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Rice Bran Affects Dry-matter Production of Chinese and Japanese Rice Cultivars

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Abstract

The effect of rice bran on dry matter production of different rice cultivars, namely the Chinese panicle weight types and Japanese panicle number types, was evaluated in field conditions, with growth, canopy production structure and the root system determined over a period of 60 days. The treatments consisted of rice cultivars with 1000 kg ha^{-1} rice bran without agrochemicals (RB), cultivars with chemical fertilizer and cultivars with herbicide, with the latter serving as a control. The crop growth rate (CGR) and mean leaf area index (mLAI) in RB treatment were lower than that of the control; however, the net assimilation rate (NAR) was higher for all growth stages in this treatment. It was noted that CGR in RB and the control treatment depended greatly on mLAI during the early and middle growth stages, whereas CGR was more dependent on NAR in the late growth stage. Correlation between CGR in middle stage and the extinction coefficient of the canopy (k) at heading was apparent ($p < 0.05$). NAR in middle stage was positively correlated with mean leaf color and specific leaf weight (SLW). The correlations between NAR in the late stage and bleeding rate per number of primary roots, and per leaf area at maturity was apparent ($p < 0.01$). Root vitality and NAR were higher in RB treatment. The photosynthesis-related traits after heading in RB treatment were better than the control. Reduction of ΔW in RB treatment as well as the spikelets number (SN) was unapparent. The panicle number type cultivars did not inhibit growth during the early and middle growth stages with the presence of rice bran. The difference between growth, panicle number and weight cultivars was insignificant in the late stage.

Discipline: Crop production
Additional key words: bleeding rate, growth analysis, light extinction coefficient, the panicle number type cultivars, root system.

Introduction

The use of nitrogen in paddy cultivation in China is three times higher than in Japan. In this context, excess application of chemical fertilizer in paddy cultivation pollutes the environment and has adverse effects on both aquatic and terrestrial organisms. The use of chemical fertilizers increases operation costs, resulting in higher rice and rice product prices. It is, therefore, important to find new alternatives as substitutes for chemical fertilizer in paddy farming to alleviate environmental issues arising from their use.

Rice bran is often used in the organic paddy farming in Japan because of its efficacy as a fertilizer and herbicide. This cultivation technique fulfills the growing demand for agriculture products with fewer or no agrochemicals to

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promote green environmental conservation in agriculture. Moreover, rice bran is inexpensive and requires minimal effort to apply under field conditions (Chiba *et al.* 2001, Fukushima and Uchikawa 2002). Unlike compost, the preparation of rice bran for paddy farming is easy. It is usually applied to paddy fields shortly after rice transplantation with no tilling required after application.

To date, studies on the application of rice bran in Chinese rice cultivars has been limited. Previous examination of the effects of rice bran on the yield, palatability, growth and root system of Chinese and Japanese rice cultivars (Bian *et al.* 2010a, b) revealed that the yield of Hinohikari rice cultivar grown with rice bran was 10 to 18% lower than conventional cultivation, the latter with agrochemicals. The reduction may have been due to the low number of spikelets resulting from a significantly lower number of panicles rather than reduced spikelets per panicle. The amount of unhulled rice per m^2 of panicle weight type cultivars was higher in panicle number type cultivars, with 80% of ripened grains from 30,000 m^2 unhulled rice. These results implied that rice cultivar response to the application of rice bran without agrochemicals differed among panicle weight type and panicle number type rice cultivars.

In the present study, the effect of rice bran in the absence of agrochemicals on dry matter production and the eco-physiological traits of panicle weight type (two Chinese) and panicle number type (two Japanese) rice cultivars was examined.

Materials and Methods

1. Field and Experimental Design

Two plots of land divided by buried vinyl chloride plates in a paddy field of the Faculty of Agriculture, Kagawa University, Japan (E134º 7’ 39”, N34º 16’ 17’’) were selected for experiment. A plot was assigned for conventional propagation (control treatment), to which chemical fertilizers consisting of 85 kg ha^{-1} of N, P_2O_5 and K_2O and a herbicide (ESPROCARB BENSULFURON-METHYL) were applied for the cultivation of Chinese rice cultivars panicle weight type (Tsumomi 308 and Tsusei 2) and Japanese rice cultivars panicle number type (Koshihikari and Hinohikari). Another plot was assigned for the application of rice bran (RB), to which 1000 kg ha^{-1} of rice bran was applied in the absence of any compound fertilizers or agrochemicals (i.e. pesticides, insecticides, or herbicides). The N, P, K content of rice bran was approximately 2%, 1.5%, 1.8%, the equivalent of 20 kg ha^{-1} N, 15 kg ha^{-1} P, 18 kg ha^{-1} K for 1000 kg ha^{-1} rice bran. The rice bran was applied 2 days after transplantation. Twenty-nine-day-old seedlings with a leaf age of 4.5 to 5 unit (including incomplete leaf) were planted in the paddy field. One seedling per hill was planted by hand at a density of 22.2 hills m^{-2} (30 inter-row and 15 cm inter-hill), with each treatment consisting of two replicates.

2. Growth parameter measurement

The leaf stage, plant height and dry weight of 100 plants per cultivar were recorded during transplantation. Growth, panicle formation, heading and maturity stages were measured, with the actual sampling date for the heading and maturity stages delayed 1 to 4 days from the observational dates of those stages (Table 1). The plant height, tiller number and leaf color of the fully expanded uppermost leaf blade of the longest tiller per hill was determined by measurement of the chlorophyll content with a chlorophyll meter, (SPAD-502, Konica Minolta Inc., Tokyo, Japan). Ten hills from each cultivar were measured. Two average-size hills from five samples collected from each plot were divided into leaf blade, culm plus leaf sheath (and panicle after heading stage), and leaf area was measured with an automatic area meter (AAM-8, Hayashi Denko Co., Tokyo, Japan). The dry weights of the individual plant parts were determined by weighing after drying 48 h at 80°C in a ventilated oven. The dry weight and leaf area were expressed as per unit of land area by multiplying by plant density. CGR,

Table 1. Observational and sampling dates of panicle formation (PF), heading (HD) and maturity (MA) stages.

Cultivar	Treatment	PF	HD		MA	
		Observ. and sampling	Observational	Sampling	Observational	Sampling
Tsumomi308	Control	7/26	8/17	8/21	9/26	9/28
	RB	7/26	8/18	8/21	9/26	9/28
Tsusei2	Control	7/30	8/22	8/25	10/05	10/08
	RB	7/30	8/24	8/25	10/05	10/08
Koshihikari	Control	7/23	8/12	8/16	9/15	9/17
	RB	7/23	8/13	8/16	9/15	9/17
Hinohikari	Control	8/06	8/27	8/30	10/09	10/11
	RB	8/06	8/29	8/30	10/09	10/11

mLAI, NAR and SLW were calculated as follows:

$$CGR = (W_2 - W_1) / (t_2 - t_1) \tag{1}$$

$$mLAI = (LAI_2 - LAI_1) / (\ln LAI_2 - \ln LAI_1) \tag{2}$$

$$NAR = [(\ln LAI_2 - \ln LAI_1) / (LAI_2 - LAI_1)] \times [(W_2 - W_1) / (t_2 - t_1)] \tag{3}$$

where W_1, LAI_1, W_2, LAI_2 are the dry weight and LAI at times t_1 and t_2, respectively.

SLW was calculated as leaf weight divided by leaf area.

$$SLW = W/L \tag{4}$$

Where W, L are the dry weight of the leaf blade and leaf area.

3. Productive structure of canopy

At the heading stage, the relative light intensity every 10 cm from the soil surface was measured by a relative photometric sensor (NS-II, Sanshin Kogyo Co., Tokyo, Japan). After light measurement, the productive structure of the canopy was determined by the stratified clip method (Monsi und Saeki 1953). The top 10 cm of the plant canopy was collected and separated into leaf blade, leaf sheath plus culm and panicle. Leaf area was measured with automatic area meter. The light extinction coefficient of the canopy (k) was calculated as:

$$\ln (I/I_0) = - kF \tag{5}$$

where F is the cumulative leaf area index from the highest layer of canopy, and I/I_0 is the relative light intensity at a given layer of the canopy (Monsi and Saeki, 1953).

4. Root system determination

Root morphological traits and bleeding rate were expressed as gain in bleeding sap weight per hour (Morita and Abe 1999). These values were measured at maturity as described (Bian *et al.* 2010a). To analyze NAR, the tiller number of 12 hills for each cultivar and treatment were counted separately and four hills, which had an average number of tillers, were selected for measurement of bleeding rate. Hill shoots were cut 10 cm above soil surface in the morning, and stump surfaces were covered with pre-weighted cotton balls enclosed in plastic film. The cotton balls were collected after one hour and weighed to determine bleeding rate. The roots of two of four selected hills were sampled with a circular steel cylinder (diameter of 15 cm and a length of 30 cm). Roots within the soil monolith (soil depth of 25 cm soil) were cleaned and the number of primary roots, total length and dry weight of the roots were determined.

Results

1. Dry matter production

The aboveground dry weight (W), leaf area index (LAI) at transplanting, panicle formation, heading and maturity stages, as well as the number of spikelets (SN) at the maturity stage are shown in Table 2. During transplantation, both the W and LAI of Tsumomi 308 were the largest and those of Hinohikari were the smallest, whereas from the panicle formation stage onward, both the W and LAI of Hinohikari were largest at all stages. W, LAI and SN

Table 2. Above ground dry weight (W), leaf area index (LAI) and the number of spikelet (SN) at transplantation (TP), panicle formation (PF), heading (HD) and maturity (MA) stages.

Cultivar	Treatment	W ($g\ m^{-2}$)				LAI				SN (no. m^{-2})
		TP	PF	HD	MA	TP	PF	HD	MA	MA
Tsumomi308	Control	2.14	264	936	1203	0.024	2.23	4.09	1.86	35840
	RB	2.14	201	859	1107	0.024	1.50	2.49	1.11	27159
Tsusei2	Control	1.45	300	917	1333	0.015	2.89	4.14	2.03	34761
	RB	1.45	284	897	1254	0.015	2.09	3.20	1.40	28157
Koshihikari	Control	1.58	313	1015	1390	0.018	2.97	4.42	2.65	42844
	RB	1.58	217	815	1129	0.018	1.83	3.03	1.63	35117
Hinohikari	Control	1.20	563	1339	1598	0.013	4.83	5.26	2.76	28510
	RB	1.20	501	1176	1393	0.013	3.45	4.10	2.28	25502
ANOVA	Cultivar	***	***	***	**	***	***	*	**	ns
	Treatment	—	***	*	*	—	***	***	***	*
	C × T	—	ns	ns	ns	—	*	ns	ns	ns

*, **, *** : Significant at 5%, 1% and 0.1% probability levels, respectively.

in RB were smaller than those of the control at all stages. The effect of cultivar on W and LAI was significant at all stages ($p < 0.05$), and the effect of RB treatment on W was significant at the heading and maturity stages ($p < 0.05$). The effect of different treatment on SN was significant; however, no effect was observed on cultivars.

The amount of dry matter production after heading (ΔW) in RB treatment was smaller than the control in all cultivars, whereas the ratio of ΔW to SN (ΔW/SN) in RB treatment were higher than the control for Tsusei 2 and Koshihikari (Fig. 1). The effect of cultivar, treatment and interactions on ΔW and ΔW/SN were insignificant.

The ratio of SN to LAI at heading (SN/LAI) was highest for Koshihikari and lowest for Hinohikari (Fig. 2). In all cultivars, although the SN and LAI at the heading of RB treatment were smaller than the control treatment, SN/LAI in RB treatment was higher than that of the control. There were not significant differences on cultivars, treatment and interactions on SN/LAI.

The leaf color and specific leaf weight (SLW) at panicle formation, heading and maturity are shown in Table 3. Both leaf color and SLW values in RB treatment in all stages were higher than the controls. Leaf color and SLW values of Hinohikari were the lowest among all with the exception of SLW at maturity. In terms of cultivars and different treatment, significant differences were observed between leaf color and SLW at all stages.

2. Growth analysis

CGR, mLAI and NAR of three growth durations: from transplantation to the panicle formation stage (stage 1), from the panicle formation stage to heading (stage 2) and from heading to maturity (stage 3) are shown in Table 4. CGR and mLAI in RB treatment were lower than control treatment; however, NAR obtained in RB was higher in all cultivars and treatments. CGR for control in the Japanese cultivars at stages 1 and 2 were higher than the Chinese cultivars. CGR in RB treatment of Koshihikari in stage 2 decreased when compared to control. mLAI in the Japanese cultivars, particularly Hinohikari, were higher than those of the Chinese cultivars for all stages and treatments with few exceptions; mLAI in RB treatment of Koshihikari in stage 1 and 2 were lower than Tsusei 2. The differences in NAR between the Chinese and Japanese cultivars, as well as among the stages, were unapparent. CGR and mLAI at stage 1 and 2, NAR at stage 3 were, however, correlated (Fig. 3).

3. Canopy structure and k

For all cultivars and treatments, the majority of leaves were distributed in the middle part of the canopy (30 to 60 cm), and leaves were absent at the lowest section (0 to 10 cm) (Fig. 4). In all canopy layers, LAI in RB treatment was smaller than the control, with the differences between the middle layer (high LAI) and the upper or lower layer (low LAI) within the same canopy larger in control than in RB treatment. The relative light intensity decreased with canopy depth, and the pattern of reduction was different between treatments. That is, the relative light absorption at the upper layer in RB treatment was greater than control, perhaps due to the small differences in LAI between the

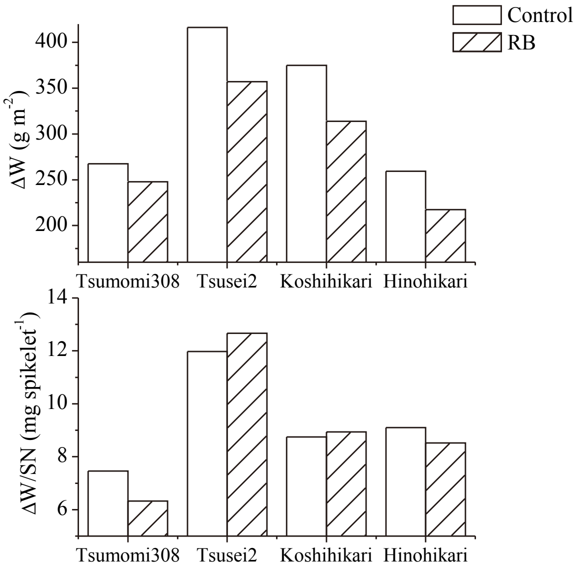

Fig. 1. The amount of dry matter production after heading (ΔW), and the ratio of ΔW to spikelet number (ΔW/SN) of rice cultivars grown by conventional cultivation (control) and cultivation with rice bran without agrochemicals (RB). Two way ANOVA showed that effects of cultivar, treatment and interactions on ΔW and ΔW/SN were not significant.

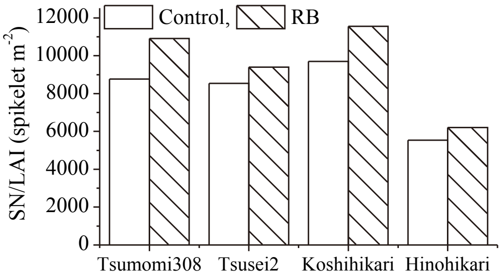

Fig. 2. The ratio of spikelet number to LAI at heading (SN/LAI) of rice cultivars grown by conventional cultivation (control) and cultivation with rice bran without agrochemicals (RB). Two way ANOVA showed that effects of cultivar, treatment and interactions on SN/LAI were not significant.

Table 3. Leaf color (SPAD value) and specific leaf weight (SLW) at panicle formation (PF), heading (HD) and maturity (MA) stages.

Cultivar	Treatment	Leaf color (SPAD value)			SLW (mg cm^{-2})		
		PF	HD	MA	PF	HD	MA
Tsumomi308	Control	42.0	35.3	24.7	4.98	6.46	5.99
	RB	45.1	36.7	24.4	5.67	7.09	5.97
Tsusei2	Control	40.2	34.2	26.2	4.80	6.52	5.97
	RB	43.5	36.4	25.4	5.21	6.65	6.37
Koshihikari	Control	39.2	34.3	24.0	4.95	6.75	4.65
	RB	41.9	37.5	25.9	5.37	7.62	5.83
Hinohikari	Control	33.2	31.0	20.6	4.60	5.57	5.59
	RB	33.7	30.6	19.9	5.17	5.71	5.97
ANOVA	Cultivar	***	***	*	ns	***	**
	Treatment	**	*	ns	**	***	**
	C × T	ns	*	ns	ns	**	*

*, **, *** : Significant at 5%, 1% and 0.1% probability levels, respectively.

Table 4. Crop growth rate (CGR), mean leaf area index (mLAI) and net assimilation rate (NAR) of three growth durations: from transplant to panicle formation stage (stage1), from panicle formation to heading (stage2) and from heading to maturity (stage3).

Cultivar	Treatment	CGR (g m^{-2} day^{-1})			mLAI			NAR (g m^{-2} day^{-1})		
		stage1	stage2	stage3	stage1	stage2	stage3	stage1	stage2	stage3
Tsumomi308	Control	7.26	25.85	7.04	0.49	3.05	2.83	14.87	8.37	2.52
	RB	5.52	25.33	6.52	0.36	1.95	1.71	15.44	12.95	3.81
Tsusei2	Control	7.46	23.72	9.46	0.55	3.48	2.96	13.66	6.83	3.28
	RB	7.05	23.60	8.11	0.42	2.61	2.18	16.89	8.93	3.93
Koshihikari	Control	9.44	29.26	11.71	0.58	3.64	3.46	16.38	8.01	3.57
	RB	6.53	24.93	9.80	0.39	2.38	2.26	16.67	10.48	4.30
Hinohikari	Control	11.95	32.34	6.18	0.81	5.03	3.85	14.65	6.36	1.64
	RB	10.64	28.11	5.18	0.62	3.77	3.10	17.22	7.47	1.67
ANOVA	Cultivar	***	ns	ns	***	***	***	ns	***	ns
	Treatment	***	ns	ns	***	***	***	**	***	ns
	C × T	ns	ns	ns	ns	ns	ns	ns	ns	ns

**, *** : Significant at 1% and 0.1% probability levels, respectively.

upper and middle layer in RB treatment.

The f *k* value is presented in Fig. 4. The *k* value in RB treatment for all cultivars was larger than the control, whereas the *k* value of Hinohikari was smallest among the cultivars.

4. The relationship between growth parameters and eco-physiological traits

The relationship between CGR in stage 2 and 3 with *k* at heading is shown in Fig. 5. The correlation between *k* at heading and CGR in stage 2 were insignificant, except in stage 3. The relationship between NAR in stage 2 and 3 and mean leaf color (SPAD value), mean SLW of corresponding stages (i.e. mean panicle formation and heading stages for NAR in stage 2, and that of the heading and maturity stages for NAR in stage 3) are shown in Fig. 6. NAR in stage 2 was correlated with leaf color and SLW. NAR in stage 3 was correlated with leaf color; however, the relationship with SLW was statistically insignificant. The root number and the bleeding rate in RB treatment were smaller than control treatment except for the bleeding rate of Hinohikari (Table 5). NAR in stage 3 and the bleeding rate per number of primary roots as well as the bleeding rate per leaf area at maturity were also correlated (Fig. 7).

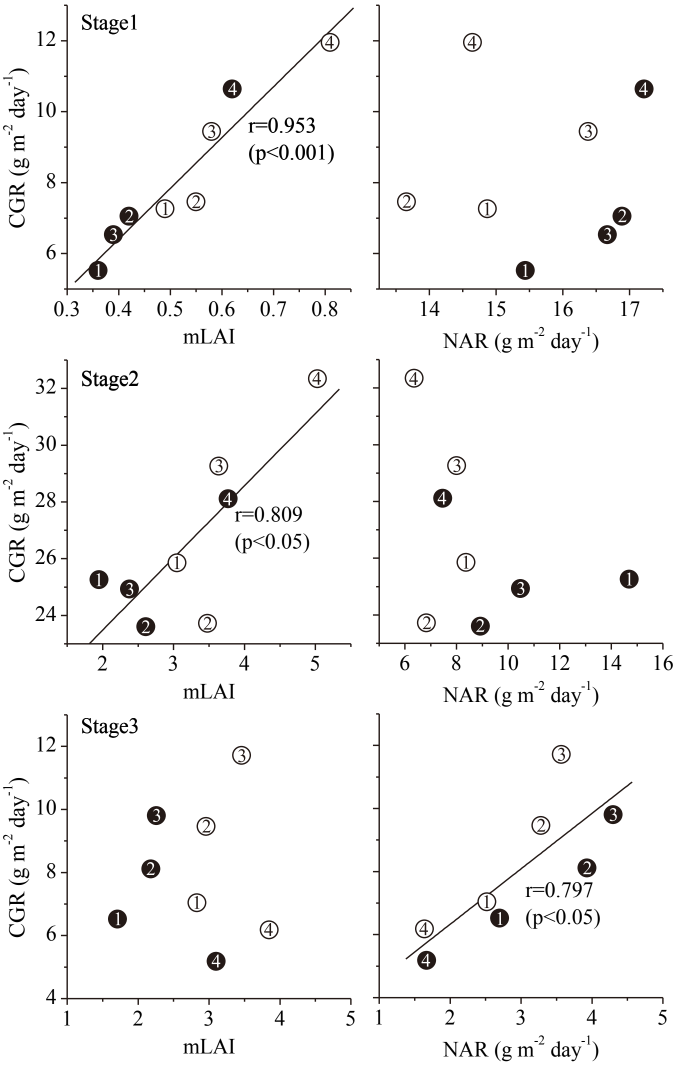

Fig. 3. Relations of CGR with mLAI and NAR in three growth durations of rice cultivars grown by conventional cultivation (control, open symbols) and cultivation with rice bran without agrochemicals (RB, closed symbols). The numbers in the symbols indicate cultivars (1: Tsumomi308, 2: Tsusei2, 3: Koshihikari, 4: Hinohikari).

Discussion

Dry matter production in crop canopy was determined by the size of leaf area, photosynthetic capacity and the light-intercepting characteristics of the canopy. In this study, we considered CGR, mLAI, NAR and *k* as indices for dry matter production, and the estimated size of leaf area, photosynthetic capacity and light-intercepting characteristics, respectively.

1. Dry matter production and growth analysis

Although growth data presented in this study were obtained from a field experiment performed in a single year (2008), the cultivar responses to the application of RB on SN showed trends similar to results obtained in 2006 and 2007 (Bian *et al.* 2010b). Throughout the cultivation period, W and LAI in RB treatment in all cultivars examined were smaller than those in control treatment (Table 2). Similarly, CGR and mLAI in RB treatment were lower than control, while NAR in RB treatment was higher in all growth stages (Table 4). CGR was correlated with mLAI in stage 1 and 2 and with NAR in stage 3 (Fig. 3). These results indicated that the dry matter production in the early and middle growth stages of paddy cultivation depends greatly on the size of leaf area, whereas in the late growth stage, dry matter was influenced by photosynthetic capacity.

Japanese panicle number type cultivars might have

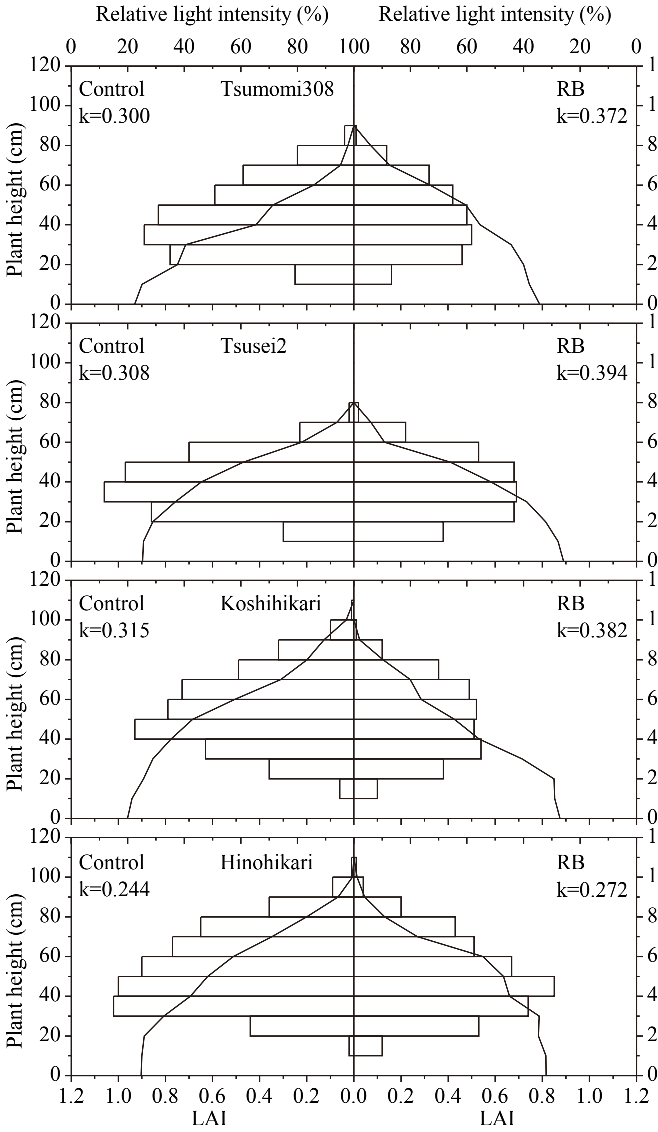

Fig. 4. Distribution of leaf area, relative light intensity and extinction coefficient (*k*) in the canopy of four rice cultivars at heading grown by conventional cultivation (control, left) and cultivation with rice bran without agrochemicals (RB, right).

a higher tillering rate in the early growth stages, which caused a higher LAI in stage 1 and 2. CGR in stage 2 and *k* at heading were correlated; with *k* of Hinohikari being the lowest among cultivars in both treatments (Fig. 5). These results indicated that light transmission within the canopy in RB treatment was more efficient than the control. The higher *k* value in RB treatment may be attributed to the low stem density in the canopy. In this context, it is noted that high nitrogen application decreased *k* value in rice plants and forage grasses (Takeda and Kumura 1959, Osada and Murata 1962, Kubota *et al.* 1973, Kusutani *et al.* 1979), which consequently led to stems holding each other mutually and mechanically, resulting in an erectophile leaf shape. In a study carried out in 2009, we observed that leaf inclination angle, flag ratio and second leaf length between RB and control treatment were similar across treatments (unpublished data). The low nitrogen application in RB treatment decreased stem density. Therefore, the high *k* in RB treatment would be due to low stem density. CGR in RB treatment of Koshihikari in stage 1 and 2 were markedly lower than other cultivars due to low mLAI. The cause of the drastic growth inhibition of Koshihikari in RB treatment was uncertain. Although CGR and NAR in stage 3 was correlated, no difference between the Chinese panicle weight type and the Japanese panicle number type rice cultivars was apparent. CGR of Tsusei 2 in stage 3 was comparable to that of Koshihikari, with CGR of Hinohikari the lowest among the cultivars in both treatments. The difference in

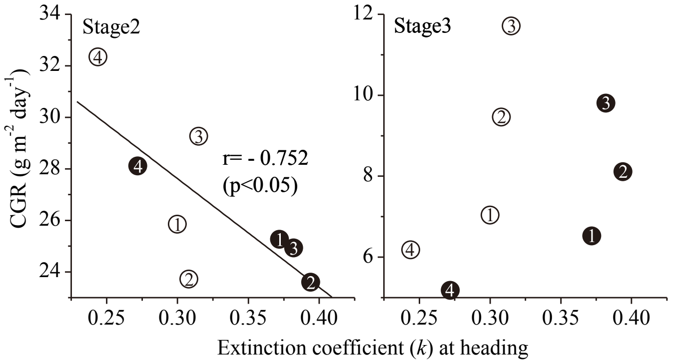

Fig. 5. Relations of CGR in stage 2 and 3 with light extinction coefficient (*k*) at heading of rice cultivars grown by conventional cultivation (control, open symbols) and cultivation with rice bran without agrochemicals (RB, closed symbols). The numbers in the symbols indicate cultivars (1: Tsumomi308, 2: Tsusei2, 3: Koshihikari, 4: Hinohikari).

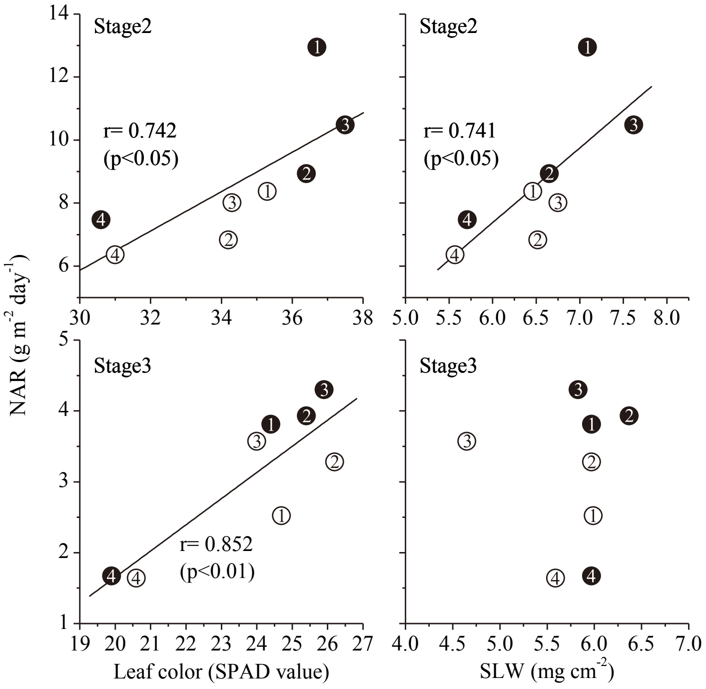

Fig. 6. Relation of NAR in stage 2 (above) and stage 3 (below) with leaf color (SPAD value, left) and specific leaf weight (SLW, right) of rice cultivars grown by conventional cultivation (control, open symbols) and cultivation with rice bran without agrochemicals (RB, closed symbols). The numbers in the symbols indicate cultivars (1: Tsumomi308, 2: Tsusei2, 3: Koshihikari, 4: Hinohikari).

CGR in stage 3 is perhaps due to the varietal differences of NAR instead of treatment types (Fig. 3).These results suggested the application of RB partially inhibited the growth of panicle number type cultivars in early and middle growth stages. Differences in growth between panicle number and weight cultivars were unapparent in late stages.

2. Factors responsible for the differences in NAR

Leaf color and SLW were closely related to photosynthetic capacity. Leaf color is an indication of fertilization and photosynthetic characteristics. Since much of leaf nitrogen is involved in enzymes associated with chlorophyll, the chlorophyll content value SPAD is used for indirect assessment of leaf nitrogen (Esfahani *et al.* 2008, Swain *et al.* 2010). A positive correlation between leaf color and photosynthetic capacity in rice plants was demonstrated (Nakazawa *et al.* 1990, Qiu *et al.* 1992, Kusutani *et al.* 1993). SLW, which represents leaf thickness, was linked to photosynthetic capacity in alfalfa (Barnes *et al.* 1969, Pearce *et al.* 1969), wheat (Khan *et al.* 1970), corn (Chatterton *et al.* 1972), soybean (Dornhoff *et al.* 1970, Bowes *et al.* 1972) and timothy (Kubota *et al.* 1977) as examples. In this study, NAR in stage 2 was correlated with both mean leaf color and SLW (the mean values of those in the panicle formation and heading stages), with the relationship indicating that NAR of Tsumomi 308 was much lower than the expected NAR values calculated without Tsumomi 308 (Fig. 6). The reasons for the low NAR of Hinohikari in stage 3 is unknown; however, poor root vitality may be a contributing factor. The bleeding rate of Hinohikari was the lowest among the cultivars, with results suggesting that rice plants with darker leaf color and thicker leaves tend toward a high photosynthetic capacity. Correlations occurred between NAR and the bleeding rate per number of primary root, and per leaf area at maturity. Bleeding rate is an indicator of root vitality (Morita 2000). Lee and Oota (1973) reported that the loss of chlorophyll from leaves in the ripening period was lower in rice cultivars with high root vitality. Ishihara and Kuroda (1986), on the other hand, reported that the photosynthetic capacity of rice plants treated with low root vitality due to small root system was much lower than rice plants with high root vitality. The correlation between NAR and the bleeding rate per the number of primary roots at maturity may best be explained by the influence of root vitality on photosynthetic capacity during the ripening period of cultivars. Moreover, the bleeding rate per leaf area would represent the balance between water uptake ability and the size of leaf area where water is transpired (Fig. 7). The positive correlation between NAR and bleeding rate per leaf area suggested that a high bleeding rate per leaf area would be favorable to maintaining the normal rigid state of fullness of cells or vascular vessels or capillaries resulting from pressure of the content against the wall or membrane (e.g. under conditions of water stress, leaf turgor decreases and stomata close) in the shoot, which resulted in high NAR (Liu *et al.* 2008).

Table 5. Root number and bleeding rate (quoted from Bian et al. 2010a).

Cultivar	Treatment	Root number (no hill^{-1})	Bleeding rate (g hill^{-1} h^{-1})
Tsumomi308	Control	357	1.28
	RB	252	1.22
Tsusei2	Control	299	2.83
	RB	248	2.48
Koshihikari	Control	366	2.82
	RB	281	2.09
Hinohikari	Control	696	0.98
	RB	560	1.12
	Cultivar	***	***
ANOVA	Treatment	**	ns
	C × T	ns	*

*, **, *** : Significant at 5%, 1% and 0.1% probability levels, respectively.

3. Dry matter production after heading and spikelet production

The amount of dry matter production after heading (ΔW) in RB treatment was smaller than the control for all cultivars, whereas the ratio of ΔW to SN (ΔW/SN) in RB treatment was higher than the control except for Tsumomi 308 and Hinohikari (Fig. 1). The reason for this difference was that photosynthesis-related traits after heading in RB treatment were better than the control; therefore, the reduction of ΔW for the RB treatment was less than

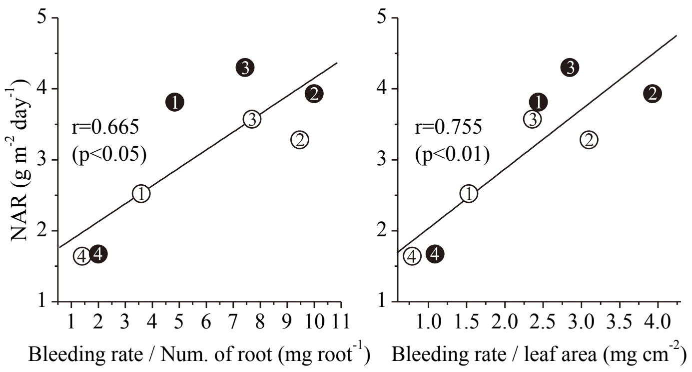

Fig. 7. Relation of NAR in stage 3 with bleeding rate per the number of primary root (left) and bleeding rate per leaf area (right) of rice cultivars grown by conventional cultivation (control, open symbols) and cultivation with rice bran without agrochemicals (RB, closed symbols). The numbers of the symbols indicate cultivars (1: Tsumomi308, 2: Tsusei2, 3: Koshihikari, 4: Hinohikari).

the reduction of SN. It is known that a high amount of assimilate per spikelet in the ripening period increases the percentage of ripened grain (Shiotsu *et al.* 2006, 2007). The percentage of ripened grain was higher in RB treatment when compared to control in this study (Bian *et al.* 2010b). Furthermore, the ratio of SN to LAI at heading (SN/LAI) was larger in RB treatment than in control for all cultivars (Fig. 2). Yamamoto *et al.* (1991) noted that the number of spikelets per leaf area at heading, as well as the number of spikelets per the unit of absorbed nitrogen and the number of spikelets per dry weight, was an index representing the efficiency of grain production. The high SN/LAI ratio in RB treatment suggested that the leaf area in RB treatment was not significantly large despite the number of spikelets, which indicated high efficiency of grain production in RB treatment.

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