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REVIEW

High-Yielding Rice Production through Ratooning in Southwestern Japan

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Abstract

Ratooning is a cultivation technique that involves harvesting a second crop (referred to as a ratoon) originating from the stubbles of the first crop. Rice ratooning has been implemented in countries located in tropical and temperate regions. Based on recent studies conducted in southwestern Japan, this review introduces and discusses the effects of harvest time and cutting height of the first crop and the roles of leaf blades and nonstructural carbohydrates (NSC) in the stubbles of the first crop on grain yield to provide the essential information necessary for the development of rice production technologies using ratooning.

Discipline: Crop Science
Additional key words: first crop, leaf area index, nonstructural carbohydrate, second crop

Introduction

The global population is predicted to grow from 8.0 billion in 2022 to around 8.5 billion in 2030, 9.7 billion in 2050, and 10.4 billion in 2100 (United Nations 2022). To resolve the global food security crisis, the global crop production needs to increase substantially. Because the arable land in the world is limited (Alexandratos & Bruinsma 2012), crop yield per unit area must increase. Rice (*Oryza sativa* L.) is a staple food for approximately 50% of the global population (GRiSP 2013). Therefore, the development of high-yielding production technologies is essential for feeding the growing population.

Compared to 1850-1900, the global surface temperature averaged over 2011-2020 was 1.09°C higher, with larger increases observed over the land (1.59°C) than over the ocean (0.88°C) (IPCC 2021). Furthermore, the temperature averaged over 2081-2100 is expected to increase by 1.0 to 1.8°C under the very low greenhouse gas (GHG) emissions scenario (SSP1-1.9), by 2.1 to 3.5°C under the intermediate GHG emissions scenario (SSP2-4.5), and by 3.3 to 5.7°C under the very high GHG emissions scenario (SSP5-8.5). In any case, the growing season for summer crops is very likely to extend in the near future.

Ratooning is a cultivation technique that involves harvesting a second crop (i.e., ratoon) originating from the stubbles of the first crop. It is applied to rice and other crop species, such as banana (*Musa sapientum*), cotton (*Gossypium* spp.), ramie (*Boehmeria nivea*), pineapple (*Ananas comosa*), sorghum (*Sorghum vulgare*), and sugarcane (*Saccharum* spp.) (Plucknett et al. 1970). Rice ratooning has been implemented in countries located in tropical and temperate regions, such as China (e.g., Peng et al. 2023), Indonesia (e.g., Mareza et al. 2016), Japan (e.g., Nakano et al. 2023), the Philippines (e.g., Bañoc et al. 2022), and USA (e.g., Ziska et al. 2018). Given the current climate change models, the production area with potential for ratooning is predicted to extend further north in the near future (Ziska et al. 2018).

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In China, the planting area for rice ratooning has reached over 1.0 million hectares (Yu et al. 2022) owing to mechanized rice ratooning technology that allows the harvesting of the first crop mechanically (Peng et al. 2023). Furthermore, the area could be significantly expanded without switching the current one from double cropping to ratooning (Yu et al. 2022). A recent study reported that the net economic return of rice ratooning was higher than that of single or double cropping (Yuan et al. 2019). It was also reported that greenhouse gas emissions were lower in the second crop season than in the first one (Song et al. 2022). Additionally, the number of scientific papers on rice ratooning has increased (Peng et al. 2023), suggesting that research interest has grown in the field.

Most of the regions in which rice ratooning is conducted are located further south than Japan; therefore, in this country, it is important to increase grain yield using limited growth duration. Based on recent studies conducted in southwestern Japan, this review introduces and discusses the results of some field studies on the effects of harvest time and cutting height of the first crop (Nakano et al. 2020) and the roles of leaf blades and nonstructural carbohydrate (NSC) in the stubbles of the first crop on grain yield (Nakano et al. 2021, 2022) to provide the essential information necessary for the development of rice production technologies using ratooning.

Grain yield response to harvest time and cutting height of the first crop

Nakano et al. (2020) conducted a study in the 2017 and 2018 crop seasons at the Kyushu Okinawa Agricultural Research Center, NARO (33° 12′ N, 130° 29′ E, 8 m above sea level), Chikugo, Fukuoka, Japan, to determine the effects of harvest time and cutting height of the first crop on grain yield and its components. The treatments included two harvest times (early and normal) and two cutting heights of the first crop (high and low). The high yielding line (HYL) used was derived from a cross between the high-yielding *indica* cultivar Hokuriku 193 and an F1, which was derived from a cross between Hokuriku 193 and the *japonica* cultivar Bekoaoba. Seedlings were transplanted by hand into a paddy field in mid-April. Plants were fertilized with N, P_2O_5, and K_2O in the form of synthetic fertilizers at a total of 340 kg ha^{-1}, 60 kg ha^{-1}, and 60 kg ha^{-1}, respectively, as a split application. At the early harvest (900°C days cumulative daily mean air temperature from the heading stage to the harvest stage, mid-August) and normal harvest times (1,200°C days cumulative daily mean air temperature from the heading stage to the harvest stage, late-August) of the first crop, the plants were harvested by hand to a stubble height of 50 cm (high cutting height) or 20 cm (low cutting height) from the ground surface.

The total grain yield of the first and second crops was higher at the normal harvest time (1,219 and 1,379 g m^{-2} in 2017 and 2018, respectively) than at the early harvest time (1,076 and 1,221 g m^{-2} in 2017 and 2018, respectively) in both years. Also, the yield was higher at the high cutting height (1,252 and 1,382 g m^{-2} in 2017 and 2018, respectively) than at the low cutting height (1,042 and 1,218 g m^{-2} in 2017 and 2018, respectively). The highest grain yield (1,291 and 1,436 g m^{-2} in 2017 and 2018, respectively) was recorded with plants harvested at the normal harvest time and at the high cutting height. Therefore, it is recommended that the first crop be harvested at the normal harvest time and at a high cutting height to increase the total grain yield of the first and second crops.

The grain yield of the first crop was higher at the normal harvest time (970 and 1,007 g m^{-2} in 2017 and 2018, respectively) than at the early harvest time (780 and 839 g m^{-2} in 2017 and 2018, respectively) in both years. The higher grain yield at normal harvest time resulted from the higher percentage of filled spikelets.

At the high cutting height, the grain yield of the second crop was higher at the early harvest time than at the normal harvest time in both years (Table 1). The higher grain yield at the early harvest time resulted from the higher percentage of filled spikelets and 1,000-grain weight. The crop growth rate of the second crop has been shown to increase with the increasing stubble leaf area index (LAI) in perennial ryegrass (*Lolium perenne* L.) (Brougham 1956). In Nakano et al. (2020), the LAI was higher at the early harvest time than at the normal harvest time (Fig. 1). Rice grain filling has been shown to decline when plants ripen under daily mean air temperatures of 20°C or less from the heading stage to 40 d after it (Tanaka 1962). According to Nakano et al. (2020), at the early harvest time, the daily mean temperature from the heading stage to 40 d after it was 22.2°C in 2017 and 21.4°C in 2018. In contrast, at the normal harvest time, the temperature was 20.0°C in 2017 and 19.7 °C in 2018, respectively. Therefore, the higher grain filling observed at the early harvest may be attributable to the higher LAI in the stubbles and the favorable air temperature at the ripening stage.

At the low cutting height, the grain yield of the second crop did not differ between harvest times in 2017 but was higher at the normal harvest time than at the early harvest time in 2018 (Table 1). The higher grain yield at normal harvest time in 2018 resulted from the

Table 1. Grain yield of the second crop and its components as affected by harvest time and cutting height of the first crop in 2017 and 2018

Year	Harvest time (HT)	Cutting height (CH)	Grain yield (g m^{-2})	Spikelet number ($\times 10^3$ m^{-2})	Panicle number (m^{-2})	Spikelet number ($panicle^{-1}$)	Filled spikelets (%)	1,000-grain weight (g)
2017								
	HT							
	Early		296	21.4	346	60.5	58.3	22.3
	Normal		249	21.0	350	59.5	53.1	22.2
		CH						
		High	378	27.4	425	64.7	59.4	23.1
		Low	167	15.0	271	55.3	52.0	21.4
	HT × CH							
	Early	High	434aA[a]	28.0	421	66.8	66.5aA	23.3aA
		Low	157b	14.7	271	54.3	50.2b	21.4b
	Normal	High	321aB	26.8	429	62.6	52.3B	22.9aB
		Low	177b	15.3	271	56.3	53.8	21.5b
	ANOVA							
	HT		ns	ns	ns	ns	ns	†
	CH		***	***	***	**	**	**
	HT × CH		**	ns	ns	ns	**	**
2018								
	HT							
	Early		382	25.2	380	65.2	68.9	22.0
	Normal		372	28.4	525	53.9	60.4	21.6
		CH						
		High	459	31.7	499	64.2	64.8	22.3
		Low	295	21.8	406	54.9	64.5	21.3
	HT × CH							
	Early	High	488aA	31.9a	452aB	70.6	68.4	22.4
		Low	276bB	18.5bB	309bB	59.8	69.4	21.5
	Normal	High	429aB	31.6a	547aA	57.8	61.2	22.2
		Low	314bA	25.2bA	503bA	50.0	59.5	21.0
	ANOVA							
	HT		ns	**	**	**	*	*
	CH		***	***	**	**	ns	***
	HT × CH		**	*	*	ns	ns	ns

ns, not significant at $P < 0.10$
† Significant at $P < 0.1$
* Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level
[a] Means within a column followed by the same lowercase letter do not differ significantly ($P < 0.1$) between cutting heights for a given harvest time. Means within a column followed by the same uppercase letter do not differ significantly ($P < 0.1$) between harvest times for a given cutting height.

higher number of spikelets. When the first crop is harvested, the starch in the stubbles is quickly hydrolyzed and transported to dormant buds at the base (Slewinski 2012), and the buds are released when the sugar content exceeds a certain threshold (Mason et al. 2014). In Nakano et al. (2020), NSC content was higher at the normal harvest time than at the early harvest time (Fig. 1). In the high-yielding cultivars Hokuriku 193 and Bekoaoba, prior to the heading stage, NSC is accumulated in the stems and, as the heading stage begins, is

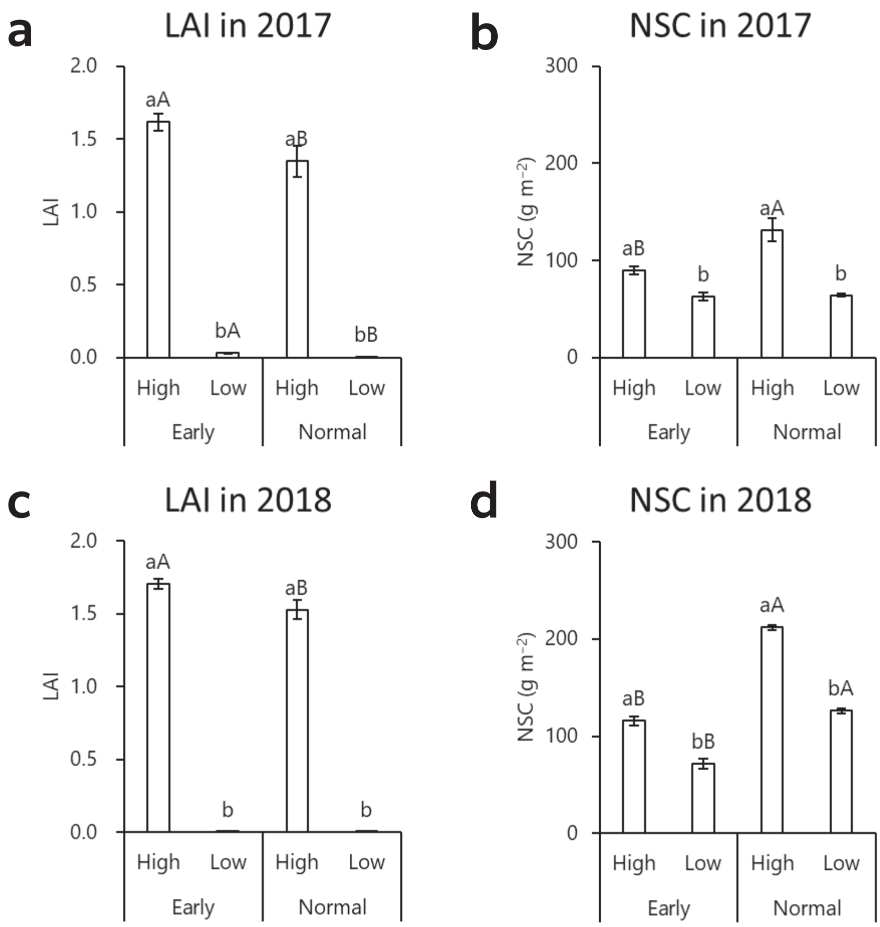

Fig. 1. Stubble leaf area index (LAI) and nonstructural carbohydrate (NSC) content as affected by harvest time (early or late harvest) and cutting height (high or low) of the first crop in 2017 and 2018

Means within a figure followed by the same lowercase letter do not differ significantly ($P < 0.1$) between cutting heights for a given harvest time. Means within a figure followed by the same uppercase letter do not differ significantly ($P < 0.1$) between harvest times for a given cutting height. Vertical bars represent standard errors of the means.

translocated to the panicle for 30 d. Once the translocation is almost over, NSC is accumulated again in the stems until the maturity stage is reached (Yoshinaga et al. 2013). Hokuriku 193 and Bekoaoba are the parent cultivars of the line used in Nakano et al. (2020). In this study, the number of spikelets was lower in 2018 (50,000 and 49,500 m^{-2} at the early and normal harvest times, respectively) than in 2017 (53,100 and 53,500 m^{-2} at the early and normal harvest times, respectively). A negative interaction between the number of spikelets and the content of reaccumulated starch in the stems at the maturity stage has been detected in *japonica* cultivars (Yamaguchi & Matsumura 2004), suggesting that the existence of a relationship between sink capacity and source ability that could influence the content of reaccumulated NSC. Therefore, the higher number of spikelets observed at the normal harvest time in 2018 may be attributable to the higher NSC content in the stubbles.

The grain yield of the second crop was higher at the high cutting height than at the low cutting height (Table 1). The higher grain yield was a result of the higher number of spikelets and grain filling due to the higher LAI and NSC content (Fig. 1). Several previous studies have reported that the optimal cutting height from the ground surface to obtain high grain yield of the second crop was 40 cm to 50 cm (Nakano et al. 2020, 2022) in Japan and 40 cm in Iran (Daliri et al. 2009, Shahri et al. 2012). A recent modeling study in China obtained a similar result (Ling et al. 2019). However, lower optimal cutting heights have been reported in Florida, USA (20 cm to 30 cm) (Jones 1993), Louisiana, USA (20 cm) (Harrell et al.

2009), the Philippines (15 cm) (Bañoc et al. 2022), and Korea (10 cm) (Shin et al. 2015). Additionally, our previous study reported that the dry matter yield of the second crop increased as the cutting height increased from 0 cm to 15 cm (Nakano et al. 2009). The optimal cutting height of the first crop to increase the grain yield of the second crop is considered to be dependent on the cultivars used and the prevailing meteorological conditions (Wang et al. 2020). Interestingly, our recent study suggests that the grain yield difference between cutting heights may narrow under high air temperature conditions (Nakano et al. 2023).

The grain yield of the second crop was more correlated with stubble LAI and NSC content than with stubble NSC concentration (Table 2). The LAI was related to the number of spikelets, number of panicles, number of spikelets per panicle, and 1,000-grain weight. Additionally, the NSC content was related to the number of spikelets, number of panicles, and 1,000-grain weight. These results suggested that stubble LAI and NSC content may be essential to increase the grain yield of the second crop.

Grain yield response to genotype and stubble leaf treatment

Nakano et al. (2021) conducted a study in the 2019 and 2020 crop seasons at the Kyushu Okinawa Agricultural Research Center, NARO (33° 12′ N, 130° 29′ E, 8 m above sea level), Chikugo, Fukuoka, Japan, to determine the role of stubble leaf blades on grain yield and its components. The treatments included two genotypes (HYL and Hokuriku 193) and two stubble leaf treatments (clipping and control). Seedlings were transplanted by hand into a paddy field in late April. The plants were fertilized with N, P_2O_5, and K_2O in the form of synthetic fertilizers at a total of 340 kg ha^{-1}, 60 kg ha^{-1}, and 60 kg ha^{-1}, respectively. Once the first crop reached maturity (1,000°C days cumulative daily mean air temperature from the heading stage to the harvest stage, late August for HYL and early September for Hokuriku 193), the plants were harvested by hand to a stubble height of 50 cm from the ground surface. The stubble leaf blades subjected to the leaf clipping treatment were clipped using scissors, while no clipping was performed in the control group.

In 2019, for both rice genotypes, the grain yield of the second crop was lower in the leaf-clipped plants than in the control group (Table 3). The lower grain yield in the leaf-clipped plants resulted from the lower yield components, particularly the lower number of spikelets calculated based on the number of panicles and number of spikelets per panicle. Therefore, stubble leaf blades may contribute to increasing grain yield by increasing the number of panicles and number of spikelets per panicle, which are determined prior to the heading stage. A previous study reported that the number of differentiated spikelets was positively correlated with N uptake per unit area at the late spikelet differentiation stage, and the number of degenerated spikelets was negatively correlated with the dry matter increase per differentiated spikelet from late spikelet differentiation to the heading stage (Wada 1969). These results suggested that the N in the stubble leaf blades and the carbohydrates produced by them may be used to increase the number of spikelets.

In 2020, for HYL, the grain yield of the second crop was lower in the leaf-clipped plants than in the control plants (Table 3). The lower grain yield in the leaf-clipped plants resulted from the lower number of spikelets and 1,000-grain weight. However, for Hokuriku 193, the grain yield did not differ between the two leaf clipping treatments. Additionally, for both rice genotypes, the

Table 2. Pearson correlation (r) between grain yield of the second crop, its components, and stubble growth-related traits in 2017 and 2018

Year		Grain yield (g m^{-2})	Spikelet number ($\times 10^3$ m^{-2})	Panicle number (m^{-2})	Spikelet number (panicle^{-1})	Filled spikelets (%)	1,000-grain weight (g)
2017 and 2018							
	Grain yield (g m^{-2})		0.947***	0.783***	0.657***	0.659***	0.622**
	LAI	0.850***	0.843***	0.604**	0.745***	0.337^{ns}	0.857***
	NSC concentration (%)	0.239^{ns}	0.405^{ns}	0.709***	−0.440*	−0.005^{ns}	−0.299^{ns}
	NSC content (m^{-2})	0.611**	0.755***	0.871***	0.024^{ns}	0.106^{ns}	0.252^{ns}

ns, not significant at $P < 0.05$
* Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level

Table 3. Grain yield of the second crop and its components as affected by rice genotype and stubble leaf clipping treatment in 2019 and 2020

Year	Rice genotype (RG)	Leaf clipping (LC)	Grain yield (g m^{-2})	Spikelet number ($\times 10^3$ m^{-2})	Panicle number (m^{-2})	Spikelet number ($panicle^{-1}$)	Filled spikelets (%)	1,000-grain weight (g)
2019								
	RG							
	HYL		248	17.8	297	58.2	62.2	21.8
	Hokuriku 193		195	19.6	459	42.5	49.2	19.7
		LC						
		Control	296	23.3	413	58.2	59.7	21.1
		Clipping	147	14.1	344	42.5	51.8	20.4
	RG × LC							
	HYL	Control	345aA[a]	23.6a	344aB	68.7aA	65.4	22.3
		Clipping	150b	11.9bB	251bB	47.6bA	59.1	21.3
	Hokuriku 193	Control	248aB	23.0a	482aA	47.6aB	54.0	19.8
		Clipping	143b	16.3bA	437bA	37.3bB	44.4	19.5
	ANOVA							
	RG		†	ns	**	*	†	**
	LC		***	***	**	***	***	*
	RG × LC		*	*	†	*	ns	ns
2020								
	RG							
	HYL		305	23.7	365	64.9	60.7	21.1
	Hokuriku 193		202	23.2	436	53.5	40.6	21.4
		LC						
		Control	278	25.2	404	63.4	50.5	21.6
		Clipping	229	21.6	398	55.0	50.9	20.9
	RG × LC							
	HYL	Control	355aA	26.7aA	378	71.3	62.1A	21.5
		Clipping	256bA	20.6b	352	58.5	59.3A	20.8
	Hokuriku 193	Control	201B	23.8B	429	55.5	38.8bB	21.8
		Clipping	202B	23	444	51.5	42.4aB	21.1
	ANOVA							
	RG		**	ns	†	†	*	ns
	LC		**	*	ns	*	ns	**
	RG × LC		**	†	ns	ns	*	ns

ns, not significant at $P < 0.1$
† Significant at $P < 0.1$
* Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level
[a] Means within a column followed by the same lowercase letter do not differ significantly ($P < 0.1$) between leaf treatments for a given genotype. Means within a column followed by the same uppercase letter do not differ significantly ($P < 0.1$) between genotypes for a given leaf treatment.

grain yield difference between the two treatments was smaller in 2020 than in 2019. The stubble NSC content was significantly higher in 2020 than in 2019 because the number of spikelets of the first crop was markedly lower in 2020 (37,600 and 40,400 m^{-2} in HYL and Hokuriku 193, respectively) than in 2019 (48,000 and 47,400 m^{-2} in HYL and Hokuriku 193, respectively) (Fig. 2). These results suggested that the contribution of stubble leaf blades to grain yield may be reduced when the stubble NSC content is high as the stubble leaf blades may compensate for the lack of stubble NSC content when NSC content is low.

Grain yield response to genotype and cutting height

The quantitative trait locus *GN1A*, which lies on chromosome 1 and encodes the enzyme cytokinin oxidase/dehydrogenase (OsCKX2), regulates the number of spikelets per panicle (Ashikari et al. 2005). The expression of *OsCKX2* in the inflorescence meristem was higher in the conventional *japonica* cultivar Koshihikari than in the high-yielding *indica* cultivar Habataki. An allele of *GN1A* derived from Habataki was found to produce more spikelets per panicle than that from Koshihikari. The near-isogenic line (NIL)-*GN1A*^{Takanari}, which carries a *GN1A* allele derived from the high-yielding *indica* cultivar Takanari in the Koshihikari genetic background, was subsequently developed (Ueda et al. 2021).

Nakano et al. (2022) conducted a study in the 2019 and 2020 crop seasons at the Kyushu Okinawa Agricultural Research Center, NARO (33° 12′ N, 130° 29′ E, 8 m above sea level), Chikugo, Fukuoka, Japan, to determine the role of NSC on grain yield and its components. The treatments included two genotypes (NIL-*GN1A*^{Takanari} and Koshihikari) and two cutting heights of the first crop (high and low). Seedlings were transplanted by hand into a paddy field in late April. Plants were fertilized with N, P_2O_5, and K_2O in the form of synthetic fertilizer at a total of 140 kg ha^{-1}, 50 kg ha^{-1}, and 50 kg ha^{-1}, respectively. Once the first crop reached maturity (1,000°C days cumulative daily mean air temperature from the heading stage to the harvest stage, mid-August for NIL-*GN1A*^{Takanari} in 2019 and for Koshihikari in both years and early August for

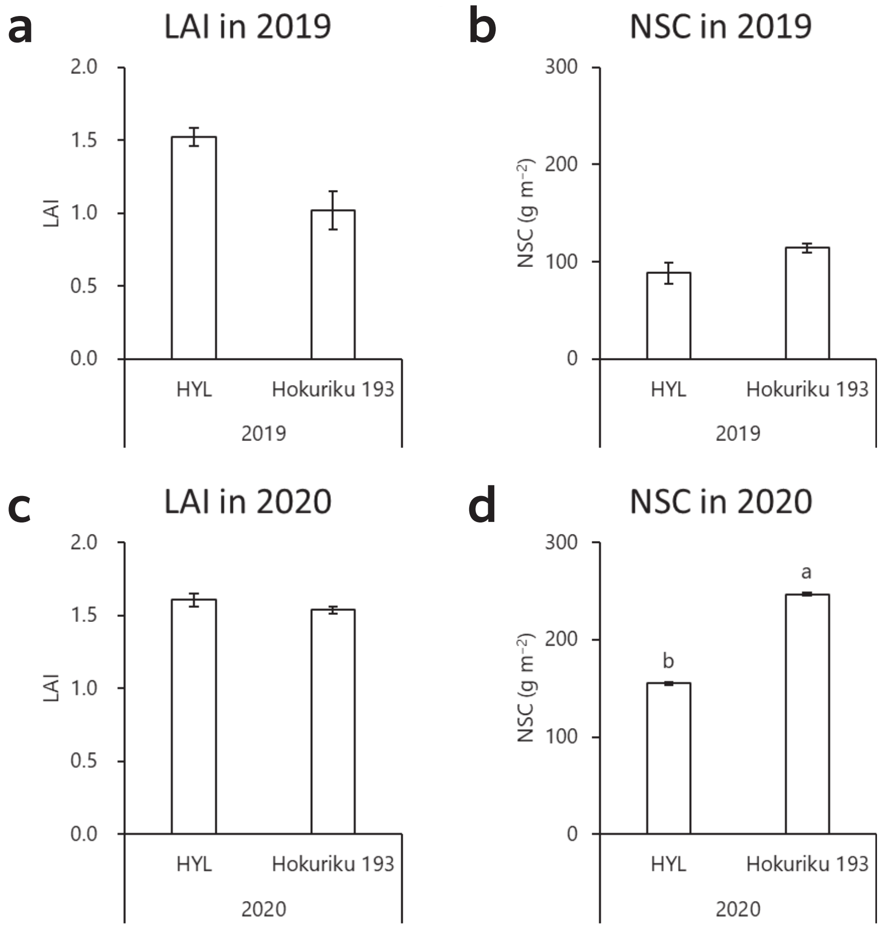

Fig. 2. Stubble leaf area index (LAI) and nonstructural carbohydrate (NSC) content as affected by rice genotype (high-yielding line or Hokuriku 193) in 2019 and 2020
Means within a figure followed by the same lowercase letter do not differ significantly ($P < 0.1$) between genotypes. Vertical bars represent standard errors of the means.

NIL-*GN1A*[Takanari] in 2020), plants were harvested by hand to a stubble height of 50 cm (high cutting height) or 20 cm (low cutting height) from the ground surface.

The grain yield of the second crop was lower for NIL-*GN1A*[Takanari] than for Koshihikari at both cutting heights in both years (Table 4). The lower grain yield for NIL-*GN1A*[Takanari] resulted from the lower number of spikelets. The LAI and NSC content were lower for

Table 4. Grain yield of the second crop and its components as affected by rice genotype and cutting height of the first crop in 2019 and 2020

Year	Rice genotype (RG)	Cutting height (CH)	Grain yield (g m^{-2})	Spikelet number (×10^3 m^{-2})	Panicle number (m^{-2})	Spikelet number ($panicle^{-1}$)	Filled spikelets (%)	1,000-grain weight (g)
2019								
	RG							
	NIL-*GN1A*[Takanari]		162	10.4	256	40.1	72.8	21.2
	Koshihikari		203	12.2	363	33.5	77.5	21.3
		CH						
		High	251	15.3	412	37.8	79.0	20.8
		Low	114	7.3	207	35.9	71.2	21.7
	RG × CH							
	NIL-*GN1A*[Takanari]	High	232	14.8	358	41.7	76.3	20.6
		Low	91	5.9	154	38.5	69.3	21.7
	Koshihikari	High	269	15.7	466	33.9	81.8	20.9
		Low	137	8.7	260	33.2	73.2	21.7
	ANOVA							
	RG		*	†	*	†	ns	ns
	CH		***	***	**	ns	*	*
	RG × CH		ns	ns	ns	ns	ns	ns
2020								
	RG							
	NIL-*GN1A*[Takanari]		106	7.3	214	34.3	66.2	21.7
	Koshihikari		157	9.5	349	27.4	76.2	21.5
		CH						
		High	148	9.5	317	30.9	73.7	20.9
		Low	115	7.4	246	30.8	68.6	22.2
	RG × CH							
	NIL-*GN1A*[Takanari]	High	122	8.1	237aB[a]	34.6	71.1a	21.1
		Low	89	6.5	192bB	34.1	61.2bB	22.3
	Koshihikari	High	173	10.8	398aA	27.2	76.3	20.7
		Low	140	8.3	300bA	27.6	76.0A	22.2
	ANOVA							
	RG		†	†	*	*	ns	*
	CH		*	**	**	ns	†	*
	RG × CH		ns	ns	†	ns	†	ns

ns, not significant at $P < 0.1$
† Significant at $P < 0.1$
* Significant at the 0.05 probability level
** Significant at the 0.01 probability level
*** Significant at the 0.001 probability level
[a] Means within a column followed by the same lowercase letter do not differ significantly ($P < 0.1$) between cutting heights for a given genotype. Means within a column followed by the same uppercase letter do not differ significantly ($P < 0.1$) between genotypes for a given cutting height.

NIL-*GN1A*^{Takanari} than for Koshihikari at the high cutting height, and the NSC content was lower for NIL-*GN1A*^{Takanari} than for Koshihikari at the low cutting height in 2019 (Fig. 3). A similar trend was observed in 2020. Therefore, the lower number of spikelets for NIL-*GN1A*^{Takanari} at high and low cutting heights may be attributable to the lower stubble LAI and NSC content and the lower stubble NSC content, respectively.

The grain yield of the first crop for NIL-*GN1A*^{Takanari} (493 g m^{-2}) was similar to that for Koshihikari (499 g m^{-2}), but the number of spikelets was higher for NIL-*GN1A*^{Takanari} (29,600 m^{-2}) than for Koshihikari (27,300 m^{-2}) in 2019. A similar trend was observed in 2020. A recent study reported that NSC accumulation from the branch differentiation stage to the spikelet differentiation stage in the stems was positively correlated with the number of differentiated secondary spikelets and that NSC accumulation at the pollen mother cell meiosis stage was negatively correlated with the number of degenerated secondary spikelets (Liu et al. 2022). These results indicated that NIL-*GN1A*^{Takanari} consumes more NSC to produce more spikelets than Koshihikari, which is the cause of the lower NSC content at the maturity stage of the first crop.

Conclusion

Based on recent studies conducted in southwestern Japan, this review introduced and discussed the roles of leaf blades and NSC in the stubbles of the first crop on

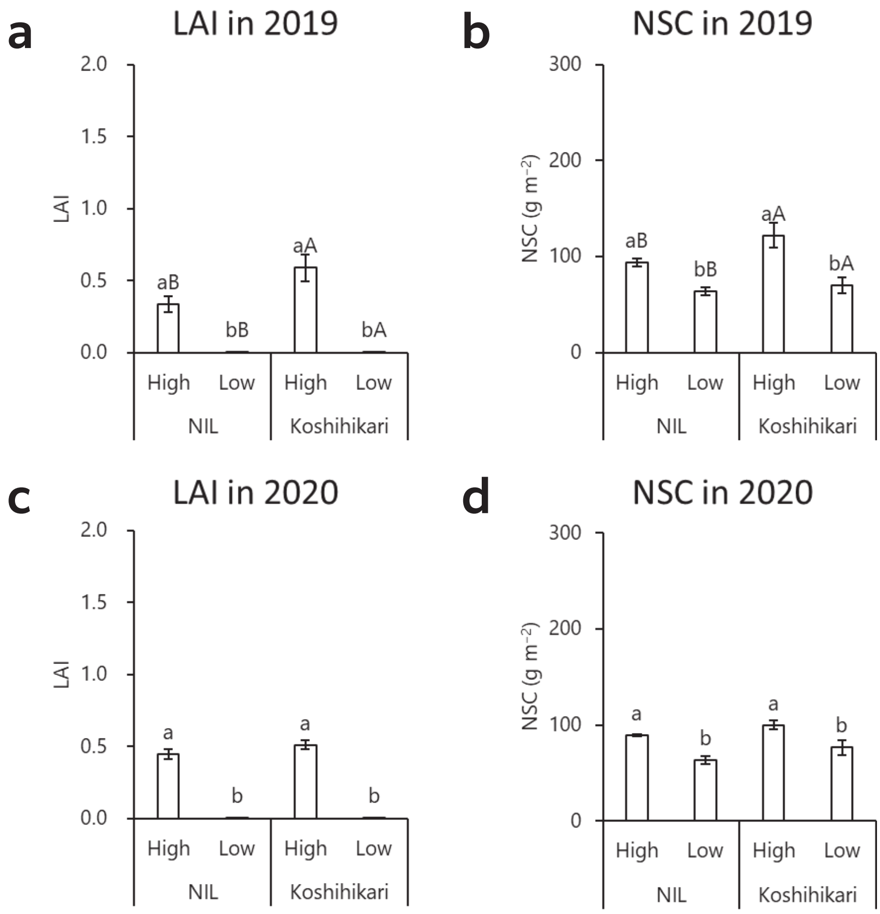

Fig. 3. Stubble leaf area index (LAI) and nonstructural carbohydrate (NSC) content as affected by rice genotype (NIL-*GN1A*^{Takanari} or Koshihikari) and cutting height (high or low) of the first crop in 2019 and 2020

Means within a figure followed by the same lowercase letter do not differ significantly ($P < 0.1$) between cutting heights for a given genotype. Means within a figure followed by the same uppercase letter do not differ significantly ($P < 0.1$) between genotypes for a given cutting height. Vertical bars represent standard errors of the means.

grain yield. The grain yield of the second crop was shown to be highly correlated with stubble LAI and NSC content, suggesting that these may be key factors for increasing the grain yield. Stubble leaf blades and NSC may contribute to increasing the grain yield by increasing the number of panicles and spikelets, which are determined prior to the heading stage. Additionally, the contribution of stubble leaf blades to grain yield may be reduced when the stubble NSC content is high as the stubble leaf blades may compensate for the lack of stubble NSC content when NSC content is low.

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