was the previous crop grown in the field. Treatments included three seeding rates and two row spacings arranged as a split-plot experiment with three replicates in a randomized complete block design. The main plot and subplot were used for seeding rate and row spacing, respectively. The daily mean air temperature and solar radiation during the growth season were generally higher than normal in 2010 (Table 1). A rice cultivar "Ruriaoba", which is a high-DM-yielding

Table 1. Daily mean air temperature and solar radiation at the NARO Kyushu Okinawa Agricultural Research Center, Chikugo, Fukuoka, Japan, in 2010 versus 30-year average from 1981 to 2010

		Daily mean air temperature		Daily mean solar radiation	
		2010 (°C)	Normal (°C)	2010 (MJ m^{-2} d^{-1})	Normal (MJ m^{-2} d^{-1})
April	Early	14.1	13.0	17.7	15.6
	Middle	13.2	14.8	14.1	16.2
	Late	14.1	16.4	18.7	16.8
May	Early	19.3	18.2	18.7	16.8
	Middle	19.0	19.3	20.3	16.8
	Late	19.0	20.5	18.1	17.7
June	Early	22.3	22.1	21.1	17.3
	Middle	24.3	23.3	13.6	15.7
	Late	24.5	24.2	9.5	13.9
July	Early	26.1	25.6	13.2	15.4
	Middle	27.2	27.0	15.8	17.8
	Late	28.9	27.9	22.2	19.1
August	Early	29.5	28.1	19.8	19.1
	Middle	28.9	27.8	18.3	17.9
	Late	29.6	27.0	21.2	17.2
September	Early	28.2	26.0	16.6	16.2
	Middle	26.0	24.5	17.6	15.3
	Late	22.5	22.5	13.5	14.1
October	Early	20.5	20.5	12.9	13.1
	Middle	19.7	18.6	13.5	12.9
	Late	17.8	16.5	9.2	11.6
November	Early	13.1	14.8	12.9	10.1
	Middle	13.1	12.6	10.9	9.1
	Late	12.3	10.6	9.8	8.5

cultivar, and commonly grown as forage rice for double harvesting in southwestern Japan, was used. A day before seeding, plots received 50 kg ha^{-1} N, 50 kg ha^{-1} P_2O_5, and 50 kg ha^{-1} K_2O in the form of synthetic fertilizer, which was incorporated into the soil by plowing. Seeds treated with insecticide and fungicide were manually seeded on April 16 at 2, 4, or 6 g m^{-2} with 10 cm or 30 cm row spacing at a depth of 2-3 cm. The percentage of seedling establishment was 46%. After trimming, each plot was 1.8 m wide × 8.0 m long. Plants received 50 kg ha^{-1} N, 50 kg ha^{-1} P_2O_5, and 50 kg ha^{-1} K_2O in the form of synthetic fertilizer on June 17, August 30, and September 10. Weeds were controlled using herbicides.

2. Sampling and measurement

Plants in the first crop were manually harvested from 2.4 m^2 or 3.6 m^2 (10 or 30 cm row spacing, respectively) to a stubble height of 5 cm at heading (August 23) because the first crop of plants harvested at a stubble height of 5 cm produces a high DM yield (Nakano et al. 2009), and plants in the second crop were manually harvested from 0.8 m^2 or 1.2 m^2 (10 or 30 cm row spacing, respectively) at heading (October 19) and from 0.8 m^2 or 1.2 m^2 (10 or 30 cm row spacing, respectively) at dough ripe (November 11). The number of tillers was counted for each plant. Approximately 10% of the plants were separated into leaf blades including dead leaf blades, leaf sheaths plus stems, and panicles. Each plant part was dried at 80°C in a ventilated oven for two days with the remaining plants to determine its dry weight.

3. Nitrogen and estimation of total digestible nutrient concentration

Nitrogen was determined using a Macro Corder JM1000CN (J-Science Lab, Kyoto, Japan). The TDN concentration of forage rice was estimated by enzymatic analysis (Hattori et al. 2005). Each dried sample was ground in a Wiley mill (WT-100, Ikemoto Scientific Technology, Tokyo, Japan) and passed through a 1 mm screen. Two subsamples of residue from each sample were prepared and used for the measurement of low digestible fiber (Ob) concentration, which is the fraction resistant to cellulase treatment (Abe 1988), and organic cell wall (OCW) concentration. TDN concentration, organic cellular content (OCC), and high digestible fiber (Oa) concentration were estimated as follows:

$$\text{TDN (g kg}^{-1}\text{)} = -54.5 + 8.9 \times [\text{OCC (g kg}^{-1}\text{)} + \text{Oa (g kg}^{-1}\text{)}] + 4.5 \times \text{OCW (g kg}^{-1}\text{)} \quad [1]$$

$$\text{OCC (g kg}^{-1}\text{)} = 1{,}000 - [\text{OCW (g kg}^{-1}\text{)} + \text{crude ash (g kg}^{-1}\text{)}] \quad [2]$$

$$\text{Oa (g kg}^{-1}\text{)} = \text{OCW (g kg}^{-1}\text{)} - \text{Ob (g kg}^{-1}\text{)} \quad [3]$$

$$\text{TDN yield (g m}^{-2}\text{)} = \text{DM (g m}^{-2}\text{)} \times \text{TDN (g kg}^{-1}\text{)} / 1{,}000 \quad [4]$$

Equation [1] is derived from Deguchi et al. (1997) and Eqs. [2] and [3] from Abe (1988). Hattori et al. (2005) have previously confirmed that Eq. [1] is suitable for forage rice.

4. Statistical analysis

Statistical analyses were performed using a general linear model in SPSS (version 17.0, SPSS Inc., Chicago, IL, USA). Analysis of variance (ANOVA) was used to test the effects of seeding rate and row spacing on the DM yield and its components, TDN concentration, and TDN yield. The seeding rate and row spacing were considered as fixed effects. Replication was considered as a random effect. Significant treatment effects ($P < 0.05$) were determined using Fisher's protected least significant difference (LSD).

Results and discussion

Because the hulls of forage rice harvested at yellow ripe can restrict cattle's ability to digest the grains (Hara et al. 1986; Nakui et al. 1988; Hosoda et al. 2005), forage rice is harvested from heading to dough ripe to increase its value. The seeding rate did not affect the total whole plant and leaf plus stem DM and TDN yields of the first and second crops harvested at heading or dough ripe (Table 2). However, the row spacing did affect those yields. Averaged over seeding rates, the whole plant and leaf plus stem DM yields and whole plant TDN yield were higher at 10 cm row spacing than at 30 cm row spacing. Thus, Ruriaoba seeded at 10 cm row spacing could show an increase in the whole plant and leaf plus stem DM yields as well as in nutritive value upon double harvesting. Because plants seeded at 10 cm row spacing have lower competition among individual plants in rows, such high whole plant and leaf plus stem DM yields and whole plant TDN yield may be observed in broadcast-seeded plants.

The first crop in the present study was harvested at heading when it achieved high whole plant DM and TDN yields without lodging in the double harvesting of Ruriaoba in previous studies (Nakano & Morita 2008; Nakano et al. 2011). In general, the first crop harvested at heading has a higher ratio of leaf plus stem dry weight to whole plant dry weight than the second crop harvested at yellow ripe. In this study, the seeding rate affected the whole plant DM yield and its components, N amount, and TDN yield of the first crop harvested at heading (Table 3). Averaged over row spacings, the whole plant DM yield,

Table 2. Total dry matter (DM) and total digestible nutrient (TDN) yields of first and second crops harvested at heading or dough ripe as affected by different seeding rate and row spacing in rice†

Seeding rate ($g\ m^{-2}$)	Row spacing (cm)	Second crop harvested at heading: Whole plant DM yield ($g\ m^{-2}$)	Leaf plus stem DM yield ($g\ m^{-2}$)	Panicle DM yield ($g\ m^{-2}$)	Whole plant TDN yield ($g\ m^{-2}$)	Second crop harvested at dough ripe: Whole plant DM yield ($g\ m^{-2}$)	Leaf plus stem DM yield ($g\ m^{-2}$)	Panicle DM yield ($g\ m^{-2}$)	Whole plant TDN yield ($g\ m^{-2}$)
2		1,692	1,526	166	877	1,836	1,630	206	937
4		1,777	1,625	152	936	1,851	1,646	206	950
6		1,810	1,656	153	947	1,861	1,661	200	955
	10	1,873a‡	1,711a	161	984a	1,932a	1,726a	206	988a
	30	1,646b	1,494b	152	857b	1,767b	1,565b	202	906b
2	10	1,775	1,599	177aA§	925	1,884	1,674	210	958
	30	1,609	1,454	155bB	830	1,788	1,585	203	916
4	10	1,906	1,745	161aAB	1,011	1,923	1,709	214	985
	30	1,648	1,505	143bAB	861	1,780	1,582	197	914
6	10	1,936	1,790	146B	1,015	1,990	1,795	194	1,021
	30	1,683	1,523	160A	879	1,733	1,527	206	888
ANOVA									
Seeding rate (SR)		NS¶	NS	NS	NS	NS	NS	NS	NS
Row spacing (RS)		**	**	NS	**	*	*	NS	*
SR × RS		NS	NS	*	NS	NS	NS	NS	NS

* Significant at $P < 0.05$

** Significant at $P < 0.01$

† First crop was harvested at heading

‡ Means within a column followed by the same lowercase letter do not differ significantly ($P < 0.05$).

§ Means within a column followed by the same lowercase letter do not differ significantly ($P < 0.05$) between row widths for a given seeding rate. Means within a column followed by the same uppercase letter do not differ significantly ($P < 0.05$) among seeding rates for a given row width.

¶ NS, not significant at $P < 0.05$

Table 3. Dry matter (DM) yield and its components, total digestible nutrient (TDN) concentration, and TDN yield of first crop as affected by different seeding rate and row spacing in rice

Seeding rate ($g\ m^{-2}$)	Row spacing (cm)	Whole plant DM yield ($g\ m^{-2}$)	Number of tillers (m^{-2})	Dry weight per tiller (g)	Leaf plus stem DM yield ($g\ m^{-2}$)	Panicle DM yield ($g\ m^{-2}$)	Whole plant N amount ($g\ m^{-2}$)	Whole plant TDN conc. ($g\ kg^{-1}$)	Whole plant TDN yield ($g\ m^{-2}$)
2		926b†	259b	3.57a	828b	99	8.5b	497	460b
4		1,011ab	298ab	3.40b	917ab	94	9.1ab	500	506ab
6		1,062a	320a	3.32b	964a	98	10.0a	500	531a
	10	1,077a	314a	3.45	975a	103a	9.9a	498	537a
	30	922b	270b	3.42	832b	91b	8.4b	500	461b
2	10	985	270	3.65	878	107	9.1	493	486
	30	867	248	3.50	777	90	7.8	500	434
4	10	1,070	318	3.36	969	100	9.6	502	536
	30	953	278	3.43	865	87	8.6	499	475
6	10	1,177	354	3.33	1,076	101	11.2	500	589
	30	946	285	3.32	852	94	8.8	500	474
ANOVA									
Seeding rate (SR)		*	**	*	*	NS‡	*	NS	*
Row spacing (RS)		**	**	NS	**	**	**	NS	**
SR × RS		NS	NS	NS	NS	NS	NS	NS	NS

* Significant at $P < 0.05$

** Significant at $P < 0.01$

† Means within a column followed by the same lowercase letter do not differ significantly ($P < 0.05$).

‡NS, not significant at $P < 0.05$

tiller number, leaf plus stem DM yield, N amount, and TDN yield increased with increasing seeding rate. In contrast, the dry weight per tiller decreased with increasing seeding rate. Thus, the high whole plant DM yield resulted from the high number of tillers with increasing seeding rate. In addition, because the number of seedling emergence was 41, 78, and 118 m^{-2} for 2, 4, and 6 g m^{-2} of seeding rate, respectively, with no large differences between 4 and 6 g m^{-2} in the whole plant and leaf plus stem DM and TDN yields, a large number of seedling emergence may be not required for the cultivation of Ruriaoba. Furthermore, as the TDN concentration did not differ among seeding rates, the high TDN yield resulted from the high DM yield with increasing seeding rate. Row spacing affected the DM yield and its components, N amount, and TDN yield of the first crop harvested at heading. Moreover, the whole plant and leaf plus stem DM yields were more sensitive to row spacing rather than seeding rate. Averaged over seeding rates, the whole plant DM yield, tiller number, leaf plus stem DM yield, panicle DM yield, N amount, and TDN yield were higher at 10 cm row spacing than at 30 cm row spacing. Thus, the high whole plant DM yield resulted from the high number of tillers at 10 cm row spacing. Furthermore, because the TDN concentration did not differ between row spacings, the high TDN yield resulted from the high DM yield at 10 cm row spacing. These results are similar to those reported by previous studies, which showed that rice plants transplanted at higher density had higher tiller numbers and whole plant DM yield at heading (Nakano et al. 2012), and that broadcast-seeded rice plants had higher tiller numbers and whole plant DM yield than drill-seeded plants (Nakano & Tsuchiya 2012). Such rice plants with higher whole plant DM yield at heading tend to lodge during ripening. However, in the present study, harvesting the first crop at heading avoided lodging. Therefore, increasing the seeding rate and reducing the row spacing may produce higher tiller numbers and lead to high whole plant DM and TDN yields of the first crop at heading.

Forage barley (*Hordeum vulgare* L.) for WCS has recently attracted attention as a potential crop to increase the production of roughage in paddy fields. For seeding forage barley in late November, which is the standard seeding time, the second crop of forage rice must be harvested by late October. In the present study conducted in the northern part of southwestern Japan, as the second crop was headed in mid-October, its optimal harvest time was considered to be at heading. The seeding rate did not affect the DM yield and its components, N amount, and TDN yield of the second crop harvested at heading, but did affect the dry weight per tiller (Table 4). Averaged over row spacings, the dry weight per tiller decreased with increasing seeding rate. However, row spacing affected the DM yield and its components, N amount, and TDN yield of the second crop harvested at heading. Averaged over seeding rates, the whole plant DM yield, tiller number, leaf plus stem DM yield, N amount, and TDN yield were higher at 10 cm row spacing than at 30 cm row spacing. Thus, in plants seeded at reduced row spacing, increasing the tiller number may be important for increasing the DM yield of the second crop harvested at heading. This result was similar to that of a study in which food rice was harvested at maturity, which indicated a positive correlation between the grain yield of the second crop and the tiller number (Chauhan et al. 1985). Furthermore, because the TDN concentration did not differ between row spacings, the high TDN yield resulted from the high DM yield. Therefore, reducing row spacing may produce higher tiller numbers and lead to high DM and TDN yields of the second crop at heading.

The second crop did not attain yellow ripeness due to low temperatures after early November (Table 1). The seeding rate did not affect the DM yield and its components, N amount, and TDN yield of the second crop harvested at dough ripe, but did affect the dry weight per tiller (Table 5). Furthermore, row spacing did not affect the DM yield and its components, N amount, and TDN yield of the second crop harvested at dough ripe.

In one study, the grain yield of the second crop was increased in response to high planting density that increased the tiller number per unit area (Bahar et al. 1976). In contrast, another study indicated that the seeding rate and row spacing did not affect the grain yield of the second crop (Jones & Snyder 1987). Applying N after the harvest of the first crop has reportedly increased the grain yield of the second crop (Evatt & Beachell 1960; Bahar & Datta 1977; Nakano & Morita 2008). In the present study, the N amount of the first crop increased with increasing seeding rate, but that of the second crop harvested at heading or dough ripe did not increase (Tables 3, 4, and 5). Similarly, the N amount of the first and second crops harvested at heading was higher at 10 cm row spacing than at 30 cm row spacing, but the N amount of the second crop harvested at dough ripe was not higher at 10 cm row spacing. The DM yield of the first crop did not correlate with that of the second crop harvested at heading or dough ripe, but negatively correlated with ΔW (representing the increase in DM of the second crop from heading to dough ripe) (Table 6). In general, rice plants directly seeded into a well-drained paddy field show a lower fertilizer response than those transplanted. Thus, the amount of N accumulated by the second crop at a high seeding rate or reduced row spacing may be insufficient, and strong growth of the first crop may not directly contribute to

Table 4. Dry matter (DM) yield and its components, total digestible nutrient (TDN) concentration, and TDN yield of second crop harvested at heading as affected by different seeding rate and row spacing in rice

Seeding rate ($g\ m^{-2}$)	Row spacing (cm)	Whole plant DM yield ($g\ m^{-2}$)	Number of tillers (m^{-2})	Dry weight per tiller (g)	Leaf plus stem DM yield ($g\ m^{-2}$)	Panicle DM yield ($g\ m^{-2}$)	Whole plant N amount ($g\ m^{-2}$)	Whole plant TDN conc. ($g\ kg^{-1}$)	Whole plant TDN yield ($g\ m^{-2}$)
2		766	292	2.62a	699	67	8.9	545	418
4		766	316	2.42b	708	58	8.9	561	430
6		748	328	2.29b	692	56	8.6	556	416
	10	795a†	328a	2.44	737a	59	9.3a	562	447a
	30	724b	296b	2.45	663b	62	8.3b	546	396b
2	10	790	297	2.66	721	70A	9.1	556	440
	30	741	288	2.58	676	65A	8.6	534	396
4	10	837	345	2.43	776	61B	9.8	568	475
	30	695	288	2.41	640	55B	7.9	554	386
6	10	759	343	2.21	713	46bC‡	9.0	562	426
	30	737	314	2.36	671	65aA	8.2	550	406
ANOVA									
Seeding rate (SR)		NS§	NS	*	NS	NS	NS	NS	NS
Row spacing (RS)		*	*	NS	*	NS	*	NS	*
SR × RS		NS	NS	NS	NS	**	NS	NS	NS

* Significant at $P < 0.05$

** Significant at $P < 0.01$

† Means within a column followed by the same lowercase letter do not differ significantly ($P < 0.05$).

‡ Means within a column followed by the same lowercase letter do not differ significantly ($P < 0.05$) between row spacings for a given seeding rate. Means within a column followed by the same uppercase letter do not differ significantly ($P < 0.05$) among seeding rates for a given row spacing.

§ NS, not significant at $P < 0.05$

Table 5. Dry matter (DM) yield and its components, total digestible nutrient (TDN) concentration, and TDN yield of second crop harvested at dough ripe as affected by different seeding rate and row spacing in rice

Seeding rate ($g\ m^{-2}$)	Row spacing (cm)	Whole plant DM yield ($g\ m^{-2}$)	Number of tillers (m^{-2})	Dry weight per tiller (g)	Leaf plus stem DM yield ($g\ m^{-2}$)	Panicle DM yield ($g\ m^{-2}$)	Whole plant N amount ($g\ m^{-2}$)	Whole plant TDN conc. ($g\ kg^{-1}$)	Whole plant TDN yield ($g\ m^{-2}$)
2		910	315	2.89a†	802	108	10.1	525	477
4		840	308	2.72ab	728	112	9.3	528	444
6		799	309	2.59b	697	102	9.0	528	423
	10	855	319	2.68	752	103	9.4	527	451
	30	845	303	2.79	733	112	9.5	527	445
2	10	899	318	2.83	796	103	9.6	526	473
	30	921	313	2.95	808	113	10.7	523	482
4	10	853	314	2.72	739	114	9.3	526	449
	30	827	303	2.73	717	110	9.3	531	439
6	10	812	327	2.48	719	93	9.3	529	432
	30	786	291	2.70	675	112	8.7	527	415
ANOVA									
Seeding rate (SR)		NS‡	NS	**	NS	NS	NS	NS	NS
Row spacing (RS)		NS	NS	NS	NS	NS	NS	NS	NS
SR × RS		NS	NS	NS	NS	NS	NS	NS	NS

* Significant at $P < 0.05$
** Significant at $P < 0.01$
† Means within a column followed by the same lowercase letter do not differ significantly ($P < 0.05$).
‡ NS, not significant at $P < 0.05$

Table 6. Pearson correlation (*r*) analysis of agronomic traits

	Second crop		
	DM† yield at heading	DM yield at dough ripe	ΔW‡
First crop	0.433	−0.428	−0.712§

† Whole plant dry matter
‡ Increase in DM of the second crop from heading to dough ripe
§ Significant at $P < 0.2$

the growth of the second crop. Therefore, to improve the whole plant DM yield of the second crop at high seeding rate or reduced row spacing, more N should be applied.

In the southern part of southwestern Japan, forage rice for WCS is implemented as an important summer crop in the paddy fields. Although these present results were obtained from a one-year field study, such data as row spacing response to the whole plant DM yield and its related traits were very clear and supported by previous studies. Hence, such findings are extremely useful for farmers producing Ruriaoba in southwestern Japan.

Conclusions

Averaged over seeding rates, the total DM and TDN yields of the first and second crops harvested at heading or dough ripe were higher at 10 cm row spacing than at 30 cm row spacing. Although the total DM and TDN yields of the first and second crops did not differ among seeding rates, those of the first crop increased with increasing seeding rate. Thus, in double harvesting of Ruriaoba, reducing the row spacing (similar to broadcast seeding) and increasing the seeding rate were effective for increasing both DM and TDN yields. A previous study identified forage barley cultivars with high DM yields and nutritive values at heading or dough ripe in paddy fields of southwestern Japan (Nakano et al. 2013). Combining such forage barley cultivations in the winter growing season with double harvesting following the direct seeding of forage rice into well-drained paddy fields in the summer growing season should result in a new labor- and cost-effective cropping system for roughage production in temperate regions in the near future.

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