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REVIEW

Developing Direct Seeding Cultivation Using an Air-Assisted Strip Seeder

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Abstract

We evaluated an air-assisted strip seeder, developed by the Hokuriku research center, in farmers' fields for four years. Plantings using the seeder had more panicles and a higher yield than those using a shooting hill-seeder. The early growth of planting using the air-assisted strip seeder was promoted by increasing the rate of seedling establishment because the seeding depth of plantings using the air-assisted strip seeder was shallower than that of plantings using the shooting hill-seeder. Tillering in this planting was also promoted, which boosted the yield, while simultaneous seeding with fertilizer application using the air-assisted strip seeder was also compared with conventional practice over two years in a field at the Hokuriku research center. During simultaneous seeding with fertilizer application, the rate of seedling establishment was equivalent to that in conventional practice. After seedling establishment, growth and yields in the simultaneous seeding with fertilizer application were equivalent to or exceeded those in conventional practice.

Discipline: Crop production
Additional key words: rice, seeding depth, seedling establishment, simultaneous seeding with fertilizer application, yield

Introduction

The Hokuriku research center has developed an air-assisted strip seeder (Chosa et al. 2009b, Fig. 1.) The seeding base width of the seeder is 10 m (base width of one side is 5 m.) The blower of the seeder conveys seeds to the injection ports; powered by the PTO of the tractor and can deposit seeds in rows with interval spacing of 30 cm. The effective field capacity is 2 ha/h, assuming a base speed of 0.8 m s^{-1} and field efficiency of 70%. Because the seeder allows planting of large fields, its technology may promote labor-saving and low-cost technologies for direct seeding culture in the near future.

In the mechanical transplanting method, a labor-saving technology for rice planting, involving the application of fertilizer or pesticide has already been developed, while in direct seeding culture, systematized techniques, such as seeding with fertilization or pesticide application, have also been introduced. In cultures using a shooting hill-seeder (Togashi et al. 2001a) and coated urea, technology simultaneously seeded with fertilizer application has been reported (Yoshinaga et al. 1997, Morita et al. 2005, Furuhata et al. 2006) In this technology, a decreased seedling emergence rate and delay in early growth was observed, compared with fertilizer incorporation into the plow layer (Furuhata et al. 2006) Furthermore, the runoff of nitrogen from the soil surface following basal dressing containing quick-acting

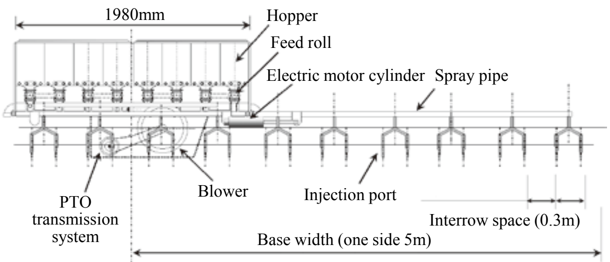

Fig. 1. Schematic diagram of air-assisted strip seeder

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components led to a decline in the dry matter production (Yoshinaga et al. 1997) Conversely, drainage management after seeding improved the seedling emergence rate and reduced the delay in early growth (Furuhata et al. 2006) The yield simultaneously seeded with fertilizer application was equivalent to that of conventional practice using basal dressing with a high slow-release component (Morita et al. 2005)

In this review, we will describe the results of culture using an air-assisted strip seeder in a farmer's fields over four years and the results simultaneously seeded with fertilizer application in a field of the Hokuriku research center over two years.

Materials and methods

Farmer's field experiments

We prepared calcium peroxide-coated seeds of the "Koshihikari" rice variety. Soil was puddled on the day before seeding, and the coated seeds were seeded with a shooting hill-seeder and air-assisted strip seeder in farmer's fields on May 1, 2008 and 2009; May 3, 2010; and May 9, 2011 respectively. The amount of sown seed was 2.5 g/m^2 of unhulled rice and we also measured the seeding operation capacity. A total of 4.4 g/m^2 of nitrogen (2.8 and 1.6 g/m^2 of basal and top dressing, respectively) was applied, plus 2.8 g/m^2 of phosphoric acid and potassium by basal dressing. Water management after seeding comprised post-drainage flood irrigation from the day of seeding for several days and intermittent irrigation before harvest time after midseason draining for approximately two weeks in late June. Pest control was applied as required. Frames of 50 × 50 cm were installed at six points in the experimental plot, and the seedlings in the frames were characterized for seeding depth, plant length, leaf age, top dry weight, and rate of seedling establishment 28 days after seeding in 2008 and 2009 and 30 days after seeding in 2010 and 2011, whereupon the yield and yield components were investigated by the following methods. Rice was harvested at maturity in areas covering 2.4 m^2 in three of the locations in the experimental plots, and the panicle number of the stubble was determined. All kernels were collected, including the empty grains during threshing, the grains were counted, and the spikelet numbers per m^2 and panicle were calculated. The yield (weight of brown rice) was measured for kernels with thickness exceeding 1.8 mm, and the percentage of ripened kernels was calculated from the spikelet number per m^2 and the number of brown rice kernels with thickness exceeding 1.8 mm. Thousand-kernel weight was calculated from the total kernels contained in approximately 20 g of brown rice, while the moisture content of the weight of brown rice and thousand-kernel weight was corrected to 15%.

Application of an air-assisted sowing machine to simultaneous basal dressing

The normal system is shown in Fig. 2. When applying simultaneous seeding with fertilizer using the air-assisted strip seeder, the injection port of this machine was moved to the right and left, and twin pairs of spraying systems were alternately deployed to spray seeds and fertilizer, respectively. Simultaneous seeding and fertilizing with the spread equipment was achieved by attaching the fertilizer injection port to the fertilizer spray system (Fig. 3.) Further, simultaneous seeding and fertilizing with the side-dress equipment was achieved by attaching the seed injection port to the fertilizer spray system (Fig. 4.) Calcium peroxide-coated seeds of the "Koshihikari" rice variety were prepared. In the field of the Hokuriku research center, the soil was puddled a day before seeding, and coated seeds were seeded with the air-assisted strip seeder on May 12, 2010 and May 11, 2011. The amount of sown seed was 3 g/m^2 of unhulled rice. LPS60 (60-day sigmoidal-release-type coated urea) was used as base manure (N component, 3 g/m^2), and simultaneous seeding with fertilizer application (spreading, S), simultaneous seeding with fertilizer application (side-dressing, SD), and conventional practice (CP), comprising pre-puddling fertilization and post-plowing leveling, were prepared. Water management after seeding consisted of flood irrigation after drainage from the day of seeding for

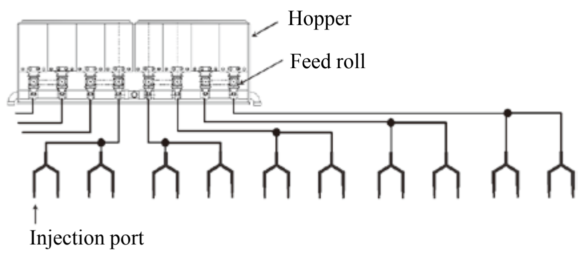

Fig. 2. Schematic diagram of normal system

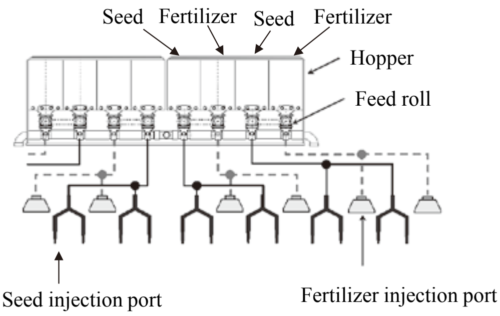

Fig. 3. Schematic diagram simultaneous seeding and fertilizing with the spread equipment

several days and intermittent irrigation before harvest time after midseason draining for approximately two weeks in late June. Pest control was performed as required. Frames of 50 × 50 cm were installed at three locations within the experimental plot, and seedlings within the frames were characterized for the seeding depth, plant length, leaf age, top dry weight, and rate of seedling establishment on the 30th day after seeding. We measured the panicle number, wet weight of culm, culm length, and pushing resistance at 15 cm above ground and approximately two weeks after heading, with three replicates of 12 hills per plot. We also calculated the lodging index [(culm length × wet weight of culm)/(15 × pushing resistance per culm)] (Seko 1962, Terashima et al. 1992, Terashima et al. 2002), taking it as an index of lodging resistance. The methods of investigating the yield and yield components in this experiment were in line with those used to investigate the farmers' field test.

Results and discussion

Farmer's field experiments

The operation of seeding with the air-assisted strip seeder and the early growth of both the culture planted by the air-assisted strip seeder and that planted by the shooting hill-seeder in the farmer's field can be seen in Fig. 5. The left figure depicts the seeding operation, and the right figure depicts the farmer's field approximately one month after seeding. The plots sown with the air-assisted strip seeder and the shooting hill-seeder are located to the left and right of the pole respectively. The early growth in the plot sown with the air-assisted strip seeder was more vigorous than that of the plot sown with the shooting hill-seeder. Generally, the final seedling establishment rate was inversely proportional to seeding depth, while the rate of seedling establishment in the plot sown with the air-assisted strip seeder exceeded that of the plot sown with the shooting hill-seeder for its shallower seeding depth (Table 1.) The top dry weight, plant length, and leaf age of the plot sown with the air-assisted strip seeder tended to be greater. These results suggested that the early growth of the plot sown with the air-assisted strip seeder exceeded that of the plot sown with the shooting hill-seeder.

The yield and yield components in the two plots were investigated over four years in farmers' fields (Table 2.) In the plot sown with the air-assisted strip seeder, the total number of grains tended to increase with the increase in panicle number, meaning the weight of the brown rice tended to exceed that of the rice in the plot sown with the shooting hill-seeder.

We evaluated the labor effectiveness of seeding using the air-assisted strip seeder (Table 3.) The field efficiency was 35.9–58.5% over the four years from 2008 to 2011 because the theoretical field capacity was 2.34 ha/h and the effective field capacity 0.84–1.37 ha/h during the same period. The fact that the effective field capacity was less than 60% of the theoretical capacity was attributable to the time required to turn the seeder in the field, load it with seed, inspect it before seeding, and address operational problems. Considering a value of 0.26 ha/h measured as

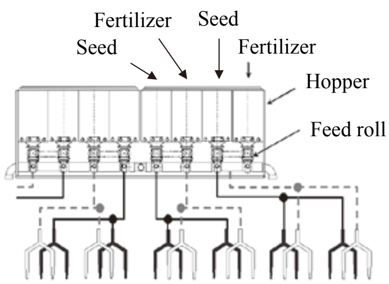

Fig. 4. Schematic diagram of simultaneous seeding and fertilizing with the side-dress equipment

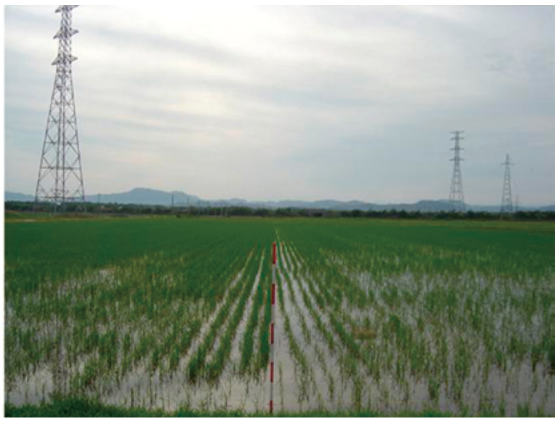

Fig. 5. The picture of seeding and early growth at a farmer's field
Left picture: seeding. Right picture: early growth (On the left side of the pole is an air-assisted strip seeder and on the right,a shooting hill-seeder.)

Table 1. The seedling emergence and establishment of direct seeded rice in a farmer's field

Coating material · method of seeding	Rate of seedling establishment (%)	Seeding depth (cm)	Top dry weight (g/m^2)	Plant length (cm)	Leaf age
CaO_2 · air-assisted strip seeder	71.1	0.39	1.8	15.8	4.8
CaO_2 · shooting hill-seeder	51.6	0.63	1.1	14.8	4.4
t-test	*	*	ns	ns	*

Values reflect the average for 4 years (2008 – 2011). *: Indicates significant differences at 5 % level by t-test. ns: Indicates no significant differences at 5 % level by t-test.

Table 2. Yield of direct seeded rice in a farmer's field

Coating material · method of seeding	Heading time (m/d)	Weight of brown rice (g/m^2)	Panicle number (/m^2)	Spikelets number per panicle (grain)	Total number of grains (×K grain/m^2)	Percentage of ripened grains (%)	Thousand kernel weight (g)	Brown rice nitrogen concentration (%)
CaO_2 · air-assisted strip seeder	8/10	605	416	80	33.1	80.2	22.9	1.28
CaO_2 · shooting hill-seeder	8/10	548	315	85	27.6	86.2	23.2	1.26
t-test		ns	*	ns	ns	ns	ns	ns

Values reflect the average for 4 years (2008 – 2011). Values by weight of brown rice were measured with a grain thickness exceeding 1.8mm. *: Indicates significant differences at 5% level by t-test. ns: Indicates no significant differences at 5% level by t-test.

Table 3. Analysis of labor effectiveness

Year		2008	2009	2010	2011
Short side of the field	m	38	40	30	40
Long side of the field	m	125	122	116	125
Area	m^2	4750	4880	3480	5000
	ha	0.475	0.488	0.348	0.500
Seeding base width	m	10	10	10	10
Base speed	m/s	0.68	0.68	0.68	0.68
Working hours	h	0.38	0.49	0.42	0.37
Net working hours	h	0.22	0.20	0.19	0.21
Average operating speed	m/s	0.654	0.654	0.662	0.660
Average width		9.1	10.3	7.2	9.5
Slip ratio	%	3.64	3.64	2.40	2.14
Theoretical field capacity	ha/h	2.34	2.34	2.34	2.34
Calculated field capacity	ha/h	2.15	2.43	1.78	2.42
Effective field capacity	ha/h	1.24	0.99	0.84	1.37
Capacity	h/ha	0.81	1.01	1.19	0.73
Field efficiency	%	53.0	42.3	35.9	58.5
Calculated field efficiency	%	57.7	40.7	47.2	56.6

an example of effective field capacity, the effective field capacity of the air-assisted strip seeder was approximately four times (3.2–5.3 times) that of a commercial row seeder (Chosa et al. 2009a) For a puddling operation compatible with the labor effectiveness of the seeding operation using the air-assisted strip seeder, the effective field capacity of the 75 PS tractor (with a puddling rotor with base width 4.1 m) is 0.86–1.5 ha/h (Japan Agricultural Mechanization

Association 2009a) If the daily duration of puddling is assumed to be 9 h, the workable puddling area using this machine the day before seeding is 7.7–13.5 ha. These estimates suggested that introduction of several tractors and puddling rotors should be considered for a farm managing more than 10 ha of paddy fields.

For a harvesting operation compatible with an appropriate reaping period in the culture using an air-assisted strip seeder, the effective field capacity of head feeding combined (and 6 row reaping type with grain tank) is 0.15–0.96 ha/h (Japan Agricultural Mechanization Association 2009b) If the daily reaping duration is assumed to be 6 h, the workable reaping area using this machine and one variety is 6–40 ha for the appropriate reaping period, which suggest that the introduction of several varieties should be considered for a farm managing more than 25 ha of paddy fields. Simulation by linear programming, assuming the first puddling a few days before seeding and the second puddling on the day before seeding, showed the potential for direct seeding over an area of at least 50 ha for puddling just before seeding using two or three tractors and four rice varieties (Shioya et al. 2011)

Application of an air-assisted sowing machine for simultaneous basal dressing

Virtually uniformly fertilizer application was observed in S, and a trace of fertilizer on the soil surface (resembling a belt along a row) was observed in SD.

The influence simultaneously seeded with fertilizer application on the emergence and establishment of seedlings in a plot sown with the air-assisted strip seeder is described in Table 4. The rate of seedling establishment showed no significant difference between three plots and two simultaneously seeded plots with fertilizer application were almost equal to that of CP. At one month after seeding, the top dry weight between two plots simultaneous seeded with fertilizer application and CP differed, but not the leaf age and plant length. In addition, the decrease in yield was not attributable to any difference between the two in top dry weight during the early growth period. Fertilizers in two simultaneously seeded plots with fertilizer application were distributed in high concentrations around the seed compared with that in CP, but the emergence and establishment of seedlings remained undisturbed due to the slow elution of the fertilizer, which was a sigmoid-type coated urea.

Growth in two simultaneously seeded plots with fertilizer application was compared with that of CP after seedling establishment (data not shown, Furuhata et al. 2014) Growth in the two simultaneously seeded plots with fertilizer application exceeded that observed in CP. Furthermore, many roots were distributed on the surface layer of soil when cultivating direct-seeded flooded paddy field compared with culture by transplanting. These results suggested that the high concentration of fertilizer near the root increased the fertilizer effect (Fig. 6) and consequently dry matter production.

The influence simultaneously seeded with fertilizer application on yield and the yield components in the plot sown with the air-assisted strip seeder is described in Table 5. The yield and yield components showed no significant difference between the three seeding methods, but two plots simultaneously seeded with fertilizer application showed a tendency equal to or exceeding CP in terms of the total number of grains and weight of brown rice, while the lodging index showed no significant difference among the three plots. The results of these experiments showed that the rate of seedling establishment in simultaneous seeding with fertilizer application was equivalent to that in CP. After seedling establishment, growth and yield in simultaneous seeding with fertilizer application were equivalent to or exceeded those in CP. Furthermore, we concluded that the technology involving simultaneous seeding with fertilizer application using the air-assisted strip seeder was a labor-saving and effective cultivation method, since it eliminated the need for basal dressing before seeding.

The problem to be solved regarding culture using the air-assisted strip seeder is securing the seeding depth under different seeding conditions. The seeding depth of

Table 4. Influence of simultaneous seeding with fertilizer application on the early growth of direct seeded rice

Method of fertilizer application	Number of seedling establishment (population number/m^2)	Rate of seedling establishment (%)	Seeding depth (cm)	Top dry weight (g/m^2)	Plant length (cm)	Leaf age
Conventional practice (CP)	124a	92.9a	0.79a	6.1a	20.2a	5.7a
Spreading (S)	102a	78.4a	0.89a	5.5ab	19.2a	5.7a
Side dressing (SD)	113a	84.8a	0.90a	4.5b	19.3a	5.6a

Values reflect the average for 2 years (2010 – 2011). Means followed by same letters do not differ significantly at the 5% level by Tukey test (n = 6).

the air-assisted strip seeder in this study was shallower than that of another seeder reported in a different study (Togashi et al. 2001b, Nishimura et al. 2003) By focusing on this characteristic, we evaluated the culture using iron- coated seeds requiring surface sowing (Furuhata et al. 2009a, 2009b, 2010) With regard to the seeding depth under different seeding conditions, the seeding depth was reportedly 3 mm on puddling on the day before seeding in the culture using the air-assisted strip seeder at the Nagano agricultural experiment station (Aoki et al. 2010) which was shallower than the 8.4–10.9 mm (Furuhata et al. 2007), 5.5 mm (Furuhata et al. 2009a), and 14 mm (Chosa & Furuhata 2009) in another report. This difference was considered attributable to two factors: varying soil texture and days from puddling to seeding. With regard to controlling the seeding depth of the air-assisted strip seeder, the speed at which the seed fell from the injection port was reportedly slower than that of the shooting hill-seeder, and closing the tip parts of the injection port of the air-assisted strip seeder caused the air flow and carrying capacity of materials to decline as well as air-flow turbulence in the tip parts of the injection port (Chosa et al. 2009b) Considering these reports, the seeding depth using the air-assisted strip seeder differed in soils with different soil textures and the days from puddling to seeding. In future, we should improve the puddling method to secure stable seeding depth and ensure smooth airflow smooth by improving the injection port.

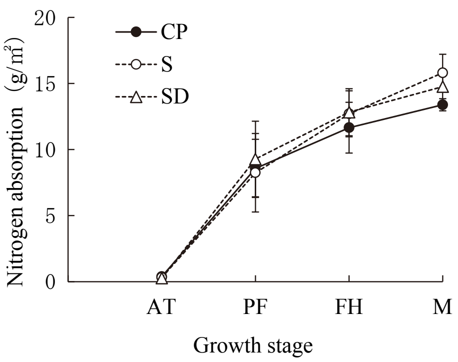

Fig. 6. Influence of simultaneous seeding with fertilizer application on the nitrogen absorption

AT: active tillering stage, PF:panicle formation stage, FH: full heading date, M:maturation stage. Error bars represent standard errors (n=3). Edited from Furuhata et al. 2014

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Table 5. Influence of simultaneous seeding with fertilizer application on the yield of direct seeded rice

Method of fertilizer application	Heading time (m/d)	Culm length (cm)	Weight of brown rice (g/m²)	Panicle number (/m²)	Spikelets number per panicle (grain)	Total number of grains (×K grain/m²)	Percentage of ripened grains (%)	Thousand kernel weight (g)	Brown rice nitrogen concentration (%)	Lodging index
Conventional practice (CP)	8/14	91.1a	548a	381a	74a	28.0a	90.5a	21.6a	1.26a	1.07a
Spreading (S)	8/14	92.1a	563a	374a	78a	29.0a	90.0a	21.5a	1.26a	0.95a
Side dressing (SD)	8/14	90.2a	552a	396a	73a	28.9a	89.3a	21.4a	1.29a	1.13a

Values reflect the average for 2 years (2010 – 2011). Values by weight of brown rice were measured with a grain thickness exceeding 1.8 mm.

Means followed by same letters do not differ significantly at the 5% level by Tukey test (n = 3).

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