A New Direct Seeding Culture of Rice in Hokkaido

—Its characteristics and stabilization of seedling establishment—

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Historically rice cultivation in Hokkaido started about 100 years ago by adopting a submerged nursery system. A method of direct seeding in submerged fields devised in 1893 made it possible to cultivate rice in further northern areas which were regarded as northern limit of rice cultivation with less than 2,400°C of accumulated air temperature from May to September. In 1905, a primitive machine for direct seeding was devised and spread rapidly owing to its high efficiency of seeding which makes widening of sowing season and getting enough number of panicles possible. In 1932, the area of direct seeding culture reached 82% of 196,000 ha of paddy field in Hokkaido. Rice cultivation in Hokkaido, however, suffered frequently from cool-weather damage in early 1930's. The occurrence of such damage stimulated the improvement of transplanting culture by the use of protected nursery beds. This system was proved to be effective in stabilizing rice cultivation against cool weather damage.[16]

Thus, the problem of rice cultivation in Hokkaido is (1) how to overcome cool-weather damage and (2) how to reduce production cost and labor.

A new direct seeding culture system of rice named "Compromise direct seeding culture" was developed by the authors. This system is the combination of direct seeding to dry fields** and much earlier start of ponding irrigation than in the traditional direct seeding to dry fields. This new method was found to be effective in overcoming the instability and low productivity of the conventional direct seeding in submerged fields. We started to study this new culture method in 1974 and recognized a variety of advantages such as better seedling establishment, better early growth, more lodging resistance and higher productivity, although some problems still remain to be solved. For example, rice varieties adaptable to this method are needed.[4,8]

Characteristics of the new direct seeding culture system

To obtain sufficient vegetative growth by good and stable seedling emergence and establishment is most important in direct seeding in Hokkaido.[12]

It was thought that direct seeding to submerged fields is better than seeding to dry fields, because in the former the effect of preserving heat by irrigated water is available. It was also pointed out that the direct seeding to dry fields was practicable only in areas with yearly mean air temperature more than 12°C.[11]

The proposed new method of direct seeding has merits of both methods, i.e. direct seeding to dry fields and that to submerged fields. As given in Fig. 1, after plowing, fertilizing, and land preparation of dry fields, rice seeds coated with CaO_2, an ozygen supplier, are directly sown. Unlike the traditional direct seeding to dry fields in which irrigation water is supplied at the 4 to 5-leaf stage of the seedlings (about 20–30 days after seeding), the new method makes dry field submerged only 10–15 days after seeding. By doing so the merit of submerged

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** Dry fields in this paper express paddy fields under the condition not submerged by irrigation water.

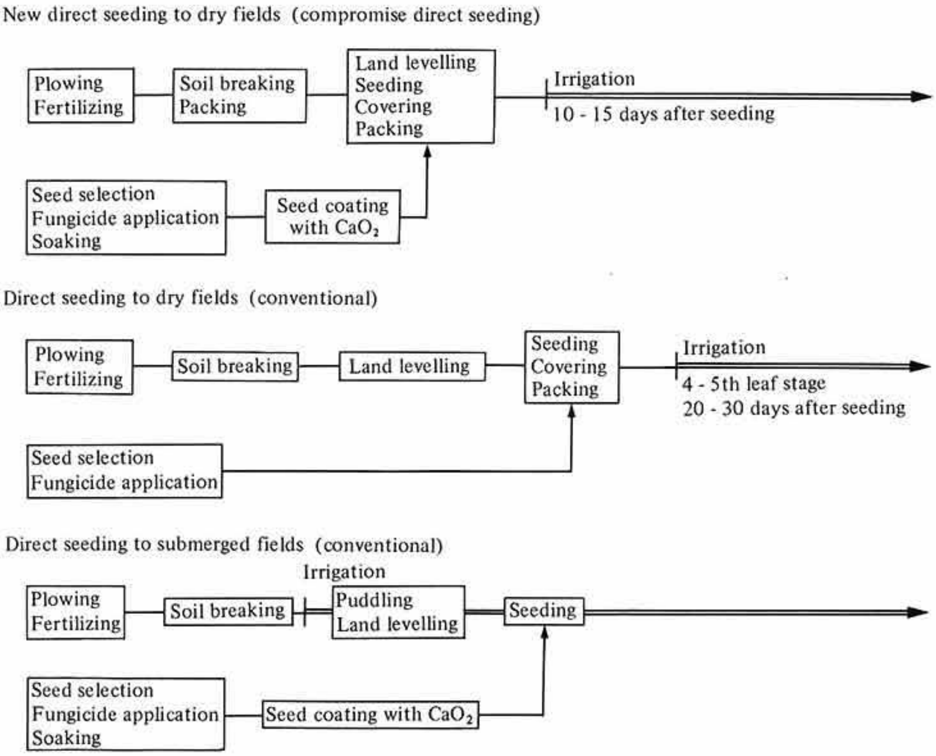


Fig. 1. Farm process of the new direct-seeding method and conventional direct-seeding methods

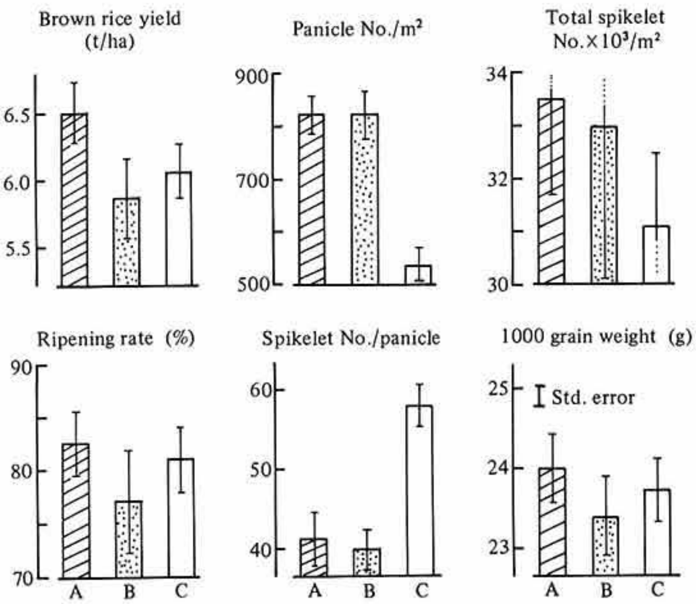
field to preserve heat for seedling growth can be obtained. On the other hand, the seeding to dry fields allows the use of big machines for seeding, resulting in labor saving and cost reduction. In addition, the use of CaO_2 makes earlier seeding and adequate soil covering possible. The oxygen supply promotes germination, makes seedling establishment stable, and causes lodging resistance of plants, because it permits adequate depth of soil covering on sown seeds. Plumules grow very slowly and they apt to be suffered from putrefaction under low temperature in submerged fields, whereas the plumules of seeds coated with CaO_2 and sown in dry fields continue to grow and soon come to be protected by submerging water from lowering of soil temperature.

The new direct seeding culture showed higher yield than the young seedling transplanting culture as shown in Fig. 2.[13] The higher yield of the new direct seeding culture was also recognized over a wide range of mean air temperature during the growing period in 1974–1984 (Fig. 3).

Effect of CaO₂, an oxygen supplier on seedling establishment

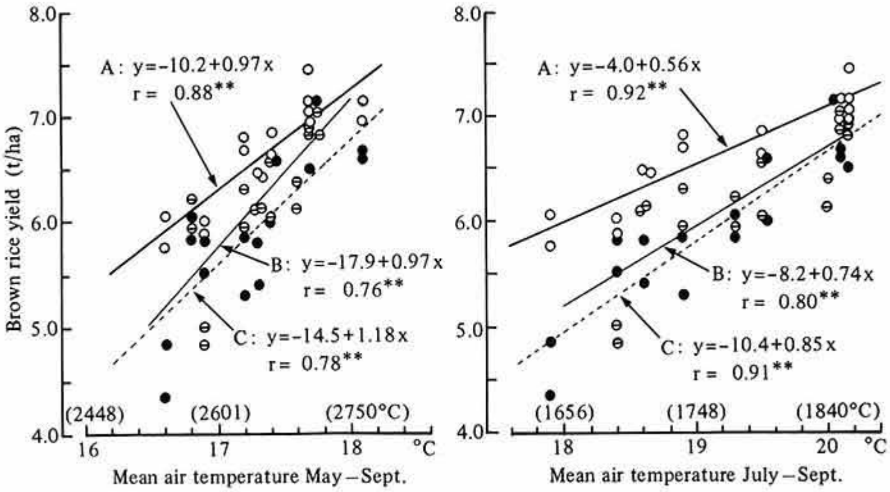
Inhibition of germination and root respiration caused by oxygen defficiency in soils is well known.[10] Yamada[18] found out that calcium peroxide can be used effectively to supply oxygen to plants under water. Later the use of CaO_2 in the form of a coating material was devised[14] by mixing gypsum with CaO_2. The product gives highly uniform coating, and makes a large scale treatment by machine possible.[1,2]

As mentioned above, seedling establishment is a major limiting factor in direct seeding culture in cool regions. Fig. 4 shows that seeds coated with CaO_2 (commercial "Calper" containing 37.5% of CaO_2, Hodogaya Chemical Co. Ltd.) gave more than 80% of seedling establishment over a range of 5–20



A : New direct-seeding to dry fields
B : Direct-seeding to submerged fields
C : Young seedling transplanting

Fig. 2. Grain yield and yield components in different culture methods of rice
Mean values for 7 years from 1974 to 1980. Accumulated mean temperature and sunshine duration in the period from May to September were 2697±89°C and 877±114 hr.



A : New direct-seeding culture to dry fields (○)
B : Direct-seeding culture to submerged fields (⊖)
C : Young seedling transplanting culture (●)

Fig. 3. Relation between mean air temperature and rice yield in different culture methods (1974-1984)

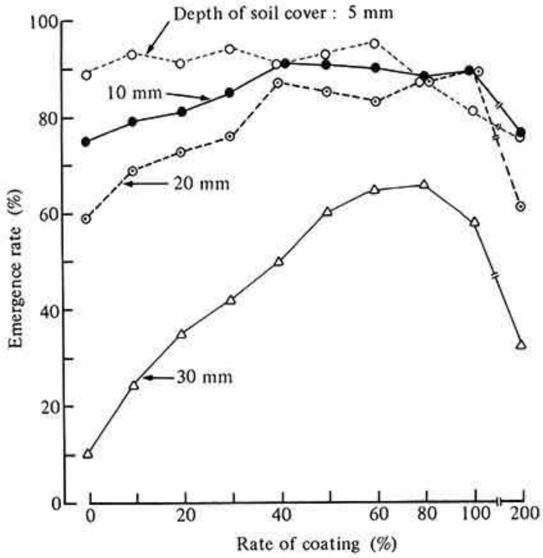


Fig. 4. Effect of seed-coating with CaO_2 on emergence rate of rice seedlings
Seeds soaked in water at 12°C for 6 days were coated with "Calper" at different rates to the weight of the soaked seeds.

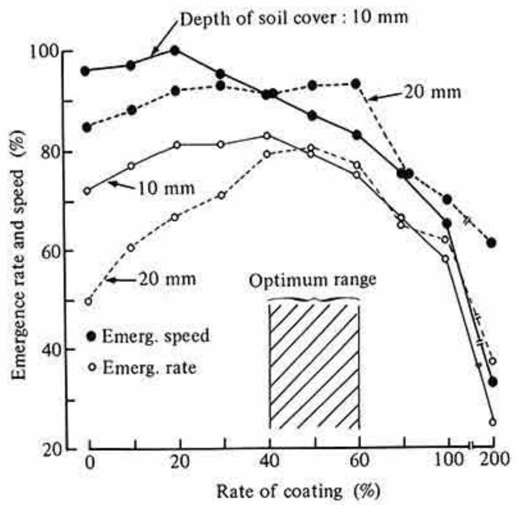


Fig. 5. Effect of seed-coating with CaO_2 on emergence percentage and emergence rate
Emergence rate: Percentage of no. seedlings emerged by the 14th day after seeding to the final no. seedlings emerged.

mm of cover soil. The optimum amount of Calper used for coating was 40–60% of the weight of soaked rice seeds, although it depends upon the depth of cover soil (Fig. 5).

Seeding time and seedling establishment

To obtain the sufficient magnitude of vegetative growth not to cause delayed flowering in cool regions, seeding must be done as early as possible. Minimum temperature for rice germination is known to be 10–13°C. The temperature lower than that delays germination and bud growth resulting in poor seedling establishment, and causes seedling rot. The safety limit of early sowing in the direct seeding to submerged fields is 11.5°C of the mean air temperature, considering the risk of temperature lowering to below 10°C. It corresponds to the middle of May in central Hokkaido.[17] In tne new direct seeding to dry fields, however, earlier sowing is possible because low-temperature damage as occurring in submerged fields is avoided. Fig. 6 shows effects of seeding time, seed soaking and coating, and depth of soil cover on seedling emergence (tests conducted in 1976–1978). Earlier seeding in the period with mean air temperature of 8.2 ± 2.5°C (April 27–May 7) gave higher emergence rate than the later seeding even without seed coating. In another experiment done in a cool year, the optimum amount of coating in earlier seeding was 20–30% of soaked seed weight while that in late seeding was 50%.[3] Effect of seed coating was more remarkable in the late seeding.

Effect of temperature on plumule elongation

Hanyu et al.[7] and Saito[15] studied effects of temperature on growth of rice seedlings in direct seeding in cool regions. By applying their methods, relation between temperature and plumule elongation was examined in the submerged condition and the dry field condition in the laboratory (Figs. 7 and 8)

Under the dry field condition, seeds were placed under soil cover of 10, 20 and 30 mm in depth, and soil moisture content was adjusted to 50–70% of the

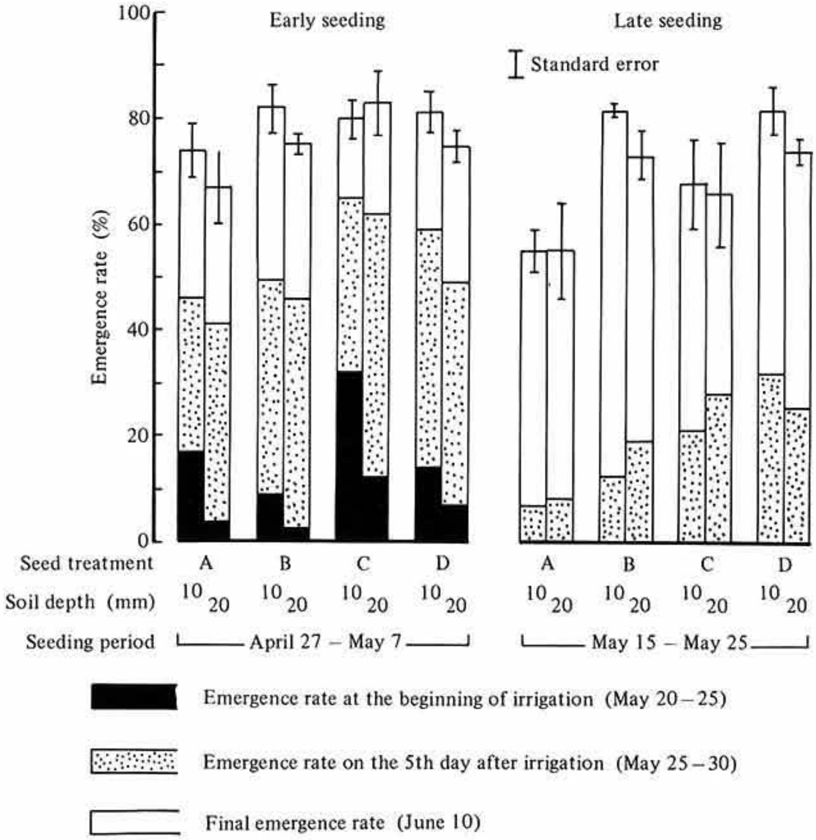


Fig. 6. Effect of seeding time, seed soaking and seed coating on emergence rate

A: Dry seeds without seed coating, B: Dry seeds treated with Calper at the rate of 50% weight of the dry seeds, C: Seeds soaked at 12 °C for 6 days and no coating, D: Soaked seeds treated with Calper at the rate of 50% weight of the soaked seeds.

Mean air temperature 8.2±2.5 °C, maximum air temperature 13.7±3.5 °C from April 27 to May 7 and 11.9±3.5 °C and 17.6±4.6 °C from May 15 to 25 respectively.

field capacity of the soil, while under the submerged condition seeds were placed on the soil surface under water. An empirical formula showing the relationship between temperature and the length of time required for plumules to reach certain length (5-30 mm) was obtained.

$$A=T/(a+bT)$$

A: Length of time (days) required for plumule elongation

T: Temperature (°C)

In case of 10 mm depth of soil cover in a dry field,

$$A=T/(0.498T-5.74)$$

was obtained (Fig. 7). In this equation $T \geqq 11.5$°C in dry field and $T \geqq 12.5$°C under submergence are necessary. The coefficient between temperature and plumule elongation velocity changes depending upon the temperature. The minimum value of A(day) × T(°C) indicates that the most effective growth of plumule is attained, which was at 22-25°C under the dry field condition and 24-27°C under submergence. Hanyu et al.[6] called the coefficient the "effective temperature coefficient". At

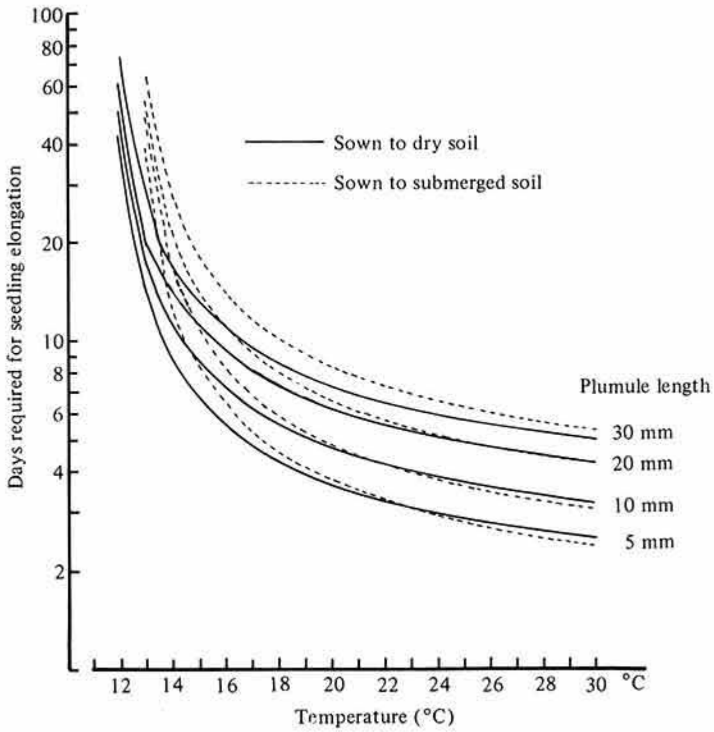


Fig. 7. Relation between temperature and the time required for elongation of plumule to certain length

Time required for plumule elongation is expressed by the following empirical formulae.

	Sown to dry soil with soil cover of 10-30 mm	Sown to soil surface under submergence
Plumule length	30 mm $A=\frac{T}{0.323T-3.72}$	30 mm $A=\frac{T}{0.315T-3.91}$
	20 mm $A=\frac{T}{0.373T-4.26}$	20 mm $A=\frac{T}{0.399T-4.95}$
	10 mm $A=\frac{T}{0.498T-5.74}$	10 mm $A=\frac{T}{0.554T-6.93}$
	1 mm $A=\frac{T}{0.643T-7.43}$	1 mm $A=\frac{T}{0.715T-8.96}$

where A=No. of days required, T=constant temperature (°C) of incubation.

about 25°C, the coefficient becomes the maximum. By taking the maximum coefficient at 25°C as 1, the effective temperature coefficient (a) for each temperature was calculated by the following equation:

$$a=A_{25}\times T_{25}/A\times T$$

As shown in Fig. 8, the effective temperature coefficient was larger in the dry field than in submerged field at temperatures below 25°C. It indicates that the submerged condition is less favorable for emergence than the dry field condition at low temperatures. Table 1 shows $A_{25} \times T_{25}$ as influenced by the depth of soil cover.

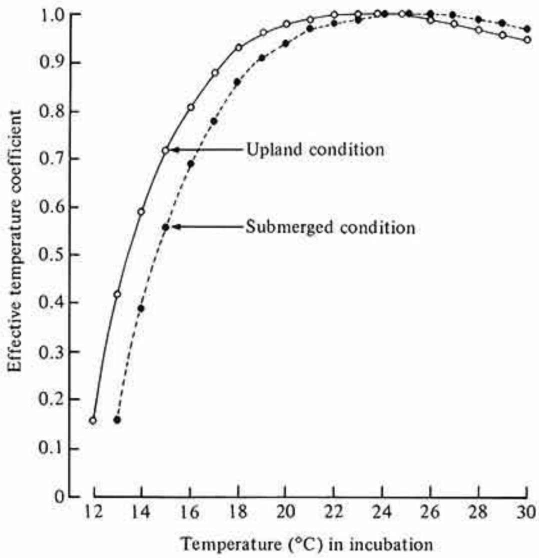


Fig. 8. Effective temperature coefficient for plumule elongation at different temperatures
Effective temperature coefficient= (minimum value of A×T)/(A×T at a given temperature)

Table 1. Relation between depth of soil covering over seeds and effective accumulated temperatuer required for plumule emergence

Depth of cover soil (mm)	Time required[a] for emergence A (day)	Temperature[b] T (°C)	Effective accumulated temperature A×T (°C)
30	5.75	25	144
20	4.94	25	124
10	3.73	25	93
5	2.89	25	72

a) Obtained from Fig. 7.
b) At 25 °C, the value of A×T showed the minimum.

Relationship between air temperature and effective temperature in plumule elongation

Seeds in soil are exposed to daily and diurnal temperature changes. Hanyu et al.[5,6] suggested from the analysis of the pattern of diurnal temperature changes in northern Japan that the duration of each temperature range in a day could be calculated

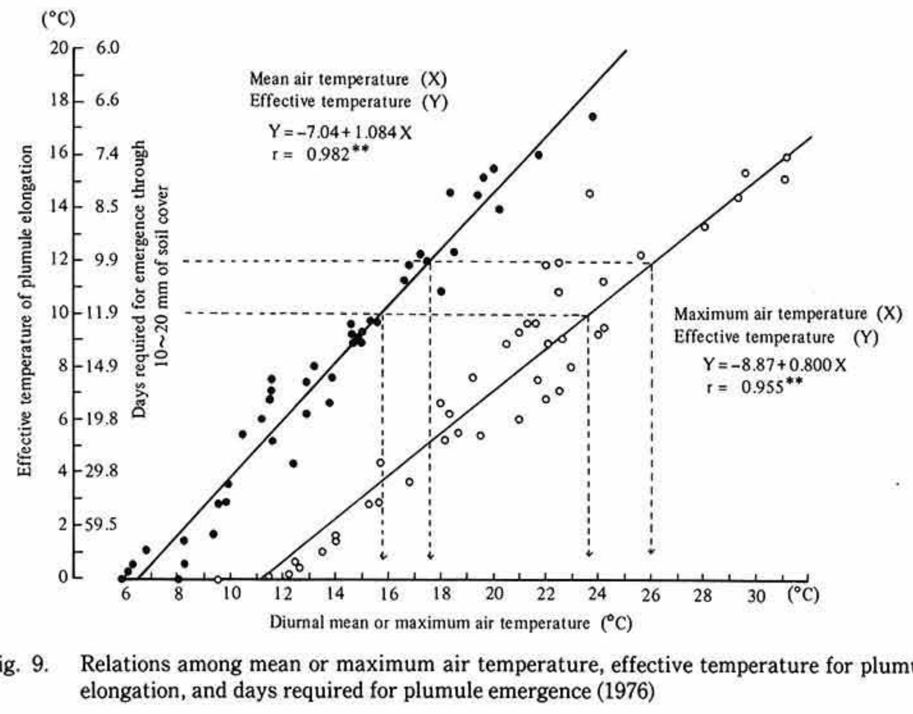


Fig. 9. Relations among mean or maximum air temperature, effective temperature for plumule elongation, and days required for plumule emergence (1976)

from the data of maximum and minimum temperature. When an air temperature change in a day is expressed by different temperature ranges (θ_a, θ_b, $\theta_c \cdots\cdots \theta_k$), duration ($T_a$, T_b, T_c, $\cdots T_k$ in terms of a fraction of a day) of each θ, and the effective temperature coefficient for plumule elongation (a_a, a_b, $a_c \cdots a_k$) for each θ, the effective temperature (θ^*) for that day is calculated as follows:

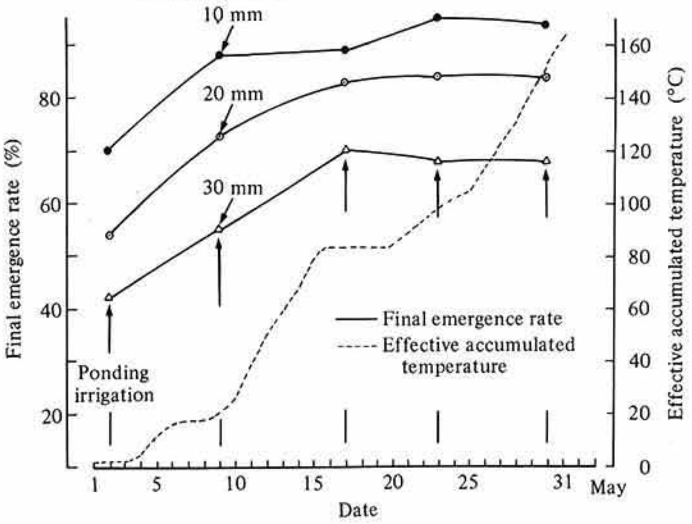
$$\theta^*=(a_a\theta_a T_a)+(a_b\theta_b T_b)+(a_c\theta_c T_c)+\cdots\cdots(a_k\theta_k T_k)$$

Similarily, the effective accumulated temperature for a given period can be calculated as an integrated θ^* against that period. The value of a is given in Fig. 8. In the calculation, θ is expressed by the average temperature of each temperature range.

As shown in Fig. 9, linear regressions were found between the effective temperature and mean or maximum temperature, and between the number of days required for plumule elongation through 10–20 mm of soil cover and each of the above temperatures. Therefore, the number of days required for plumule emergence can be predicted by diurnal mean or maximum temperature. At the diurnal mean temperature of 16–18°C or maximum temperature of 24–26°C, the number of days required for the plumule emergence is 10–12 days after seeding. In practice, seeding is possible, when the mean and maximum temperature attains 10–12°C and 18–20°C, respectively, because of the warming effect of irrigation water by 6.6±3°C.

Effect of starting time of irrigation, water depth and soil crushing on seedling establishment

To decide when ponding irrigation should be started in the dry fields after the direct-seeding, the relation between the rate of seedling establishment



Air temperature for 10 days after flooding

Period	May 2–11	9–18	17–26	June 23 -July 1	June 30 -July 8
Max. air temp. (°C)	15.9±6.6	19.8±7.5	14.5±5.1	20.4±3.3	23.5±2.2
Mean air temp. (°C)	9.3±3.9	11.6±4.8	8.9±3.3	14.3±2.8	17.7±1.5

Fig. 10. Final emergence rate as influenced by different depth of soil cover and time of starting flooding irrigation

Soaked seeds coated with Calper (at 50% of soaked seed weight) were sown under soil cover of different depth on April 30, and final emergence rate was observed on June 10, 1977.

and effective accumulated temperature during the dry field condition, and temperature during about 10 days after seeding were examined (Fig. 10). Under the soil cover of 10-20 mm in depth the final emergence rate of about 80% was obtained by starting irrigation when the maximum and mean temperature became about 20 and 12°C, respectively. In case when the effective accumulated temperature after seeding attained 80°C, the start of irrigation at an earlier date with maximum and mean temperature lower than the above ones, namely, 15 and 9°C, respectively, caused no decrease in the emergence rate. Bud growth in dry fields is an important factor for the seedling establishment.

Five cm is the optimum depth of water. Deeper water such as more than 7 cm lowered the rate of seedling establishment (Fig. 11).

Degree of soil clod crushing also influenced seedling establishment. Sufficient crushing (clods

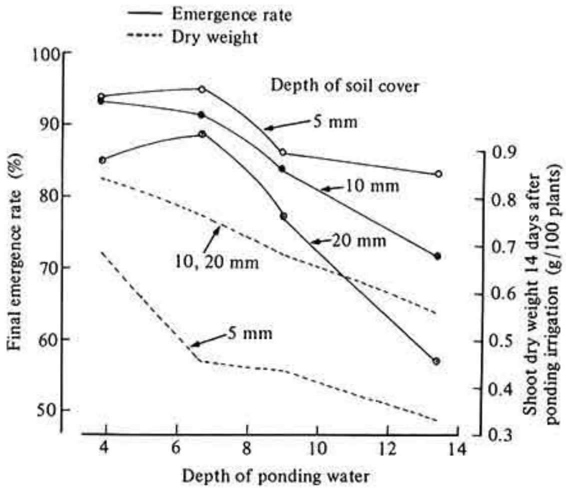


Fig. 11. Relation among emergence rate, depth of cover soil and depth of water
Seeds treated as in Fig. 10 were seeded on May 15. Irrigation began on May 24, 1977.

Table 2. Effect of seeding time in the new direct seeding system on emergence rate, growth, and yield of rice[a)]

Year (Accumulated temp.)[b)]	Seeding time	Mean temp. for 5 days after seeding (°C)	Final emergence (%)	Plant dry weight at panicle formation stage (kg/ha)	Flowering time	Ripening time
1976	New system					
(2579°C)	April 28	8.8	84.3	2280	Aug. 4	Sept. 28
	May 6	9.3	81.0	1380	Aug. 7	Sept. 30
	May 15	14.3	75.8	980	Aug. 12	Oct. 3
	Transplanted[c)]	—	—	—	Aug. 5	Sept. 27
1978	New system					
(2834°C)	April 27	9.4	81.3	2180	July 28	Sept. 14
	May 16	13.5	73.0	1770	July 31	Sept. 17
	Transplanted	—	—	—	July 27	Sept. 15

Year	Seeding time	Grain yield (t/ha)	Panicle No./m²	Spikelet No. /panicle	Spikelet No. $\times 10^3/m^2$	Ripening rate (%)	1000 grain weight (g)
1976	New system						
	April 28	5.80	702	38.6	27.0	87.5	24.6
	May 6	5.87	717	39.0	27.9	85.0	24.8
	May 15	5.14	721	39.4	28.4	76.8	24.0
	Transplanted	5.52	488	56.1	27.4	88.8	23.2
1978	New system						
	April 27	6.70	837	42.2	35.3	80.3	23.7
	May 16	6.30	704	47.4	33.4	77.7	24.3
	Transplanted	6.06	440	61.5	27.7	85.4	24.7

a) Rice variety used: Ishikari in 1976. Kitaake for new direct seeding culture and Ishikari for transplanting culture in 1978.
b) Sum of mean air temperature from May to September.
c) Young seedling at the 3rd leaf stage.

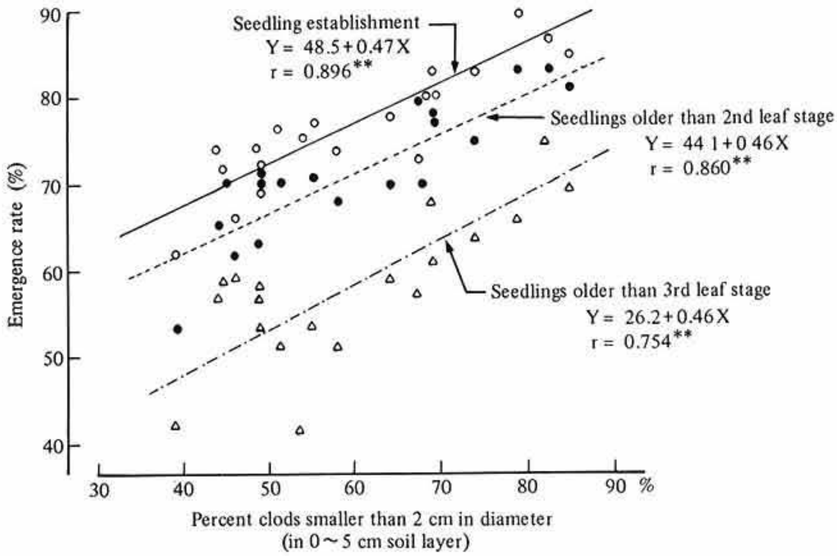


Fig. 12. Relation between clod size and final emergence rate on the 27th day after irrigation

Seeds coated with Calper (at 80% of soaked seed weight) were sown in light clayey soil.

with diameter less than 2 cm exceed 60–70% in volume) is desirable.

Effect of earlier seeding

Although a possible seeding period is from April 25 to May 20, earlier seeding is desirable for higher grain yield, as shown in Table 2. The earlier seeding increased the rate of seedling establishment, promoted heading, and consequently gave higher yields, even in comparison with the young seedling transplating culture by machine, due to increased ripening in a cooler year 1976, and to increased grain number in a warmer year 1978.

The earlier seeding solved the largest problem, namely, growth delay. When the seeding is finished before May 7, the time of emergence nearly corresponds to the season of transplanting young seedlings and no delay of heading was observed compared with transplanting culture.

In this experiment a variety "Ishikari" was used. Earlier varieties are desirable in areas with cool climate in early spring. At present, earlier varieties "Kitaake" and "Tomohikari" are more suitable than Ishikari in getting stable, high productivity.

Conclusion

A new direct-seeding culture of rice named "compromise direct-seeding culture of rice", which suits the cool climate of Hokkaido, and shows higher grain yields with less labor and cost than other methods of rice cultivation so far practiced in Hokkaido was developed.

In the present paper, salient characteristics of the new system are described and advantages of this system are analized in detail.

1) The new direct seeding culture system developed by the authors consists of direct seeding of paddies coated with an oxygen supplier (CaO_2) to dry fields (not submerged), and ponding irrigation started 10–15 days after the seeding. The seeding to dry fields can avoid many troubles associated with the seed germination and seedling growth under water at low temperature, such as seed putrefaction and poor seedling establishment. The use of CaO_2 for coating seeds before seeding enhanced such effectiveness of the direct seeding to dry fields. On the other hand, the start of ponding irrigation soon after the seeding (exactly speaking, when the plumules nearly emerged on the surface

of soil cover) has an effect to keep soil temperature from lowering.

2) The use of CaO_2 (commercial name "Calper") at the rate of 60% of the weight of soaked seeds, and the soil cover (on seeds) of 10–20 mm in depth were most effective in increasing the rate of seedling establishment.

3) In direct seeding of any type, it is essential to obtain sufficient magnitude of vegetative growth not to cause delayed heading and to get high yields. Therefore, earlier seeding and earlier seedling establishment are most desirable. This can be done by adopting the new direct seeding method. In this connection relationship between temperature and velocity of plumule growth was examined in detail.

4) When daily maximum and mean air temperature reaches higher than 18 and 10–12°C, irrigation can be started. In the earlier seeding, the earlier irrigation is possible whenever the effective accumulated temperature attained 80°C.

5) Rice plants grown by the new direct seeding culture were able to obtain more than 80% or 250 hills per m^2 in seedling establishment even in cool years. Their grain yield was significantly higher than the yields of plants grown by the young seedling transplanting culture or by traditional direct-seeding to submerged fields.

In conclusion, the new direct-seeding culture makes it possible to secure good and stable seedling establishment, a sufficient amount of vegetative growth in an early stage, and high grain yields.

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