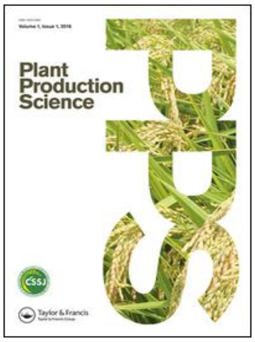

Taylor & Francis
Taylor & Francis Group

Plant Production Science

ISSN: 1343-943X (Print) 1349-1008 (Online) Journal homepage: https://www.tandfonline.com/loi/tpps20

Effects of the Tillering Nodes on the Main Stem of a Chinese Large-Panicle-Type Rice Cultivar, Yangdao 4, on the Growth and Yield-Related Characteristics in Relation to Cropping Season

Peter Aglua Gendua, Yoshinori Yamamoto, Akira Miyazaki, Tetsushi Yoshida & Yulong Wang

To cite this article: Peter Aglua Gendua, Yoshinori Yamamoto, Akira Miyazaki, Tetsushi Yoshida & Yulong Wang (2009) Effects of the Tillering Nodes on the Main Stem of a Chinese Large-Panicle-Type Rice Cultivar, Yangdao 4, on the Growth and Yield-Related Characteristics in Relation to Cropping Season, Plant Production Science, 12:2, 257-266, DOI: 10.1626/pps.12.257

To link to this article: https://doi.org/10.1626/pps.12.257

Plant Prod. Sci. 12(2) : 257―266 (2009)

Effects of the Tillering Nodes on the Main Stem of a Chinese Large-Panicle-Type Rice Cultivar, Yangdao 4, on the Growth and Yield-Related Characteristics in Relation to Cropping Season

Peter Aglua Gendua[1], **Yoshinori Yamamoto**[2], **Akira Miyazaki**[2], **Tetsushi Yoshida**[2] **and Yulong Wang**[3]

([1]United Post Graduate School of Ehime University, Matsuyama, Ehime 790-8566, Japan;
[2]Faculty of Agriculture, Kochi University, Nankoku, Kochi 783-8502, Japan;
[3]Faculty of Agriculture, Yangzhou University, Yangzhou 225009, China)

Abstract : Using a Chinese large-panicle-type high-yielding indica rice cultivar, Yangdao 4 (YD), pot experiments were carried out to determine the effects of the removal of the lower nodal primary tillers on the growth and yield-related characteristics in comparison with a Japanese cultivar, Hinohikari (HH), with almost the same growth duration. The plants with all tillers remaining (Cont), those with tillers from the 5th and higher nodes (T5) and those with tillers from the 8th and higher nodes (T8) were prepared by removing the other tillers and grown in early, normal and late cropping seasons, sowing in late April, May and June, respectively. The lowest nodal primary tillers in each group emerged earlier and the number of days from sowing to flag leaf expansion and to full heading stage was reduced in the late cropping season, especially in HH. The maximum number of stems and number of panicles were larger in HH than in YD, and tended to be higher in the order of Cont>T5>T8 plants. The average panicle weight per stem was higher in YD than in HH and higher in the order T8>T5>Cont. Panicle weight per hill was higher in YD than in HH in each cropping season and higher in early cropping season in both cultivars. Panicle weight decreased with delayed tiller emergence in YD, but not in HH. Panicle weight was more closely related to straw weight in YD than in HH. Therefore, the promotion of vegetative growth by early sowing and development of lower nodal tillers is more effective for attaining a high yield in YD than in HH.

Key words : Chinese cultivar, Cropping season, Large panicle type cultivar, Lowest tillering node, Panicle weight, Rice, Straw weight, Tiller removal.

Rice yield is affected by crop growth duration and environmental conditions. Growth duration is determined mainly by the time of sowing or transplanting in the cropping season, and was reported to be prolonged, especially the vegetative growth period, by early planting (Yamakawa and Nishiyama, 1954; Yamada and Ota, 1956; Samoto, 1966). Yamakawa and Nishiyama (1954) and Samoto (1966) also reported that early planting resulted in higher yielding than normal or late planting because of an increase in panicle number.

On the other hand, in rice crops sown or transplanted at the same time, the time of tiller emergence and the node of the lowest nodal tiller affect rice yield through differences in maximum numbers of tillers and panicles. Matsuo (1951) and Matsuo (1952) reported that the tiller positioned lower and emerging earlier was superior in growth and panicle weight among the primary tillers on the main stem. The lowest tillering node on the main stem is affected by cultivation method, such as direct sowing and transplanting (Matsuo, 1952), and in transplanting culture by seedling age, seedling characteristics, planting depth and environmental conditions after transplanting such as water temperature and irrigation water depth (Yamamoto, 1997). Panicle number and weight are affected by the position of the lowest tillering node, the maximum tiller number and the percentage of productive tillers. Generally, it is very important to promote the development of lower nodal primary tillers (Matsushima, 1957); that is, lowering the first tillering node of seedlings after transplanting, to achieve a high yield in Japan (Yamamoto, 1991).

Large-panicle-type high-yielding rice cultivars bred recently in China have increased rice yield (Higashi, 1988; Wan and Ikehashi, 1994a, b; Wang et al., 1995, 1997). In these rice cultivars, early tillering is important to produce a larger spikelet number per m^2 as a prerequisite for high yields, because the spikelet number per panicle, rather than panicle number contributed more to spikelet number per m^2 (Wan and Ikehashi, 1994a, b; Wang et al., 1995, 1997). Therefore, the early emergence of tillers from a lower nodal position may be important in these large-panicle-type

Received 10 June 2008. Accepted 4 October 2008. Corresponding author: Y. Yamamoto (yamayosi@kochi-uac.jp, Fax: +81-88-864-5199).

Abbreviations : DAS, days after sowing; HH, Hinohikari; T5, tillering from the 5th and higher nodes; T8, tillering from the 8th and higher nodes; YD, Yangdao 4.

Table 1. Average temperature and sunshine hours during 20 d after sowing, 40 d after tiller emergence and from sowing to full heading and from full heading to maturity in 2006.

Cultivar	Cropping season[1)]	20 d after sowing		40 d after E.L.T.[2)]		Sowing-Full heading		Full heading-Maturity	
		Aveg. T.	Aveg. S.H.[3)]	Aveg. T.	Aveg. S.H.	Aveg. T.	Aveg. S.H.	Aveg. T.	Aveg. S.H.
Yangdao 4	Early	20.0	5.7	23.2	6.8	23.9	6.4	27.9	7.5
Hinohikari	Early	20.0	5.7	23.2	6.8	24.2	6.5	26.9	6.6
Yangdao 4	Normal	21.8	7.0	25.7	6.4	25.8	6.7	25.9	7.1
Hinohikari	Normal	21.8	7.0	25.7	6.4	25.8	6.7	25.4	7.4
Yangdao 4	Late	25.5	5.0	28.5	7.2	27.0	6.6	22.4	8.2
Hinohikari	Late	25.5	5.0	28.5	7.2	27.3	6.7	23.9	7.4

Data are shown only for the control plants. [1)]Sowing date in the early, normal and late cropping seasons were April 29, May 25 and June 22, respectively; [2)]The emergence of lowest nodal tiller; [3)]Sunshine hours. (Source: Meteorological data of the Faculty of Agriculture, Kochi University).

high-yielding rice cultivars different from conventional Japanese cultivars.

In this study, the relationship between the earliness of tillering and yielding ability was determined by controlling the tillering nodes on the main stem of rice plants cultivated in different cropping seasons, using a Chinese high-yielding large panicle-type-indica cultivar, Yangdao 4, which we have been studying for its high-yielding ability (Yao et al., 2000a, b; Yamamoto et al., 2001; Ansari et al., 2003; Ju et al., 2006), in comparison with a Japanese rice cultivar (japonica), Hinohikari, which has almost the same growth duration.

Materials and Methods

The experiment was carried out in 2005 and 2006 at the Faculty of Agriculture, Kochi University, Japan, using a Chinese large-panicle-type high-yielding indica rice cultivar, Yangdao 4 (YD), and a Japanese medium type japonica rice cultivar, Hinohikari (HH). Sterilized and pre-germinated seeds of the two rice cultivars were sown in plastic pots with a 39 cm top diameter ×30 cm bottom diameter ×36 cm height (ca. 1/1000 a) at a rate of 5 seeds per hill with 4 hills per pot and thinned before the 5th leaf stage to 1 plant per hill and grown under good nutritional conditions. Sowing dates were April 28 (early cropping), May 25 (normal cropping) and June 22 (late cropping) in 2005, and April 29, May 25 and June 22, in 2006. The plants with all tillers remaining (Cont), those with tillers from the 5th and higher nodes (T5) and those with the 8th and higher nodes (T8) were prepared by removing the other tillers. Two pots were allocated to each group. At each planting, basal fertilizer (10, 10, 5 and 20 g of ammonium sulfate, superphosphate, potassium chloride and calcium silicate, respectively, per pot) was mixed thoroughly with the soil and the pots were watered to full capacity a day before sowing. For fertilizer topdressing, 20 mL of NPK [1000 times concentration of Kasugai A solution (Baba and Takahashi, 1957)] was applied per pot every 10 d from 40 d after sowing (DAS) until the full heading stage after dilution in one liter of tap water and poured evenly around the plants in each pot. The primary tiller emergence date was recorded every day, and tillers were removed by hand; newly appearing tillers were also removed daily. The growth characteristics of each plant were measured almost weekly starting 12–15 DAS until the full heading stage. Growth characteristics measured included plant length and successive leaf length on the main stem and tiller number. At maturity, all plants in the pots were harvested and air-dried in a glasshouse. After drying, the panicle of each stem was cut just below the neck node, and panicle number and weight in each hill were measured. Straw weight was measured only in 2006.

Meteorological conditions for each cropping season were analyzed based on the data of Faculty of Agriculture, Kochi University.

Data for growth and yield-related characteristics were processed in an Excel spreadsheet (Microsoft Corp. 2002) and the statistical analysis was done by JMP (SAS Institute, Inc., V5.1). The average of the 8 hills (plants) in each treatment was compared for statistical differences by Tukey's test and the mean of the two cultivars was compared by a *t*-test.

Results

The results obtained in 2006 are mainly presented in this paper because the growth performance and yield-related characteristics of the two rice cultivars under the different treatments showed almost the same trend in 2005 and 2006.

1. Meteorological conditions in each cropping season

Average air temperature during 20 DAS, 40 d after the emergence of lowest nodal tiller and from sowing to full heading were higher in the late cropping season (Table 1). However, the average temperature from full heading to maturity was higher in the early cropping season. Noticeable differences in daily sunshine hours were not observed among the cropping seasons in each growth period.

Table 2. Effects of cropping season and primary tiller removal on growth duration in 2006.

Cultivar	Cropping season[1)]	Tillering node[2)]	Number of days from sowing to						Accumulated Temp.[6)] (℃)
			Lowest tiller emergence		Maximum tillering stage	Flag leaf emergence	Full heading	Maturity	
			Date 1[3)]	Date 2[4)]					
Yangdao 4	Early	Cont (2)	20.6 g	20.6 k	61.1 cde	87.6 a	100.5 e	134.0 d (33.5)[5)]	2059
		T5 (5)	28.6 e	28.6 j	68.1 cd	87.9 d	101.4 de	134.0 d (32.6)	2050
		T8 (8)	40.3 b	40.3 h	83.0 ab	88.8 d	102.1 d	134.0 d (31.9)	2082
		Average	*29.8 B*	*29.8 E*	*70.8 B*	*88.1 B*	*101.3 B*	*134.0 B (32.7)*	*2064*
	Normal	Cont (2)	13.0 h	40.0 h	46.5 f	80.3 h	89.4 i	123.0 i (33.6)	2054
		T5 (5)	22.6 f	49.6 f	63.1 cde	80.9 gh	90.9 ghi	123.0 i (32.1)	2095
		T8 (8)	32.4 d	59.4 e	62.3 cde	82.0 fg	91.6 gh	124.0 h (32.4)	2121
		Average	*22.7 D*	*49.7 C*	*57.3 C*	*81.1 D*	*90.6 D*	*123.3 D (32.7)*	*2090*
	Late	Cont (2, 3)#	12.0 h	67.0 c	53.5 ef	74.9 j	90.3 ghi	128.0 f (37.7)	2077
		T5 (5)	19.6 g	74.6 b	58.6 def	74.5 j	90.3 hi	128.0 f (37.7)	2088
		T8 (8)	27.5 e	82.5 a	63.8 cde	76.6 i	92.1 g	128.0 f (35.7)	2136
		Average	*19.7 E*	*74.7 A*	*58.6 C*	*75.3 E*	*90.9 D*	*128.0 C (37.1)*	*2100*
	Cultivar average		*24.1 b**	*51.4 b**	*62.2 b**	*81.5 a**	*94.3 a**	*128.4 b*(34.1)*	*2085*
Hinohikari	Early	Cont (2)	21.0 g	21.0 k	68.1 cd	95.1 c	105.4 c	144.0 c (38.6)	2245
		T5 (5)	31.5 d	31.5 i	71.5 bc	97.0 b	109.6 b	146.9 b (37.3)	2304
		T8 (8)	43.9 a	43.9 g	91.8 a	99.9 a	117.1 a	151.0 a (33.9)	2390
		Average	*32.1 A*	*32.1 D*	*77.1 A*	*97.3 A*	*110.7 A*	*147.3 A (36.6)*	*2313*
	Normal	Cont (2)	13.0 h	40.0 h	61.4 cde	82.0 fg	91.8 g	127.0 g (35.2)	2121
		T5 (5)	23.9 f	50.9 f	63.1 cde	83.0 f	92.3 g	127.0 g (34.7)	2152
		T8 (8)	35.0 c	62.0 d	81.4 ab	85.0 e	96.4 f	130.0 e (33.6)	2208
		Average	*24.0 C*	*51.0 B*	*68.6 B*	*83.3 C*	*93.5 C*	*128.0 C (34.5)*	*2160*
	Late	Cont (2)	11.5 h	66.5 c	56.3 def	63.3 k	74.0 j	114.0 j (40.0)	1743
		T5 (5)	19.6 g	74.6 b	60.3 cde	63.4 k	73.6 j	114.0 j (40.4)	1740
		T8 (8)	28.9 e	83.9 a	65.8 cde	63.0 k	73.0 j	113.0 k (40.0)	1783
		Average	*20.0 E*	*75.0 A*	*60.8 C*	*63.2 F*	*73.5 E*	*113.7 E (40.2)*	*1755*
	Cultivar average		*25.4 a**	*52.7 a**	*68.8 a**	*81.3 a**	*92.6 b**	*129.7 a*(37.1)*	*2076*

1)Sowing dates in the early, normal and late cropping seasons were April 29, May 25 and June 22, respectively; 2)Cont, ordinary tillering; T5, tillering from 5th and higher nodes; T8, tillering from 8th and higher nodes. Numerals in the parenthesis show the lowest tillering nodes on the main stem. 3)Days after sowing; 4)Days after the sowing date of early cropping season; 5) Full heading to maturity; 6)Accumulated mean temperature from sowing to flag leaf emergence; Values followed by the same letter in a column are not significantly different at 5% level by Tukey's test. Capital letters compare the averages of treatments in each cropping season in each column. *Comparison of the cultivar averages by a *t* test in a column. #The first remaining nodes on the main stem were the 2nd node for 3 plants and the 3rd node for 5 plants.

2. Plant growth performance

The lowest nodal primary tillers in the Cont plot emerged from the 2nd node except for YD grown in the late cropping season, in which the lowest nodal primary tillers emerged from the 2nd and 3rd nodes in 3 and 5 plants out of 8 plants, respectively (average lowest tillering node; 2.6). The time of the emergence of the lowest nodal primary tillers was delayed by tiller removal, but slightly advanced by delaying sowing date (Table 2). Emergence time of the lowest nodal primary tiller was earlier in the late and normal cropping seasons than in the early cropping season, but its date of emergence was delayed by about 20 and more than 40 d in the normal and late cropping seasons than in the early cropping season, respectively. In each cropping season, emergence of the lowest nodal primary tillers and the time of the maximum tillering stage was earlier in YD than in HH, while the days to the maximum tillering stage increased in the order T8>T5>Cont plants in both cultivars (Fig. 1 and Table 2).

Delaying the cropping season reduced the days to flag leaf expansion and full heading stage, especially in HH, while little difference was observed during tiller removal treatments in each cropping season (Table 2). Accumulated mean temperature in each cropping season from sowing to flag leaf expansion in YD was

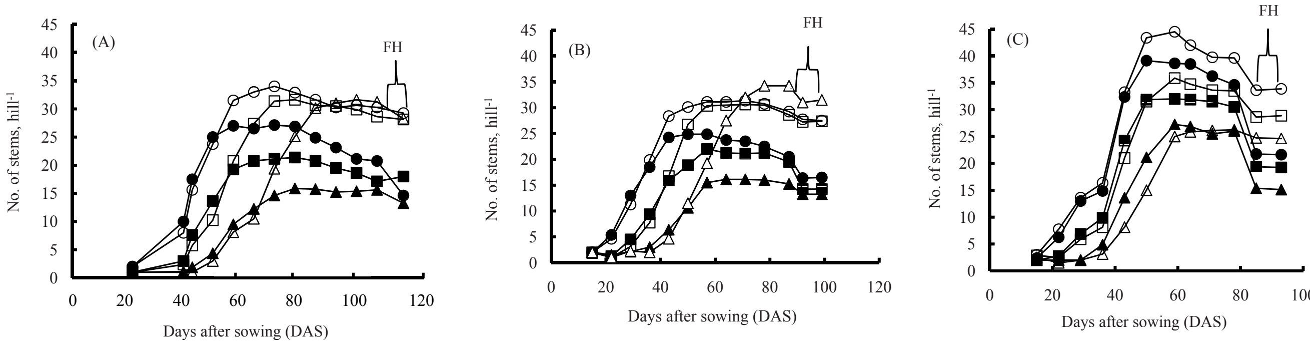

Fig. 1. Changes in the number of stems per hill from sowing to full heading in Yangdao 4 (YD) and Hinohikari (HH) under different tillering nodes in early cropping season (A), normal cropping season (B) and late cropping season (C). FH = full heading stage.
●, YD Cont; ○, HH Cont; ■, YD T5; □, HH T5; ▲, YD T8; △, HH T8. Cont, ordinary tillering; T5, tillering from 5^{th} and higher nodes; T8, tillering from 8^{th} and higher nodes.

Table 3. Effects of cropping season and primary tiller removal on the growth of main stems and tillers, and final plant and culm lengths in 2006.

Cultivar	Cropping season[1)]	Tillering node[2)]	Nodes major prim.tillers[3)]	No. of prim. tillers	No. of leaves on main stem	Max. No. of stems, hill^{-1}	% of Prod. stems, %	Final length. (cm)	
								Plant	Culm
Yangdao 4	Early	Cont (2)	2–8	5.1 cdefg	16.0 gh	28.1 defgh	52.0 e	112 ab	84 a
		T5 (5)	5–10	4.9 efg	17.0 f	21.9 hi	82.3 bc	110 abc	81 abc
		T8 (8)	8–12	4.5 g	18.6 abc	16.6 i	79.7 bc	113 ab	84 a
		Average	—	*4.8 D*	*17.2 B*	*22.2 C*	*71.3 B*	*112 AB*	*83 A*
	Normal	Cont (2)	2–7	5.8 bcdef	16.0 gh	25.8 gh	64.1 d	110 abc	84 a
		T5 (5)	5–10	5.4 bcdefg	17.0 f	22.6 hi	63.0 de	114 ab	82 ab
		T8 (8)	8–12	5.0 defg	18.0 cde	16.4 i	80.9 bc	115 a	83 ab
		Average	—	*5.4 CD*	*17.0 B*	*21.6 C*	*69.3 B*	*113 AB*	*83 A*
	Late	Cont (2, 3)[#]	2–8	6.0 bcde	17.1 f	39.6 b	54.6 de	104 def	69 f
		T5 (5)	5–10	5.9 bcdef	17.6 def	32.6 cde	59.0 de	101 ef	74 def
		T8 (8)	8–12	4.8 fg	19.0 ab	27.6 efgh	54.8 de	100 f	70 ef
		Average	—	*5.6 BC*	*17.9 A*	*33.3 B*	*56.1 C*	*102 C*	*71 C*
	Cultivar average			*5.3 b**	*17.4 a**	*25.7 b**	*65.6 b**	*109 a**	*79 a**
Hinohikari	Early	Cont (2)	2–8	6.5 ab	16.0 gh	34.1 bcd	85.7 abc	109 bc	76 def
		T5 (5)	5–10	6.0 bcd	17.8 def	32.1 cdef	87.5 abc	109 bcd	77 bcd
		T8 (8)	8–13	6.1 abcd	19.1 a	32.3 cdef	87.6 abc	112 ab	76 cd
		Average	—	*6.2 A*	*17.6 A*	*32.8 B*	*87.0 A*	*110 B*	*76 B*
	Normal	Cont (2)	2–7	6.0 abcdef	15.9 h	31.6 edefg	87.0 abc	105 cde	75 de
		T5 (5)	5–11	6.0 bcde	17.8 def	31.3 cdefg	87.6 abc	99 fg	74 def
		T8 (8)	8–13	6.3 abc	19.4 a	34.8 bcd	90.6 ab	99 fgh	74 def
		Average	—	*6.1 AB*	*17.7 A*	*32.5 B*	*88.4 A*	*101 C*	*74 B*
	Late	Cont (2)	2–7	6.3 abcdef	15.6 h	44.9 a	75.5 c	94 gh	74 def
		T5 (5)	5–11	7.3 a	17.3 ef	36.4 bcd	79.4 c	93 h	74 def
		T8 (8)	8–13	6.0 bcde	18.3 bcd	26.3 fgh	93.8 a	93 h	73 def
		Average	—	*6.5 A*	*17.1 B*	*35.8 A*	*82.9 A*	*93 D*	*74 BC*
	Cultivar average			*6.3 a**	*17.5 a**	*33.8 a**	*86.1 a**	*101 b**	*75 b**

[1),2),#] Refer to Table 2; [3)] Nodes of major primary tillers; Values followed by the same letter in a column are not significantly different at 5% level by Tukey's test. Capital letters compare the averages of treatments in each cropping season in each column. *Comparison of the cultivar averages by a *t* test in a column.

Table 4. Effects of cropping season and primary tiller removal on yield-related characteristics in 2006.

Cultivar	Cropping season1)	Tillering node2)	No. of panicles, hill^{-1}	Panicle Wt., g hill^{-1}	A panicle Wt., g stem^{-1}	Straw Wt., g hill^{-1}	Panicle / straw ratio	Total Wt., g hill^{-1}
Yangdao 4	Early	Cont (2)	14.4 gh	72.8 ab	5.06 ab	85.2 bcde	0.85 b	158.0 ab
		T5 (5)	17.9 fgh	77.0 a	4.30 c	85.0 bcde	0.91 b	162.0 a
		T8 (8)	13.4 h	72.1 ab	5.38 ab	87.0 abcd	0.83 bc	159.1 ab
		Average	*15.2 C*	*74.0 A*	*4.9 A*	*85.7 B*	*0.86 B*	*159.7 A*
	Normal	Cont (2)	17.1 fgh	73.7 ab	4.31 c	83.2 bcde	0.89 b	156.9 ab
		T5 (5)	14.4 gh	69.7 abc	4.84 ab	85.2 bcde	0.82 bc	154.9 ab
		T8 (8)	13.4 h	65.6 abcd	4.90 b	78.7 cdef	0.83 bc	144.3 abc
		Average	*15.0 C*	*69.7 AB*	*4.7 A*	*82.4 B*	*0.85 B*	*152.0 AB*
	Late	Cont (2, 3)#	21.6 def	70.1 abc	3.25 d	74.4 cdef	0.94 b	144.5 abc
		T5 (5)	19.8 efg	65.2 abcd	3.29 d	71.5 def	0.91 b	136.7 abc
		T8 (8)	15.4 gh	59.8 bcde	3.88 c	62.8 fg	0.95 b	122.6 cd
		Average	*18.9 B*	*65.0 B*	*3.5 B*	*69.6 C*	*0.93 A*	*134.6 C*
	Cultivar average		16.4 *b**	*69.6 a**	*4.4 a**	*79.2 a**	*0.88 a**	*148.8 a**
Hinohikari	Early	Cont (2)	29.8 bc	50.2 ef	1.68 e	98.6 ab	0.51 e	148.8 abc
		T5 (5)	28.1 bc	52.9 def	1.88 e	104.2 ab	0.53 e	157.1 ab
		T8 (8)	29.9 bc	57.7 cdef	1.93 e	96.8 ab	0.60 de	154.5 ab
		Average	*29.3 A*	*53.6 C*	*1.8 C*	*99.9 A*	*0.55 C*	*153.5 AB*
	Normal	Cont (2)	27.5 bcd	49.8 def	1.81 e	95.5 abc	0.52 de	145.3 abc
		T5 (5)	25.6 cd	48.6 ef	1.90 e	92.0 abc	0.51 de	140.6 abc
		T8 (8)	31.8 ab	53.2 def	1.67 e	79.0 cdef	0.67 cd	132.2 bc
		Average	*28.3 A*	*50.5 C*	*1.8 C*	*88.8 B*	*0.57 C*	*139.2 BC*
	Late	Cont (2)	37.0 a	51.0 def	1.38 e	63.5 efg	0.80 bc	114.5 cde
		T5 (5)	28.1 bc	46.1 ef	1.64 e	53.3 gh	0.86 b	99.4 de
		T8 (8)	24.6 cde	43.8 f	1.78 e	36.7 h	1.19 a	80.5 e
		Average	*29.9 A*	*47.0 C*	*1.6 C*	*51.2 D*	*0.95 A*	*98.1 de*
	Cultivar average		*29.2 a**	*50.4 b**	*1.7 b**	*80.0 a**	*0.69 b**	*130.3 b**

1),2),#)Refer to Table 2; Values followed by the same letter in a column are not significantly different at 5% level by Tukey's test. Capital letters compare the averages of treatments in each cropping season in each column. * Comparison of the cultivar averages by a *t* test in a column.

almost constant within the range of 2064- 2100°C. However, in HH it was 2313°C in the early cropping season, 2160°C in the normal cropping season and 1755°C in the late cropping season. A similar tendency was seen in 2005, when the ranges of accumulated mean temperature in YD and HH were 2034–2080°C and 1829–2332°C, respectively. Days to maturity also decreased significantly in the late cropping season in HH, although the number of days from full heading to maturity in the early and normal cropping seasons were fewer than those in the late cropping season.

The number of primary tillers tended to decrease with increasing nodes of tiller removal in YD (Table 3). Tiller removal significantly increased the number of leaves on the main stem in both YD and HH, but in the late cropping season YD had a larger number of leaves, and HH had a smaller number of leaves than in the early cropping season. Although the final plant length decreased in the late cropping season compared with the early and normal cropping seasons in both cultivars, it was not significantly affected by tiller removal treatments in each cropping season except for HH in the normal cropping season. Final culm length decreased in the late cropping season only in YD. The maximum number of stems was larger in HH than in YD and tended to increase in the order Cont>T5>T8, and the highest values were observed in the late cropping season, except for the T8 plants of HH (Table 3). Tiller removal reduced the maximum stem number and eventually gave a higher percentage of productive stems in both YD and HH. Percentage of productive stems tended to be higher with the greater removal of tillers in both cultivars and was higher in HH than in YD.

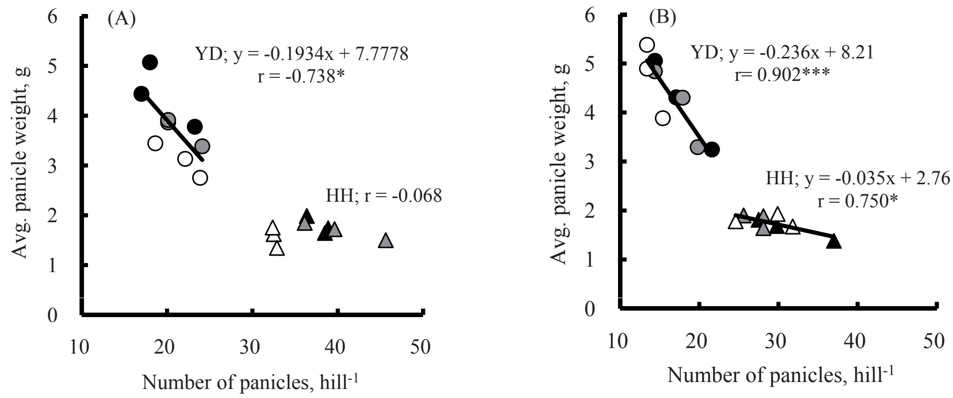

Fig. 2. Relationship between panicle number per hill and average panicle weight in 2005 (A) and 2006 (B).
Circles, Yangdao 4 (YD); Triangles, Hinohikari (HH). Black, gray and white symbols indicate Cont, T5 and T8 plants. Each set of the same three symbols in the figure from right to left indicate the values in the early, normal and late cropping seasons, respectively. * and ***, significance at 5% and 0.1% levels, respectively.

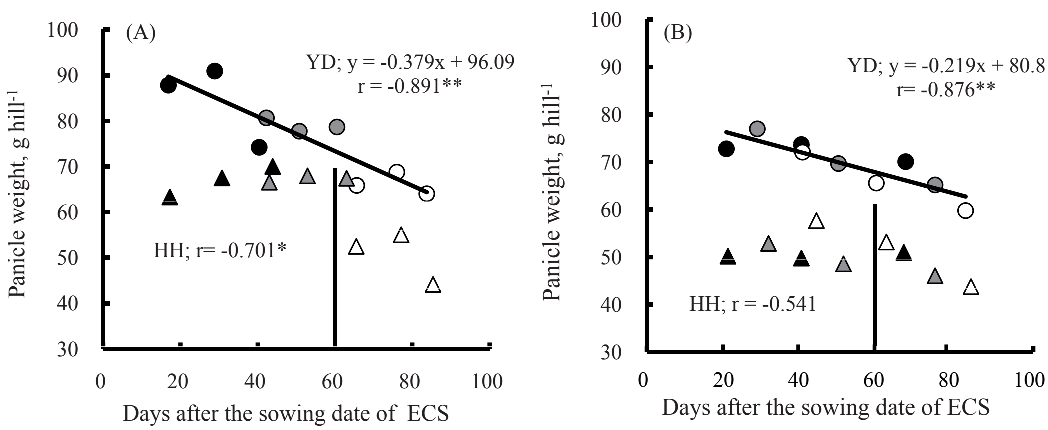

Fig. 3. Relationship between the lowest nodal primary tiller emergence days after the sowing date of the early cropping season (ECS) and panicle weight per hill in 2005 (A) and 2006 (B). Symbols are the same as those in Fig. 2. * and **, significance at 5% and 1% levels, respectively.

3. Yield-related characteristics

Panicle number per hill was significantly higher in HH than in YD, and tended to be higher in the order of Cont>T5>T8 except for YD in the early cropping season and HH in the early and normal cropping seasons. The average panicle weight per stem was significantly higher in YD than in HH, and higher in the order T8>T5>Cont, except for the early cropping season in YD and the normal cropping season in HH (Table 4). The average panicle weight per stem was significantly lighter in the late cropping season than in the other seasons in YD, but not in HH (Table 4). Negative correlations were observed between panicle number per hill and average panicle weight per stem in both cultivars in 2005 and 2006, but the correlation coefficient was higher in YD than in HH in 2005 and 2006, and the rate of decrease in average panicle weight with increase in panicle number was higher in YD than in HH (Fig. 2).

Panicle weight per hill was significantly heavier in YD than in HH in each cropping season, and was heavier in the early cropping season in both cultivars, although the differences between the early and normal cropping seasons in YD and among the cropping seasons in HH were not significant. Tiller removal treatments had no significant effect on panicle weight in either cropping season in either cultivar. Panicle weight increased somewhat in the T5 plants in the early cropping season in YD and in T5 and/or T8 plants in the early and normal cropping seasons in HH.

Fig. 3 shows the correlations between panicle weight per hill and the emergence days of the lowest nodal primary tillers in the early cropping season in 2005 and 2006. The later the emergence day of the lowest nodal primary tillers, the lighter the panicle weight per hill in YD in both years, but not in HH, when the lowest nodal primary tiller emerged within 60 d after the early sowing date.

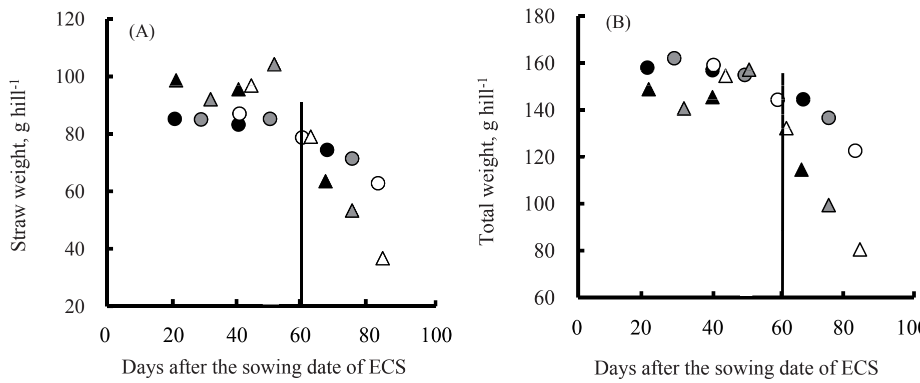

Fig. 4. Relationship between the lowest nodal primary tiller emergence days after the sowing date of the early cropping season (ECS) and straw weight per hill (A) and total (panicle+straw) weight per hill (B) in 2006. Symbols are the same as those in Fig. 2.

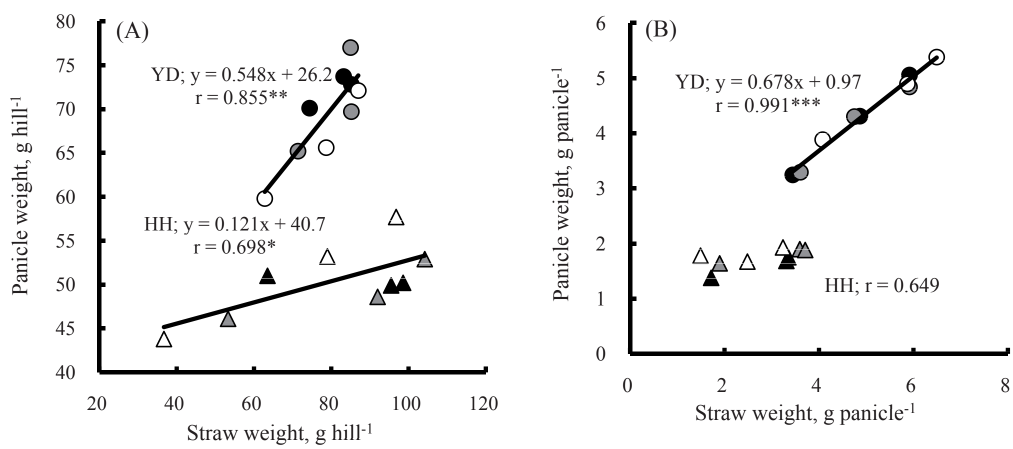

Fig. 5. Correlation between straw and panicle weights per hill (A) and average straw and panicle weights (B). Symbols are the same as those in Fig. 2. *, ** and ***, significance at 5%, 1% and 0.1% levels, respectively.

Straw weight per hill was significantly heavier in HH than in YD in the early cropping season and in YD than in HH in the late cropping season, although it did not differ significantly between the cultivars in the normal cropping season (Table 4). In both cultivars, straw weight per hill tended to be higher in the early cropping season, and significant differences were observed among the cropping seasons in HH and between the early cropping season or normal cropping season and the late cropping season in YD. Considerable treatment differences were observed in the late cropping season, although they were not significant except for the difference between the Cont and T8 plots of late cropping season in HH.

Panicle and straw weights tended to be heavier in the early cropping season in both cultivars, and the difference between the early and late cropping season was significant (Table 4). The effect of the tiller removal was more obvious in the late cropping season, but they were not significant.

Straw and total dry weight per hill were not influenced by the time of the emergence of the lowest tillers within 60 d after the sowing date of the early cropping season (Fig. 4A, B). However, it decreased when the lowest nodal primary tillers emerged later, especially in HH.

Panicle/straw weight ratio was significantly higher in YD than in HH in the early and normal cropping seasons, but was higher in HH than in YD in the late cropping season (Table 4). In both cultivars, the panicle/straw weight ratio was higher in the late cropping season than in the early and normal cropping seasons. No significant effect of tiller removal treatment was observed in YD, but the panicle/straw weight ratio in HH was higher in the T8 plants than in Cont and T5 plants in the late cropping season. A significant increase in panicle/straw weight ratio in both cultivars in the late cropping season was caused by a significantly lower straw weight in the late cropping season, although in YD the change of the ratio by the cropping seasons was smaller than that in HH (Table 4).

Higher and significant positive correlations were observed between panicle and straw weight per hill or per stem in YD than in HH (Fig. 5).

Discussion

Higher temperature after sowing in the late cropping season advanced the date of emergence of the primary tillers in both cultivars (Tables 1 and 2) owing to the faster leaf emergence rate (Sato, 1972). This result is similar to those of Samoto (1966) and Yamamoto et al. (1988). The difference in tillering dates of the lowest nodal primary tillers among the treatments (tiller removal) declined in the late cropping season, although the tillering date was earlier in the order of Cont>T5>T8.

There was a tendency that the days to flag leaf expansion or full heading increased, and days from full heading to maturity decreased in the early cropping season compared with the other cropping seasons. However, the effect of the tiller removal on the growth duration was weaker than that of the cropping season in both cultivars in each cropping season (Table 2). The seasonal differences in vegetative growth and grain filling periods were caused mainly by differences in temperature (Table 1) (Yamakawa and Nishiyama, 1954; Samoto, 1966; Yamamoto et al., 1988). The final number of leaves on the main stems increased in the order of T8>T5>Cont in both cultivars, irrespective of cropping season (Table 3), while little difference was observed in days to flag leaf expansion. This result demonstrated the increased leaf emergence rate by the tiller removal treatments (Yamamoto and Ikeuchi, 1990). The difference in days to flag leaf expansion or full heading among the cropping seasons was smaller in YD than in HH. The days to flag leaf expansion in YD was 75-89 d, and the accumulated mean temperature during this period was around 2100°C (Table 2). As a result, the days to flag leaf expansion was about 10 d longer in HH than in YD in the early cropping season, but almost the same in the normal cropping season and was about 10 d shorter in HH than in YD in the late cropping season (Table 2). Kubota et al. (1988) cultivated a high-yielding rice cultivar of high-panicle-weight type, Suweon 258, at 20-d intervals from late May to early August by transplanting young seedlings with a leaf age of 3.0-3.5, and found that the days from transplanting to heading were 68-81 d and accumulated mean temperature during this period was about 2000℃. The days to flag leaf expansion or full heading varied with the cropping seasons due to cultivar differences in thermosensitivity and photosensitivity (Yamakawa and Nishiyama, 1954; Asakuma, 1958), as well as the basic vegetative growth period. The thermosensitivity and photosensitivity of YD might be lower than those of HH, although the cultivar difference in the basic vegetative growth was not clear.

The number of primary tillers, maximum number of stems and percentage of productive stems were significantly higher in HH than in YD, irrespective of the tiller removal treatments and the cropping seasons (Table 3). Although the number of primary tillers was lower in T5 and T8 plants compared with the Cont plants in both cultivars in each cropping season, the difference was less than 1 tiller, suggesting little effect of tiller removal treatments on number of primary tillers. This is closely related to the increase in flag leaf number with increasing removal of primary tillers showing a close relationship between the maximum number of stems and the average number of tillers per primary tiller (YD: r=0.947***; HH: r=0.907***). The coefficient of correlation between the number of higher order tillers and the number of primary tillers was 0.747* in YD and 0.417 in HH. The percentage of productive stems showed a negative correlation with the maximum number of stems, and the higher correlation in YD resulted in a smaller difference among tiller removal treatments in the number of panicles than in HH.

Panicle number per hill was significantly higher in HH than in YD, but the average panicle weight per stem was higher in YD than in HH (Table 4). Gendua et al. (2009) reported that the spikelet number per panicle in YD was considerably higher than that in HH under field conditions, although the panicle number per hill in YD was significantly lower than that in HH. Panicle number showed a stronger positive correlation with maximum number of stems in both cultivars (YD; r=0.832**; HH: r=0.908***), and tended to be higher in the late cropping season than in the early and normal cropping seasons. This result differed from those of Yamakawa and Nishikawa (1954), Yamada and Ota (1956) and Samoto (1966), who observed the highest panicle number in the early cropping season owing to an increase in tiller number. The higher tiller number in the early cropping season was caused by lower temperature and longer sunshine hours during tillering (Samoto, 1966), but in the present experiment, daily sunshine hours during tillering (40 d after the tiller emergence from the lowest node) varied little with the season (Table 1). A higher temperature during tillering in the late cropping season might affect tillering through water temperature (Tsunoda, 1964; Yamamoto et al., 1988). Average panicle weight per stem decreased with an increase in panicle number in both cultivars, but the rate of decrease was larger in YD than in HH (Fig. 2). Furthermore, the average panicle weight per stem in YD tended to decrease by delaying cropping season or emergence days of the remaining primary tillers, but it did not change in HH (Table 4).

Panicle weight per hill, defined as yield in this study, was significantly heavier in YD than in HH, irrespective of the tiller removal treatments and cropping season (Table 4). We observed that brown rice yield was higher in YD than in HH in the field under several cultivation practices (Gendua et al., 2009). Panicle weight tended to decrease with increasing delay of the time of tiller emergence, but panicle weight of T5 and T8 plants of YD in the early cropping season and that of HH in the early and normal cropping seasons were the same or heavier than those of the Cont plants. This result suggests a high yielding ability of higher nodal tillers under conditions suitable for vegetative growth such as early planting (Yamamoto and Ikeuchi, 1990; Yamamoto et al., 1994). The deep-water irrigation culture after transplanting used in some districts of Japan was based on this potentiality of tillers (Nishiki et al., 1988). Moreover, the rate of decrease in panicle weight per hill with delaying tiller emergence was greater in YD than in HH, and panicle weight was significantly and negatively correlated with the earliness of the tiller emergence in YD, but not in HH when the emergence was within 60 d after the sowing date of early cropping season (Fig. 3A ,B). These results suggest that the effects of cropping season and the tillering node on the panicle weight are stronger in YD than in HH.

Straw and total (panicle+straw) weights per hill were not affected by the time of tiller emergence within 60 d after the sowing date of early cropping season in both cultivars, but decreased by further delay of tiller emergence and the rate of decrease was higher in HH than in YD (Fig. 4A, B). Yamakawa and Nishiyama (1954) reported that the rate of decrease in straw weight with delay in cropping season was higher in cultivars having higher photosensitivity. Further studies are needed to clarify the effects of cropping seasons on straw weight as well as panicle weight in rice cultivars with different photosensitivity and/or thermosensitivity.

Panicle weight was strongly and positively correlated with straw weight per hill and per stem in YD (Fig. 5), indicating that sufficient vegetative growth is necessary for a higher yield in YD. Yao et al. (2000a) showed that the number of spikelets per panicle was determined by two factors, average stem dry weight at heading and spikelet number per unit dry weight (spikelet production efficiency), and that in YD the higher spikelet number per stem depended mainly on higher stem dry weight, but not on spikelet production efficiency. Spikelet production efficiency in YD was not higher than that in conventional and normal panicle size cultivars. Therefore, the promotion of vegetative growth was necessary to increase spikelet number per panicle (panicle size) in YD. On the other hand, the correlation between panicle and straw weights in HH was lower than in YD and the correlation was not significant on a per stem basis (Fig. 5). This result suggests that HH keeps panicle weight heavier and straw weight lighter under the conditions of a shorter vegetative growth period, owing to the delay in tiller emergence resulting in a marked increase in panicle/straw weight ratio in the late cropping season, which is comparable to or higher than that in YD (Table 4). Removing primary tillers from the 2nd to 5th, 8th and 11th nodes in four rice cultivars, Nuruzzaman et al. (1989) found that panicle weight per plant did not differ from that in the control in the cultivars tested, but straw weight per plant in japonica cultivars sharply decreased in proportion to the number of tillers removed; straw weight and panicle/straw weight ratio did not change in high-yielding indica and japonica-indica hybrid rice. The factors responsible for the different cultivar responses to the removal of lower primary tillers in straw weight and the panicle/straw weight ratio remains to be clarified.

This study showed that the average panicle weight per stem of a Chinese high-yielding, large panicle type rice cultivar, YD, is sharply decreased by an increase in panicle number per hill and panicle weight per hill as yield decreased with a delay in emergence of the primary tillers. Panicle weight is highly correlated with straw weight compared with a Japanese rice cultivar, HH. We conclude that in order to realize the high-yielding potential of YD, it is important to promote vegetative growth by early sowing (or planting) and to develop lower nodal tillers.

Reference

Ansari, T.H., Yamamoto, Y., Yoshida, T., Miyazaki A. and Wang, Y. 2003. Cultivar differences in the number of differentiated spikelets and percentage of degenerated spikelets as determinants of the spikelet number per panicle in relation to the dry matter production and nitrogen absorption. Soil Sci. Plant Nutr. 49 : 433-444.

Asakuma, S. 1958. Ecological studies of heading of rice. Relationship between the days from seeding to heading and several conditions. Proc. Crop Sci. Soc. Jpn. 27 : 61-66*.

Baba, I. and Takahashi, T. 1957. Methods of water culture and sand culture. In Y. Togari, T. Matsuo, M. Hatamura, N. Yamada, T. Harada and N. Suzuki eds., Sakumotsusikenho, Nogyo-gijyutu-kyoukai, Tokyo. 157-185.

Gendua, A.P., Yamamoto, Y., Miyazaki, A., Yoshida, T. and Wang, Y. 2009. Responses of yielding ability, sink size and percentage of filled grains to the cultivation practices in a Chinese large-panicle-type rice cultivar, Yangdao 4. Plant Prod. Sci. (In press).

Higashi, T. 1988. Present situation and research subject in future of breeding for superior high yielding rice cultivars. Agric. Hort. 63 : 793-799***.

Ju, J., Yamamoto, Y., Miyazaki, A., Yoshida, T. and Wang, Y. 2006. Effects of the amount and the kinds of fertilizer on the bleeding rate and nitrogen absorption in a Chinese high-yielding cultivar, Yangdao 4. Jpn. J. Crop Sci. 75 : 249-256**.

Kubota, F., Tanaka, N. and Arima, S. 1988. Study on the productive ecology of a high yielding japonica-indica hybrid rice cultivar Suweon 258. Jpn. J. Crop Sci. 57 : 287-297*.

Matsuo, D. 1951. Rice cultivation [I] Diagnosis. Yokendo, Tokyo. 66-87*.

Matsuo, T. 1952. Theory and practice of rice cultivation.

Nogyogijyutukyokai, Tokyo. 22-36*.

Matsushima, S. 1957. Analysis of developmental factors determining yield and yield prediction in lowland rice. Bull. Natl. Inst. Agric. Sci. A5 : 1-271.

Nishiki, T., Hasegawa, S., Haga, S. and Jimbo, K. 1988. Rice growth and deep water management. Agric. Hort. 63 : 723-731*.

Nuruzzaman, MD., Yamamoto, Y. and Nitta, Y. 1989. Removal of Primary Tillers and its Impact on Growth and Productivity of Rice Varieties with Different Plant Types. In Hsiu-Ying Lu, Jih-Min Sung and Ching uei Kao eds., Asian Crop Science 1989. Proc. Of the 3rd Asian Crop Science Conference, Taichug, Taiwan, April 27- May 2. 500-509.

Sato, K. 1972. Growth responses of rice plant to environmental conditions. I. The effects of air-temperature on the growth at vegetative stage. Proc. Crop Sci. Soc. Jpn. 42 : 388-393***.

Samoto, K. 1966. Studies on the ecology of rice plants cultivated in early season, especially upon the reason of higher yield in early season cultivations and shifting of cultivation season at Tokai Kinki District. Bull. Tokai-Kinki Natl. Agric. Exp. Stn. 15 :1-42***.

Tsunoda, K. 1964. Studies on the effects of water –temperature on the growth and yield in rice plant. Bull. Natl. Inst. Agric. Sci. Series A 11 : 75-174***.

Wan, J. and Ikehashi, H. 1994a. The cultivation and cultivars of rice in China [1]. Agric. Hort. 69 : 1181-1186*.

Wan J. and H. Ikehashi 1994b.The cultivation and cultivars of rice in China [2]. Agric. Hort. 69 : 1275-1278*.

Wang, Y., Yamamoto, Y. and Nitta, Y. 1995. Analysis of the Factors of High Yielding Ability with a Japonica Type Rice Line, 9004, Bred in China. I. Comparison of yielding ability with a Japanese rice variety under the same level of spikelets number per area. Jpn. J. Crop Sci. 64 : 545-555**.

Wang, Y., Nitta,Y. and Yamamoto, Y. 1997. Effect of timing and rate of nitrogen application on root growth with special reference to Chinese F1-hybrid rice “Shanyou 63”. Jpn. J. Crop Sci. 66 : 588-595**.

Yamada, N. and Ota, Y. 1956. Growth phase of early and late cropping rice plant. Agric. Hort. 31 : 769-774*.

Yamakawa, Y. and Nishiyama, H. 1954. Effects of the difference of cultivating periods on the characters of rice plant. Kyusyu Nogyou Kenkyu 14 : 158-160*.

Yamamoto, Y., Yoshida, T. and Yoshikawa, G. 1988. Effect of cultivation season on the pattern of growth and mineral absorption in short-season rice variety. Jpn. J. Soil Sci. Plant Nutr. 59 : 279-287***.

Yamamoto, Y. and Ikeuchi, H. 1990. Difference in grain productivity of tillers among main stem nodes in rice plant, I. Effects of the number and position of tillering nodes on grain productivity. Jpn. J. Crop Sci. 59 : 8-18*.

Yamamoto, Y. 1991. Studies on transplanting injury and its culture significance in rice plant. Mem. Fac. Agric., Kochi Univ., No. 54, pp.167.

Yamamoto, Y., Nouno, J. and Nitta, Y. 1994. Difference in grain productivity of tillers among main stem nodes in rice plant. II. Comparison under the conditions of the same panicle number and constituent of each order tiller per plant. Jpn. J. Crop Sci. 63 : 601-609*.

Yamamoto, Y. 1997. What is the transplanting for crops? Nobunkyo, Tokyo. pp.208*.

Yamamoto, Y., Ansari, T.H., Yamamoto, M., Yoshida, T., Miyazaki A. and Wang, Y. 2001. Comparison of sink capacity and its components in japonica and indica rice cultivars with different plant types. Jpn. J. crop Sci. 70 (Extra issue 2) : 41-42*.

Yao, Y., Yamamoto, Y., Wang, Y., Miyazaki A. and Cai, A. 2000a. Number of degenerated and surviving spikelets associated with the number of differentiated spikelets among various rice cultivars. Jpn. J. Trop. Agr. 44 : 41-60.

Yao, Y., Yamamoto, Y., Wang, Y., Miyazaki A. and Cai, A. 2000b. Response of differentiated and degenerated spikelets to top-dressing, shading and day/night temperature treatments in rice cultivars with large panicles. Soil Sci. Plant Nutr. 46 : 631-641.

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