

REVIEW

Improved Lodging Resistance in Rice (*Oryza sativa* L.) Cultivated by Submerged Direct Seeding Using a Newly Developed Hill Seeder

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Abstract

Submerged direct-seeded rice is more susceptible to lodging during the ripening period than is transplanted rice. Comparing different seeding methods of direct seeding cultivation, lodging resistance is considered to be highest in hill-seeded rice. However, practical hill-seeders did not exist, and previously direct-seeding had been conducted by broadcast- or row-seeding. This paper discusses the development of a hill seeder and improvements in the lodging resistance of hill-seeded rice, both of which have contributed to the recent widespread cultivation of submerged, direct-seeded rice in Japan. The newly developed hill-seeder effectively drives seeds intermittently into the puddled soil and enabled establishment of a hill which is composed of several plants as is a transplanted hill. Hill-seeded rice showed remarkable higher pushing resistance than broadcast-seeded rice across a range of seedling density and seeding depth after heading, while the plant length was longer in hill-seeded rice. It is suggested that the high lodging resistance of the hill-seeded rice is derived from the larger number of panicles per hill, because the lodging resistance varied depending on the number of panicles in a hill. The area cultivated by hill-seeding has been increasing since 1998, in 2004, it occupied 25% of the total submerged direct-seeded area.

Discipline: Crop production

Additional key words: hill-seeding, seeding method

Introduction

The aging of farmers and falling rice prices have created serious problems for rice farmers in Japan, and have led, recently, to demands for reductions in the costs and labor required for rice (*Oryza sativa* L.) production. Direct seeding, which does not require seedlings to be raised or transplanted, is regarded as the most effective method for reducing costs and labor. However, direct-seeded fields currently represent less than 1% of the total rice cultivation area, despite the fact that the area of well-drained paddy fields increased during the 1970s, before the use of transplanting machines had become widespread. The widespread use of direct seeding has been limited because of the unstable yields of direct-seeded fields, as compared to those of transplanted fields. The main causes for the lower yields of submerged, direct-seeded fields are poor seedling establishment and frequent plant lodging.

Lodging is problematic for rice production because it makes machine harvesting difficult. Furthermore, the lodging of rice plants during the ripening period results not only in a reduction in yield, owing to decreased canopy photosynthesis as a result of self-shading, but also in a decrease in the grain quality, due to increased coloring of brown rice and/or decreased flavor^{1,6}. Submerged, direct-seeded rice is more susceptible to lodging during the ripening period than is transplanted rice. Popular cultivars are utilized in direct-seeding to achieve better producer prices, but most of these cultivars show insufficient lodging resistance. Therefore, an alternative means of improving the lodging resistance of direct-seeded rice, such as adjusting the application of nitrogen, the seeding depth, and/or the seeding method, is required. The lodging resistance is highest in hill-seeded rice and higher in row-seeded rice than in broadcast-seeded rice³. However, practical hill seeders did not exist until the late 1990s and, previously, direct seeding took place through broadcast or row seeding.

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Fig. 1. Newly developed hill seeder in operation

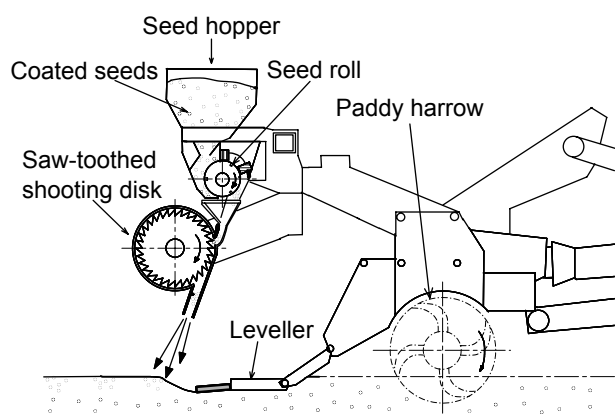


Fig. 2. Outline of the newly developed hill seeder

This paper discusses the development of a hill seeder and improvements in the lodging resistance of hill-seeded rice, both of which have contributed to the recent widespread use of submerged, direct-seeding cultivation of rice.

Development of a hill seeder

A practical hill seeder was developed in the late 1990s at the National Agricultural Research Center for Kyushu Okinawa Region (Fukuoka, Japan). Combined with a harrow, the hill seeder enables seeding and puddling to be performed simultaneously (Fig. 1)⁷. The seeder is composed of seed hoppers, seed rolls, and saw-toothed shooting disks (Fig. 2).

The rice seeds used in this seeder are coated with calcium peroxide (CaO_2), which promotes the emergence of seedlings in puddled soil. This seeder effec-

tively drives seeds intermittently into puddled soil at depths of 5 to 20 mm using the rotating saw-toothed shooting disks. The seeding depth can be controlled by the rotation speed of the saw-toothed shooting disks (varying from 100 to 1,500 rpm), depending on the soil conditions. Control of the seeding rate can also be achieved by varying the distance between the hill and the number of seeds provided by the seed rolls. This seeder enables the establishment of a hill composed of several plants, just as in a transplanted hill.

Improvement of lodging resistance in hill-seeded rice

1. Effects of seedling density

Most previous studies on the lodging resistance of direct-seeded rice plants have been conducted with broadcast-seeded rice, and so the lodging resistance of hill-seeded rice has not been well examined. On the other hand, it has been shown that the plant density, which varies depending on the seeding rate and percentage of seedlings established, affects the lodging resistance of rice plants⁸. Therefore, we examined the lodging resistance of hill-seeded rice that had been seeded using the newly developed hill seeder, as well as that of broadcast-seeded rice, at different seedling densities. The experiment was carried out at the National Agricultural Research Center for Kyushu Okinawa Region, in 1998 and 1999, using the popular Japanese variety Hino-hikari. Pregerminated seeds coated with calcium peroxide were broadcast-seeded by hand and hill-seeded using the hill seeder at a hill density of 30×20 cm. The plant population was adjusted to 40, 80, or 160 plants/m² (the number of plants per hill was adjusted for the hill-seeded rice). The fertilizer application and water management practices used were the conventional methods used in the Kyushu area. The pushing resistance was measured with a digital force gauge, at 20 days after heading, by bending a hill 45° at a height of 15 cm⁹. The lodging index was estimated using the following formula: (above-ground weight \times culm length) / (pushing resistance \times 15; measured height in cm)^{4,8}.

In hill-seeded rice (hereafter referred to as HS), the culm length was greater than that for broadcast-seeded rice (hereafter referred to as BS) (Table 1). However, the pushing resistance for HS was higher than that for BS, and the differences became greater at higher plant densities (Table 1, Fig. 3). This result indicates that the base of the HS hill can sustain a larger force than can that of BS, in spite of the plant density. The lodging index, which estimates the lodging resistance and is closely related to the actual lodging, was constant for HS and smaller than

Table 1. Effects of seeding method and plant density on characteristics of plants and lodging resistance

Seeding method (A)	Plant density (B) (no./m ²)	Culm length (cm)	No. of panicles (no./hill)	Pushing resistance (g/culm)	Lodging index	Lodging degree (0-4)
Broadcast-seeding	40	81.5	8.7	71.1	0.81	0.96
	80	80.9	4.7	59.2	0.97	1.54
	160	79.4	2.7	39.5	1.44	1.87
	mean	80.6	5.4	56.6	1.08	1.46
Hill-seeding	40	86.1	21.6	89.9	0.69	0.48
	80	85.8	23.2	84.7	0.72	0.69
	160	84.5	25.0	71.9	0.75	0.67
	mean	85.5	23.3	82.2	0.72	0.61
ANOVA	A	*	**	*	*	**
	B	ns	*	**	**	*
	A×B	ns	**	*	**	*

Values are means of 3 years (1997–1999). Pushing resistance was measured at 20 days after heading by bending a hill 45° from the vertical at a 15 cm height. Lodging index was estimated by the following formula: (above-ground weight × culm length) / (pushing resistance × 15; measured height in cm). Lodging degree is estimated by actual lodging at maturity (Small value represents small degree of lodging). ANOVA : Results of analysis of variance. * & **: Significant at 0.05 and 0.01 probability levels, respectively. ns : Not significant.

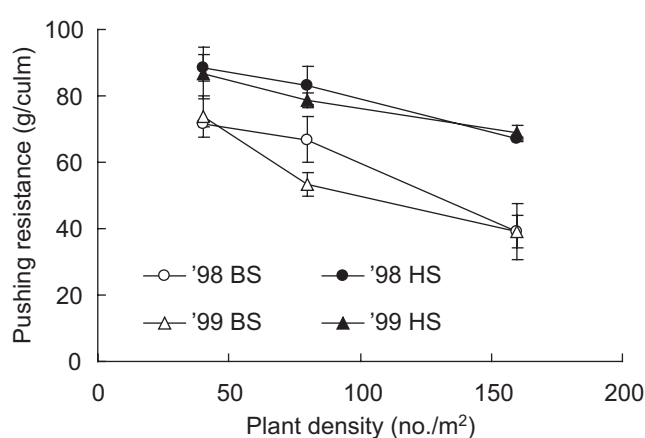


Fig. 3. Relationship between plant density and pushing resistance in broadcast-seeded rice (BS) and hill-seeded rice (HS)

Pushing resistance was measured at 20 days after heading by bending a hill 45° from the vertical at a 15 cm height. Vertical bars indicate standard errors (n = 3).

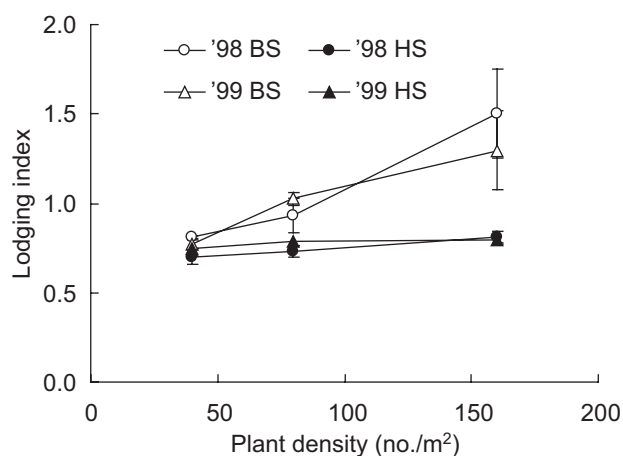


Fig. 4. Relationship between plant density and lodging index in broadcast-seeded rice (BS) and hill-seeded rice (HS)

Lodging index was estimated by the following formula: (above-ground weight × culm length) / (pushing resistance × 15; measured height in cm). Vertical bars indicate standard errors (n = 3).

that for BS, especially at the highest plant density (Fig. 4). The smaller lodging index for HS is probably due to its higher pushing resistance.

2. Effects of seeding depth

The seeding depth is an important factor for the stabilization of direct-seeded plants because it influences not only the establishment of seedlings but also the lodg-

ing resistance^{2,5}. It has been shown that greater seeding depths for direct-seeded rice result in increased lodging resistance^{2,8}. However, the interactions of the seeding method and depth on the lodging resistance have not been examined. We examined the effects of seeding depth on the lodging resistance of hill-seeded and broadcast-seeded rice. The experimental fields, cultivars, and methods used were the same as in the plant density exper-

iment, except for the plant density and the seeding depth. Seedlings with coleoptiles of about 20 mm were planted in puddled soil at depths of 2, 5, 10, 15, and 20 mm, and the plant density used for BS and HS was 80 plants/m².

The pushing resistance for HS was higher than that for BS across the entire range of seeding depths examined (Fig. 5). This result indicates that the base of a HS hill can sustain a greater force than can that of BS, even at a shallow seeding depth. For HS, the lodging index was constant for all seeding depths, and was smaller than that for BS, especially at shallow seeding depths (Fig. 6).

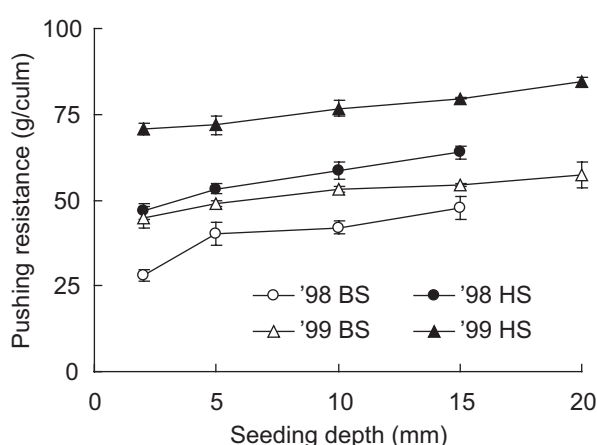


Fig. 5. Relationship between seeding depth and pushing resistance in broadcast-seeded rice (BS) and hill-seeded rice (HS)

Pushing resistance was measured at 20 days after heading by bending a hill 45° from the vertical at a 15 cm height. Vertical bars indicate standard errors (n = 3).

The smaller lodging index for HS is likely to be derived from its higher pushing resistance.

3. Factors in the improvement of lodging resistance

It was shown that the pushing resistance and lodging index vary, depending on the number of panicles per hill (Figs. 7 & 8). For BS, the plant density affected the number of panicles per hill, and the pushing resistance and lodging index ranged widely when the number of panicles per hill was decreased (Table 1, Figs. 7 & 8). However, the number of panicles per HS hill was not

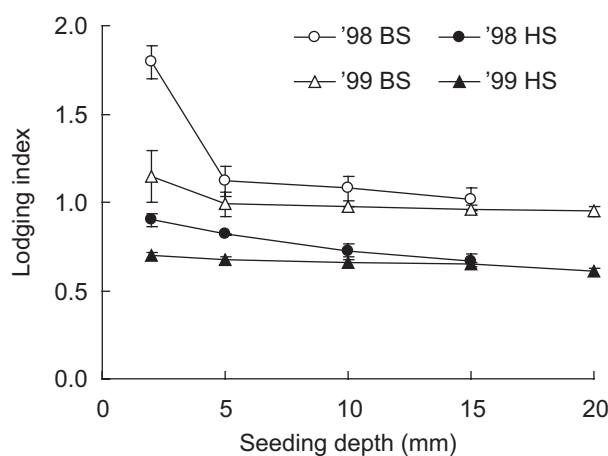


Fig. 6. Relationship between seeding depth and lodging index in broadcast-seeded rice (BS) and hill-seeded rice (HS)

Lodging index was estimated by the following formula: (above-ground weight × culm length) / (pushing resistance × 15; measured height in cm). Vertical bars indicate standard errors (n = 3).

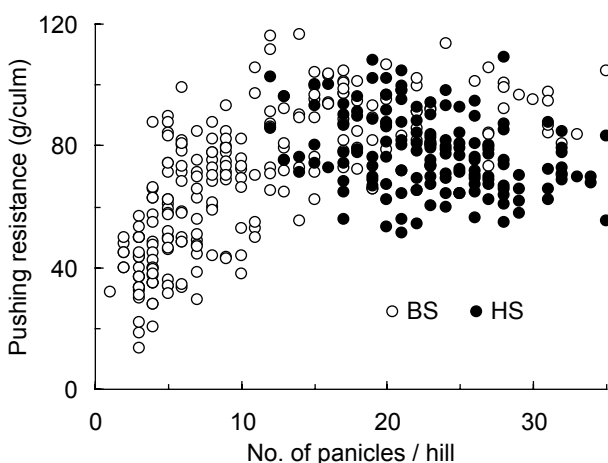


Fig. 7. Relationship between number of panicles per hill and pushing resistance in broadcast-seeded rice (BS) and hill-seeded rice (HS)

Pushing resistance was measured at 20 days after heading by bending a hill 45° from the vertical at a 15 cm height.

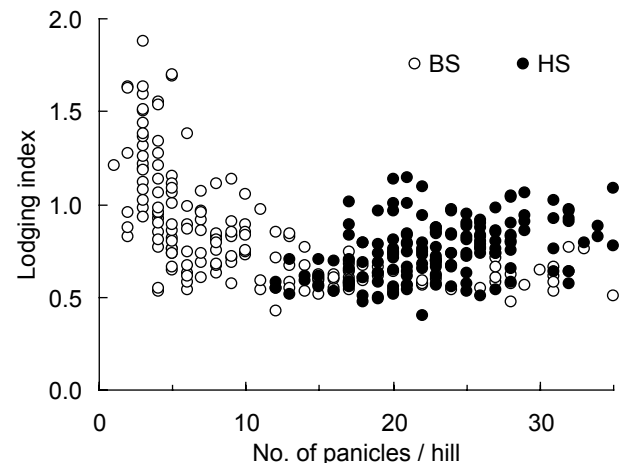


Fig. 8. Relationship between number of panicles per hill and lodging index in broadcast-seeded rice (BS) and hill-seeded rice (HS)

Lodging index was estimated by the following formula: (above-ground weight × culm length) / (pushing resistance × 15; measured height in cm).

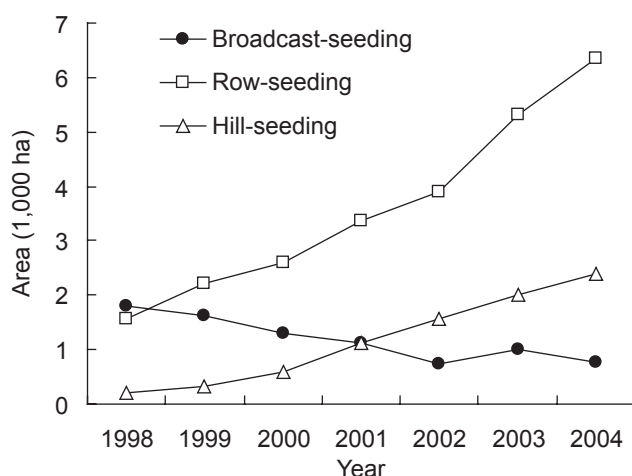


Fig. 9. Changes in seeding methods of submerged direct-seeding cultivation in Japan

influenced by the plant density, and the pushing resistance and lodging index for HS did not vary with the plant density (Table 1, Figs. 7 & 8).

These results suggest that HS, by which a hill was composed of several plants, had a larger number of panicles per hill, resulting in a higher lodging resistance than did BS, the hills of which were usually composed of one isolated plant. Furthermore, the lodging resistance of HS was not affected by the plant density. This can be attributed to the small differences between plant densities in the number of panicles per hill of HS, given that the HS hill density is not influenced by plant density.

Increases in the area of hill-seeded rice

Hill seeding has enabled popular cultivars with low lodging resistance to be grown in areas normally cultivated by submerged direct seeding. The area cultivated using hill seeders has been increasing since 1998, and in 2002 overtook the area cultivated by broadcasting. In 2004, hill-seeded rice occupied 25% of the total area of submerged, direct-seeded rice (Fig. 9). The hill seeder has contributed to the recent widespread use of submerged direct seeding, given that the area of submerged, direct-seeded rice cultivation has doubled in the last five years (Fig. 10).

Conclusion and perspectives

This report confirmed the high lodging resistance of hill-seeded rice across a range of plant densities and seeding depths. In Japan, popular cultivars for transplanting are utilized in direct seeding because they have better producer prices, even though most do not have adequate lodging resistance. In this situation, selecting the best

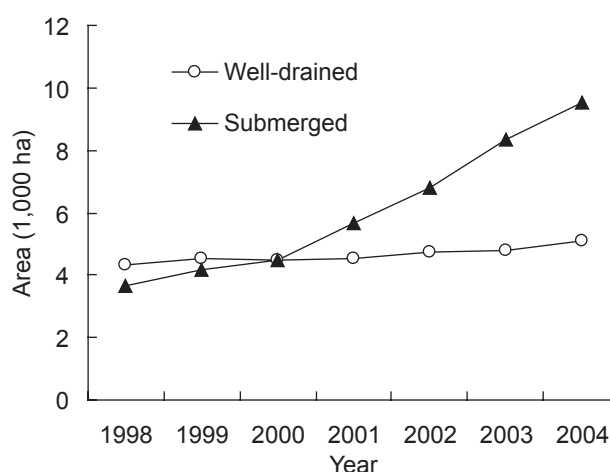


Fig. 10. Direct-seeded rice area under well-drained and submerged conditions in Japan

seeding method is an important factor for consideration. Hill seeding has enabled popular cultivars with low lodging resistance to be grown in areas where submerged direct seeding is normally used. Thus, the development of hill-seeding cultivation has contributed to the recent increase in the direct-seeded area.

For further expansion in the use of direct seeding, the breeding and introduction of cultivars with appropriate traits for direct-seeding cultivation will be necessary. In addition, it has been reported that seeding methods affect growth behaviors of direct-seeded rice, including the tillering rate, nitrogen uptake, and dry matter production^{10,11}. Therefore, further studies on the rational management of crops, seeded using different methods, could contribute to the stabilization of direct-seeding cultivation.

References

1. Matsue, Y. et al. (1991) Studies on palatability of rice grown in northern Kyushu. *Nihon sakumotsu gakkai kiji (Jpn. J. Crop Sci.)*, **60**, 490–496 [In Japanese with English summary].
2. Nakamura, Y. (1981) Study on the direct underground sowing machine in the submerged paddy field. *Nougyo kikai gakkaiishi (J. Jpn. Soc. Agric. Mach.)*, **43**, 203–209 [In Japanese with English summary].
3. Ogata, T. & Matsue, Y. (1998) Studies on direct sowing culture of rice in northern Kyushu. *Nihon sakumotsu gakkai kiji (Jpn. J. Crop Sci.)*, **67**, 485–491 [In Japanese with English summary].
4. Seko, H. (1962) Studies on lodging in rice plants. *Kyushu nougyo shikenjou ihou (Bull. Kyushu. Agric. Exp. Stn.)*, **7**, 419–499 [In Japanese with English summary].
5. Seko, H., Samura, T. & Koshio, H. (1987) Effect of seed depth on the emergence and establishment in direct sowing culture of rice plant in flooded paddy field. *Kinki*

- sakumotsu-ikusyu kenkyu (Rep. Soc. Crop Sci. Breed. Kinki)*, **32**, 17–19 [In Japanese].
6. Setter, T. L., Laureles, E. V. & Marazedo, A. M. (1997) Lodging reduces yield of rice by self-shading and reductions in canopy photosynthesis. *Field Crops Res.* **49**, 95–106.
 7. Shimotsubo, K. & Togashi, T. (1996) Study on submerged direct seeding combined puddling with seeding operation. *Nihon sakumotsu gakkai kiji (Jpn. J. Crop Sci.)*, **65** (Extra issue 1), 12–13 [In Japanese].
 8. Terashima, K., Akita, S. & Sakai, N. (1992) Eco-physiological characteristics related with lodging tolerance of rice in direct sowing cultivation I. Comparison of the root lodging tolerance among cultivars by the measurement of pushing resistance. *Nihon sakumotsu gakkai kiji (Jpn. J. Crop Sci.)*, **61**, 380–387 [In Japanese with English summary].
 9. Togashi, T., Yoshinaga, S. & Shimotsubo, K. (1997) Measuring method of root lodging tolerance of rice plant in submerged hill seeding. *Nihon sakumotsu gakkai Kyushu shibu kaihou (Rep. Kyushu Breed. Crop Sci. Soc. Jpn.)*, **63**, 7–9 [In Japanese].
 10. Yoshinaga, S. et al. (2001) Growth characteristics of submerged hill-seeded rice (*Oryza sativa* L.) in warmer regions of Japan—Difference of growth as compared with broadcast-seeded rice—. *Nihon sakumotsu gakkai kiji (Jpn. J. Crop Sci.)*, **70**, 541–547 [In Japanese with English summary].
 11. Yoshinaga, S. et al. (2002) Growth characteristics of submerged hill-seeded rice (*Oryza sativa* L.) in warmer regions of Japan—Improvement of growth and yield by basal application of controlled release fertilizer at a later growth stage—. *Nihon sakumotsu gakkai kiji (Jpn. J. Crop Sci.)*, **71**, 328–334 [In Japanese with English summary].