

Growth Enhancement by Drainage during Seedling Establishment in Rice Direct-Sown into Puddled and Leveled Soil

— Comparison with seed coating with calcium peroxide —

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Abstract : Growth enhancement by drainage during seedling establishment was compared with seed coating with calcium peroxide in rice direct-sown into puddled and leveled soil. Coated and noncoated seeds were sown about 10 mm deep, three times from April to June at two locations (Niigata and Ibaraki, Japan). Seed coating with calcium peroxide accelerated seedling emergence at an early stage, whereas drainage during 10 to 13 days after sowing promoted it at a late stage. Although drainage was less effective in increasing the number of finally emerged seedlings than seed coating with calcium peroxide, the drainage clearly improved seedling establishment. Seed coating with calcium peroxide enhanced shoot elongation during seedling emergence. In contrast, drainage somewhat inhibited shoot elongation at this time, but promoted it after drained soil was flooded. Drainage also increased the dry weight of shoots more than flooding after seedling emergence. These results indicate that seed coating with calcium peroxide enhances plant growth during seedling emergence, whereas drainage after sowing promotes plant growth mainly after seedling emergence. This suggests that seed coating with calcium peroxide accelerates seedling emergence, but drainage after sowing enhances seedling establishment.

Key words : Calcium peroxide, Direct sowing, Drainage, Growth, *Oryza sativa* L., Rice, Seedling emergence, Seedling establishment.

The expensiveness of Japanese rice in the global market makes it vital to reduce cost and save labor wherever possible (Nishiyama, 1996). Direct sowing, which eliminates seedling raising and transplanting, is regarded as the most effective solution (Washio, 1984), but is not yet widespread in Japan because the yield of direct-sown rice remains lower and less stable than that of transplanted rice.

Direct sowing has constraints such as unstable seedling emergence, weed infestation, and frequent lodging (Washio, 1984). Inconsistent seedling establishment is a particular constraint in rice direct-sown into puddled and leveled soil (Tanaka, 2000). Seed coating with calcium peroxide (CaO_2) was developed to improve plant growth during seedling establishment in direct sowing (Mitsuishi and Nakamura, 1977), based on the findings that CaO_2 promotes germination and enhances seedling growth in flooded soil (Yamada, 1951; Ota and Nakayama, 1970).

Oba (1997) found that drainage promoted seedling emergence of rice more than flooding when CaO_2 -coated seeds were direct-sown into puddled and leveled soil. Subsequent studies showed that drainage

enhanced plant growth and seedling establishment in direct sowing (Tanaka, 2000; Yoshinaga et al., 2000). Our previous study confirmed these findings, showing that drainage improved seedling emergence and establishment independent of seed coating with CaO_2 (simply called seed coating hereafter) and sown depth (Sato and Maruyama, 2002). It remains to be clarified, however, whether the physiological mechanism of growth enhancement by drainage is similar to that by this seed coating. We therefore conducted field experiments to compare the effect of drainage and seed coating on seedling growth of rice direct-sown into puddled and leveled soil.

Materials and Methods

1. Plants and growth conditions

Experiments 1 and 2 were conducted at the paddy fields of the Niigata Agricultural Research Institute Crop Research Center (Nagaoka, Niigata) in 2000, and Experiment 3 at the Yawara Lowland Field of the National Agriculture Research Center (Yawara, Ibaraki) in 2001. Rice (*Oryza sativa* L., cv. Koshihikari) seeds were presoaked in tap water for four to ten days, and some were coated with CaO_2 as previously

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Abbreviations : CaO_2 , calcium peroxide; DAS, days after sowing; SWC, soil water content.

Table 1. Weather conditions, soil temperatures and soil water content during drainage.

No. of Exp.	Place	Sowing date	Duration of drainage (day)	Mean air temperature (°C)	Mean soil temperature		Precipitation (mm)	SWC _a † (%)	SWC _b ‡ (%)
					Flooding (°C)	Drainage (°C)			
1	Nagaoka	April 28, 2000	13	14.3	16.3	15.8	45.5	102.7±8.0	64.5±3.3
2	Nagaoka	May 12, 2000	10	16.7	18.9	18.6	25.5	132.8±8.9	75.8±3.5
3	Yawara	June 6, 2001	10	19.4	-	-	107.5	93.6±1.9	65.7±2.1

†SWC_a, Soil water content at the beginning of drainage; ‡SWC_b, soil water content at the end of drainage. SWC is the mean ± SE of 3 replications.

described elsewhere (Sato and Maruyama, 2002). Briefly, presoaked seeds were mixed with twice the seed dry weight of 16% CaO₂ (Calper Fine Granule 16, Hodogaya Chemical Co., Kanagawa) in a coating machine (YCT15, Yanmar Agricultural Equipment Co., Osaka) until seeds were thoroughly coated with fine CaO₂ granules by water spraying. These CaO₂-coated seeds were dried for 20 to 40 hours at room temperature.

Two nursery fields, 20 m² in Exp. 1 and 2 and 36 m² in Exp. 3, were used for different water management during seedling establishment. Each field was puddled and leveled, then drained 1 to 2 days before sowing. Fields were basally fertilized with 1.5 g m⁻² of nitrogen, phosphate, and potash in Exp. 1 and 2, and 3 g m⁻² of these elements in Exp. 3. Seeds were sown on April 28 (Exp. 1) and May 12 (Exp. 2) at Nagaoka in 2000 and on June 6 (Exp. 3) at Yawara in 2001. Coated and noncoated seeds were sown at 6 cm intervals in rows 30 cm apart. Seeds were placed 10 mm below the soil surface with forceps in Exp. 1 and 2, and with a thin rod in Exp. 3. Actual sowing depth was estimated by measuring the length of the whitish part at the base of the shoot at seedling establishment. Five to 6 seedlings were measured in each plot.

Water management was begun just after sowing. In drainage plots, water was not added after sowing, and water was introduced up to 5 cm above the soil surface 13 days after sowing (DAS) in Exp. 1, and 10 DAS in Exp. 2 and 3. Water was maintained at 5 cm above the soil surface throughout the experiment in flooded plots.

2. Seedling emergence and establishment

Seedling emergence was followed up at 2- to 4-day intervals from sowing to 20 DAS, with emerged seedlings counted 20 DAS in Exp. 1 and 2, and 25 DAS in Exp. 3. Floating, turned down, and delayed seedlings with a leaf age less than 2.0 were removed from finally emerged seedlings and remaining seedlings defined as established. To measure seedling emergence and establishment, we used 35 to 40 seeds in each of three replications in Exp. 1 and 2, and 4 to 7 replications in Exp. 3. The mean of replications from different places in each treatment was calculated and differences of means between treatments were

subjected to the least significant difference test at the 0.05 level.

3. Seedling growth and dry weight of shoots

Three established seedlings were sampled in each plot 25 DAS in Exp. 1 and 27 DAS in Exp. 2, and then plant age in leaf number and plant length were measured. Six seedlings were sampled at roughly 5-day intervals from sowing to 26 DAS in Exp. 3. Roots were removed from seedlings, and then plant age in leaf number and plant length were recorded. Separated shoots were dried at 80°C for 48 hr, then the dry weight of shoots was determined. The mean of replications from different plants in each treatment was calculated and differences of means between treatments were subjected to the least significant difference test at the 0.05 level.

4. Weather conditions and soil water content during drainage

Daily mean air temperature and precipitation were obtained from the meteorological observatory at the Niigata Agricultural Research Institute Crop Research Center for Exp. 1 and 2, and at the Yawara Lowland Field of National Agriculture Research Center for Exp. 3. Soil temperature was recorded 10 mm below the soil surface of drainage and flooded plots in Exp. 1 and 2.

Soil water content (SWC) was measured as previously described elsewhere (Sato and Maruyama, 2002). Soil was sampled from 1 to 3 cm depth at 3 places in the drainage plot at the start and the end of treatment. Soil weight was quickly determined and soil dried at 105°C for 24 hr. Dry soil weight was measured and SWC calculated as the percentage of water in oven-dried soil.

Results

1. Weather conditions and soil water content during drainage

Table 1 shows drainage duration, mean air temperature, mean soil temperature and precipitation during treatment, and SWC at the start and end of treatment. Soil was drained for 13 days after sowing in Exp. 1, and 10 days in Exp. 2 and 3. Mean air temperature during the treatment was low in Exp. 1, moderate in Exp. 2 and relatively high in Exp. 3.

Precipitation was low in Exp. 1 and 2, and high in Exp. 3. SWC was nearly unaffected by precipitation, except in Exp. 2, due to higher evaporation at higher air temperature. SWC was higher in Exp. 2 than in other experiments due to water flowing from surrounding paddy fields.

Soil temperature was measured during drainage in Exp. 1 and 2 (Table 1). Mean soil temperature in the drainage plot was 15.8°C in Exp. 1 and 18.6°C in Exp. 2, which were lower than in the flooded plots by 0.5 and 0.3°C.

2. Seedling emergence and establishment

Sowing depth was estimated by measuring the length of the whitish part at the base of shoots at seedling establishment. Estimated sowing depth with standard deviation in flooded plots in Exp. 1 was 5.8±1.3 mm, 7.2±1.1 mm in Exp. 2, and 10.2±3.0 mm in Exp. 3 for

noncoated seeds, and 7.2±2.2 mm in Exp. 1, 8.8±1.1 mm in Exp. 2, and 7.0±3.9 mm in Exp. 3 for coated seeds. Similarly, those in drainage plots were 7.6±1.7, 8.8±2.3, and 7.7±2.9 mm for noncoated seeds, and 6.4±2.2, 9.6±1.7, and 9.0±2.3 mm for coated seeds.

Fig. 1 shows that seedling emergence in Exp. 3 was more rapid and greater for coated seeds than for noncoated seeds. Although water management affected seedling emergence less than the seed coating, the percentage of seedling emergence after 6 DAS increased more rapidly in drainage plots than in flooded ones. Similar trends were observed in Exp. 1 and 2.

Table 2 shows that the rate of seedling emergence and establishment were low in Exp. 1 and 2, and high in Exp. 3, for non-coated seeds, but low in Exp. 1, and high in Exp. 2 and 3, for coated seeds. Drainage had relatively little effect in seedling emergence, but significantly affected seedling establishment except in Exp. 2, in which SWC was high due to water flowing from surrounding paddy fields. The rate of seedling emergence and establishment were, however, significantly higher for coated seeds than for noncoated seeds in Exp. 1 and 2. A similar tendency was also found in Exp. 3, although significant difference was detected only in seedling establishment in flooded plots.

3. Plant growth during seedling establishment

Fig. 2 shows the change in plant length in Exp. 3. The plant length for coated seeds increased more rapidly than for noncoated seeds until 10 DAS, but at a similar rate as for noncoated seeds after 10 DAS. By contrast, shoot growth in drainage plots was slower than that in flooded plots in an early stage, but more rapid after 10 DAS when drained soil was flooded, and plant length in drainage plots exceeded that in flooded plots at 20 DAS. Similar trends were observed in plant age in leaf number in Exp. 3 and in plant length during seedling establishment in Exp. 1 and 2.

Table 3 shows the changes in dry weight of shoots during seedling establishment in Exp. 3. Drainage

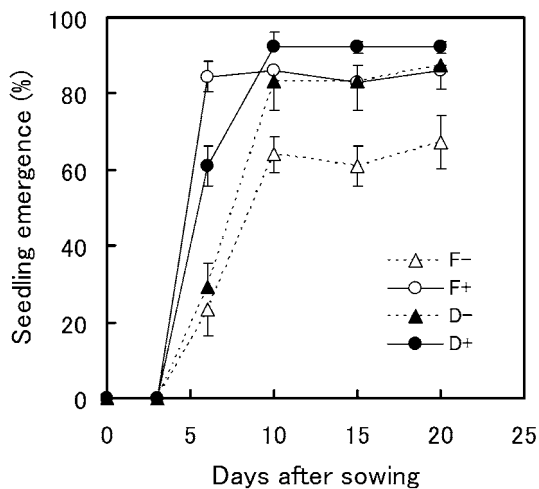


Fig. 1. Emergence of rice seedlings direct-sown into puddled and leveled soil with or without seed coating with calcium peroxide under different water management (Exp. 3). F, Flooding; D, drainage; -, without seed coating; +, seed coating with calcium peroxide. The vertical line indicates the standard error of results from 4 replications.

Table 2. Effect of seed coating with calcium peroxide and water management on seedling emergence and establishment in rice direct-sown into puddled and leveled soil.

Treatment	Seedling emergence (%)			Seedling establishment (%)		
	Exp. 1	Exp. 2	Exp. 3	Exp. 1	Exp. 2	Exp. 3
Flooding/-CaO ₂ †	62.0 ^b	58.3 ^b	75.0 ^b	38.5 ^c	45.6 ^b	62.5 ^c
Flooding/+CaO ₂ ‡	77.8 ^a	90.7 ^a	84.8 ^{ab}	54.2 ^b	84.4 ^a	81.7 ^b
Drainage/-CaO ₂	59.3 ^b	63.0 ^b	84.8 ^{ab}	49.0 ^b	56.7 ^b	84.8 ^{ab}
Drainage/+CaO ₂	82.4 ^a	90.7 ^a	92.9 ^a	71.9 ^a	90.7 ^a	92.9 ^a

†-CaO₂, Without seed coating; ‡+CaO₂, seed coating with calcium peroxide. Seedling emergence and establishment were measured 20 to 25 DAS, and expressed as the mean of 3 replications in Exp. 1 and 2, and 4 to 7 replications in Exp. 3. Figures followed by a different letter are significantly different at 5% LSD.

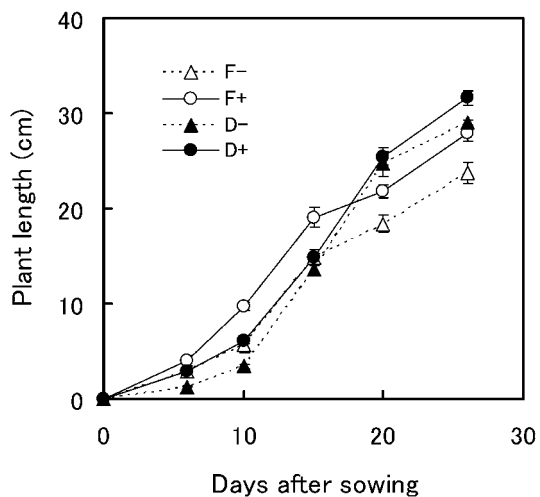


Fig. 2. Changes in plant length of rice seedlings direct-sown into puddled and leveled soil with or without seed coating with calcium peroxide under different water management (Exp. 3). F, Flooding; D, drainage; -, without seed coating; +, seed coating with calcium peroxide. The vertical line indicates the standard error of results from 6 replications.

affected dry weight of shoots only negligibly until 10 DAS, but significantly increased it after 15 DAS as compared with in flooded plots. Dry weight of shoots for coated seeds was significantly heavier than for noncoated seeds throughout the experiment, i.e. dry weight of shoots at 26 DAS was the heaviest for coated seeds with drainage.

Discussion

Seed coating with CaO_2 promotes germination and subsequent growth of rice in flooded soil (Ota and Nakayama, 1970), thus enhancing the emergence of rice direct-sown into puddled and leveled soil (Hagiwara and Imura, 1993). In our experiments, seed coating enhanced seedling emergence both in flooded and drained soil, indicating that seed coating accelerates seedling emergence regardless of water management.

In contrast to seed coating, drainage after sowing does not always enhance seedling emergence. Some investigators observed the promotion of seedling emergence by drainage (Yoshinaga et al., 1997; Sato and Maruyama, 2002), but some failed to detect the differences in the seedling emergence between the flooding and drainage conditions (Furuhata et al., 1998; Takahashi et al., 1998). In our experiments, the effect of drainage on seedling emergence was detected only negligibly in Exp. 1 and 2 at Nagaoka, probably due to low air temperature in Exp. 1 and high SWC in Exp. 2. In Exp. 1, the fall of soil temperature in drainage plots reduced seedling emergence, because seedling growth changes markedly in this temperature

Table 3. Effect of seed coating with calcium peroxide and water management on shoot dry weight of rice direct-sown into puddled and leveled soil (Exp. 3).

Treatment	Shoot dry weight (mg)				
	6 DAS	10 DAS	15 DAS	20 DAS	26 DAS
Flooding/- CaO_2 †	0.6 ^b	2.8 ^b	9.1 ^d	23.0 ^d	123.5 ^c
Flooding/+ CaO_2 ‡	1.7 ^a	4.3 ^a	17.6 ^b	44.4 ^b	199.5 ^b
Drainage/- CaO_2	0.5 ^b	2.3 ^b	14.7 ^c	34.3 ^c	198.7 ^b
Drainage/+ CaO_2	1.7 ^a	4.7 ^a	21.1 ^a	57.4 ^a	334.3 ^a

DAS, Days after sowing; †- CaO_2 , without seed coating; ‡+ CaO_2 , seed coating with calcium peroxide. Values are the mean of 6 plants. Figures followed by a different letter are significantly different at 5% LSD.

range (Maruyama and Tajima, 1986). This suggests that the effect of drainage on seedling emergence is less stable than that of seed coating.

Seed coating increases shoot and root length in flooded soil (Ota and Nakayama, 1970), and enhances leaf development in rice direct-sown into puddled and leveled soil (Hagiwara and Imura, 1993). Our results showed that seed coating increased the dry weight of shoots and enhanced seedling establishment. Our results also indicate that changes in plant length for coated seeds paralleled those for noncoated seeds after seedling emergence. Seed coating promotes coleoptile elongation in flooded soil, but not the development of green leaves or seminal roots (Mitsuishi, 1975). Morphological and anatomical aspects of seedlings germinated from coated seeds resemble those germinated under anaerobic conditions (Imura, 1986). This suggests that seed coating with CaO_2 improves seedling establishment by accelerating coleoptile elongation and seedling emergence.

Drainage after sowing promotes leaf development after seedling emergence (Furuhata et al., 1998), increasing plant length and dry weight and enhancing seedling establishment (Yamauchi and Chuong, 1995; Sato and Maruyama, 2002). Our results confirmed these effects of drainage on plant growth and seedling establishment, and showed that drainage rather inhibited shoot growth until seedling emergence, but markedly enhanced it after drained soil was flooded. Drainage after sowing thus improves seedling establishment by promoting plant growth mainly after seedling emergence. Drainage increases root length, number of roots and dry weight of roots at seedling establishment (Sato and Maruyama, 2002), therefore promotion of root development may relate the enhancement of shoot growth after seedling emergence.

Both seed coating and drainage after sowing enhance plant growth and seedling establishment (Sato and Maruyama, 2002). The effect of drainage appears to differ from that of seed coating. That is, seed coating accelerates early-phase seedling emergence, while drainage after sowing promotes seedling

emergence at a late stage (Sato and Maruyama, 2002). This finding is supported by our results. We also showed that seed coating enhanced shoot elongation during emergence, whereas drainage after sowing promoted it mainly after seedling emergence. Seed coating suppresses the development of soil reduction in the vicinity of the seeds direct-sown into puddled and leveled soil (Hagiwara et al., 1987), but drainage after sowing maintains high oxidation-reduction state in top soil, both in the vicinity of and outside seeds (Tanaka, 2000). Drainage also affects soil properties such as the compositions of three phases in soil and soil hardness (Furuhata et al., 1998). These factors may cause the difference between the effects of seed coating and drainage on plant growth during seedling establishment. Our results suggest that drainage after sowing does not substitute for seed coating and both seed coating and drainage after sowing are required to improve seedling establishment. In fact, we obtained the highest seedling establishment in seed coating plots subjected to drainage.

In conclusion, our results indicate that seed coating enhances plant growth during seedling emergence, whereas drainage after sowing promotes it mainly after seedling emergence. This suggests that seed coating accelerates seedling emergence, but drainage after sowing enhances seedling establishment. The physiological mechanism of growth enhancement by drainage thus appears to differ from that by seed coating. Further studies are therefore required to clarify the physiological mechanism of growth enhancement by drainage after seedling emergence.

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