Direct seeding of rice using iron-coated seeds

2025

December 2025

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Preface

In recent years, against the backdrop of rapid economic growth and the resulting agricultural labor shortages, particularly in Asia and Africa, direct seeding of rice, which is more labor-efficient than traditional transplanting cultivation, has attracted widespread attention. In these circumstances, wet seeding (a method in which pregerminated seeds are sown in a paddy field after forced drainage immediately after puddling) has been popular in Asia since 1980s. However, it is widely recognized that the infestation by weeds, particularly weedy rice, is serious. The reason behind the use of this method is that when rice seeds are sown in flooded paddies, they float and wash away, making seedling establishment unstable.

In 2004, iron coating technology was developed which successfully suppressed floating seedlings, making water seeding (a method in which pregerminated seeds are sown into standing water, without drainage in puddled fields) possible. However, this technology presented challenges that needed to be overcome, such as the complicated coating process due to the heat generated during iron oxidation, and unstable seedling establishment due to slow germination.

The core of this manual is the new iron coating technology developed in 2022 to solve these challenges in conventional iron coating technology. By appropriately adjusting the heat generation in iron oxidation and selecting the calcined gypsum suitable for water seeding, this new technology enables sowing immediately after seed coating, and even allows for the long-term storage of surplus seeds. It also achieves rapid germination equivalent to that of pregerminated seeds, stabilizing early growth.

Common direct-seeding cultivation methods often require forced drainage and excessive use of chemical fertilizers and pesticides to compensate for unstable seedling establishment. This manual proposes a sustainable direct-seeding rice cultivation method that uses new iron-coating technology avoiding both the forced drainage and excessive reliance on inputs.

The cultivation methods presented in this manual were primarily developed in Japan. Therefore, further ingenuity and improvement may be required to adapt them to the unique environment and farming practices of your region. We hope you will use this manual as the first step toward successful direct-seeding cultivation in your region.

1 Basics of iron coating

1.1 Purpose and principle of coating

When rice seeds are sown under flooded conditions in puddled fields (i.e., water seeding), they are buoyant in water and tend to float. Therefore, they are coated with a heavy iron material (a mixture of iron and iron oxide) so that they do not float.

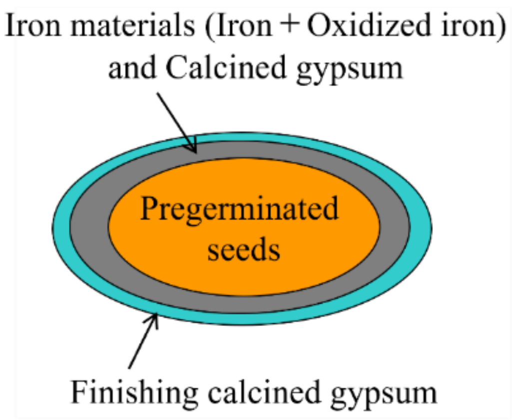
The coating requires a glue component called a binder. For iron-coated seeds, the binders are water, iron rust, and calcined gypsum.

Water is sprayed onto the seed during the coating process. Pregerminated seeds are wrapped first with the mixture of iron materials and calcined gypsum, which is followed by a thin layer of finishing calcined gypsum.

Water is an important binder as long as the coated seeds are wet. Water's binding role disappears when the coated-seeds dry out.

Rust is formed by the oxidation of iron, so the higher the iron concentration in the iron material, the stronger the coating is. Although rust is a stable and strong binder, its amount in the coating layer should be optimized in terms of the heat generation during the oxidation reaction of iron (which damages seed viability), the hardness of coating layer (which reduces germination speed), and the effectiveness of the suppression of damage caused by birds.

Calcined gypsum acts as a binder and also promotes the oxidation reaction of iron. Since calcined gypsum dissolves in water little by little, its role as a binder is temporary.



The surface of the rice seeds is covered with iron material and calcined gypsum while spraying with water.

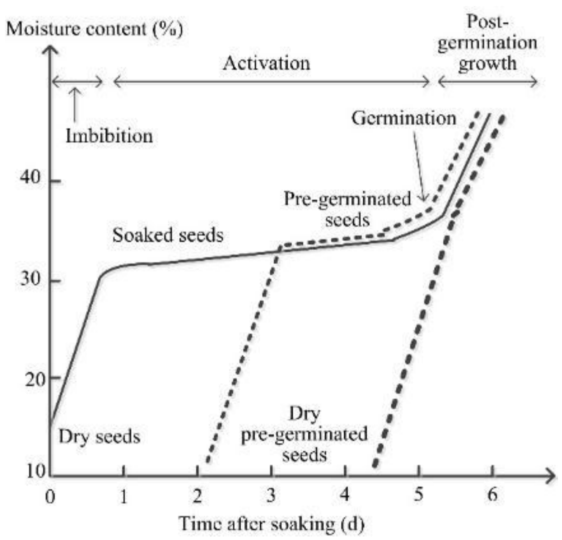
When the iron starts to oxidize, heat is generated, so by mixing iron oxide, the concentration of iron is changed to adjust the strength of the oxidation reaction and heat-generation.

Iron oxidizes in air and, after sowing, in water.

1.2 Seed preparation, speed of germination, and varieties

When direct seeding, it is advantageous to use seeds that germinate quickly in order to ensure a stable number of seedlings and to compete with weeds. The germination is faster in the following order:

Germinated seeds > Pregerminated seeds > Soaked seeds >
Dried pregerminated seeds > Dry intact seeds



When seeds are soaked in water, they go through a period of water absorption and then, into metabolic process preparing for germination, and germinate (protruding coleoptile or root) and elongate 1st leaf.

Metabolically activated dry seeds (which we call “dry pregerminated seeds”) are those that have been soaked and pregerminated, and dried during the preparation stage for germination. They germinate faster than intact dried seeds. Because they require time to absorb water (1 day) to restart growing, they germinate after the pregerminated seeds.

If the germination percentage is maintained at a high level, the seeds from the previous year's crop stored in a low-temperature storage facility are metabolically activated even without soaking, and germinate faster than the seeds immediately after harvest.

On the other hand, if seeds with a low germination rate (below 95%) are soaked and pregerminated, and then dried, the germination percentage may drop by another 10% based on our experience. Therefore, seeds with a low germination percentage should not be used as dry-pregerminated seeds, but be sown in a pregerminated state.

There is no difference in suitability for iron coating among varieties. However, there are differences between varieties in terms of the germination speed, early growth, plant height, and lodging resistance, making some varieties more suitable for direct seeding than the others.

Iron coating reduces the occurrence of seed-borne diseases and pests. Therefore, in areas where the occurrence of seed-borne diseases is low annually, seed disinfection could be omitted. Seeds that have been disinfected (including hot water disinfection) can be used, but seeds disinfected with Padan SG (which reduces the germination of iron-coated seeds) and Momi Guard (which makes the iron coating brittle) are not suitable.

1.3 Coating materials

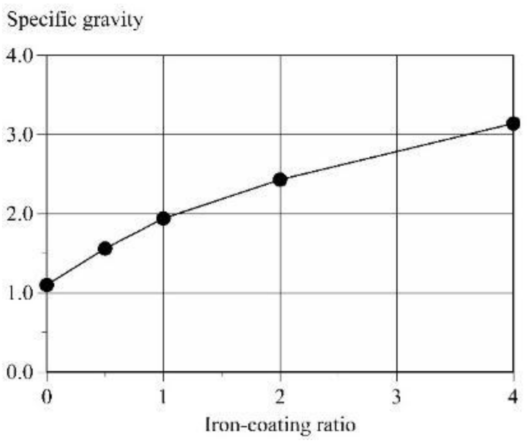
The materials are iron materials (a mixture of iron powder and iron oxide powder) and calcined gypsum. The iron powder is "reduced iron powder" and the iron oxide is mill scale (an iron oxide film generated during the steel manufacturing process), and the composition is indicated by the iron concentration. The standard iron concentration is between 10 and 25%. The concentration could be varied between 0 and 100%.

Iron concentration (%) =
weight of iron powder / (weight of iron powder + weight of iron oxide) x 100

The amount of iron material applied to rice seeds is expressed as the iron coating ratio. The standard iron coating ratio is 0.5. The ratio can be varied from 0.01 to 2.00.

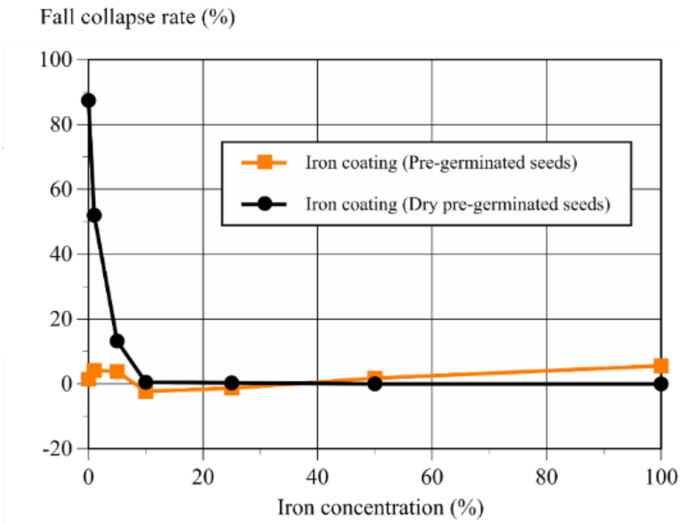
Iron coating ratio = weight of iron material / dry weight of rice seeds

The calcined gypsum is selected so that it will not easily disintegrate even if it is sown in water immediately after coating.

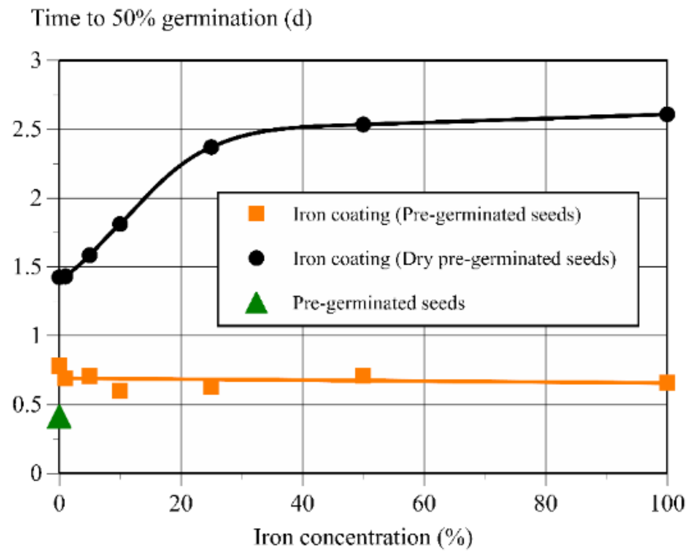


Relationship between the iron coating ratio and specific gravity of coated seeds. Rice seeds have a specific gravity of about 1.0, and tend to float in water. As the coating ratio increases, the specific gravity also increases, making the seeds heavier and more likely to adhere to the soil and take root, rather than floating.

The strength of the coating layer is determined by the moisture content and the concentration of iron powder in the iron material. If the coated seeds are moist and pregerminated, they are mechanically strong when sown or stored. This is because water acts as a binder. However, if the coating layer is dried to produce metabolically activated dry seeds (i.e., dry pregerminated seeds), the only binder is rust. Therefore, when the iron concentration is low, below 10%, the coating layer becomes weak.



Relationship between the iron concentration in the coating layer and the rate of collapse in the falling test. The strength of the coating layer is measured by the degree to which the coating layer breaks when the coated seeds are dropped from a 1.3 m-high place onto a steel board. If the rate of collapse due to falling is 65% or more, the coated seeds are more likely to break during seeding.



Relationship between the iron concentration in the coating layer and the time of 50% germination. The speed of germination is expressed as the time it takes for half of the seeds to germinate after soaking, that is, time to 50% germination.

Germination is fastest in pregerminated seeds, then coated pregerminated seeds, slower in coated dry pregerminated seeds and even slower when iron levels are increased above 50%.

Increasing the iron concentration makes the coating layer harder and stronger, but the heat generated by the oxidation of iron is strong and the temperature of the seeds rises, so heat dissipation is necessary. The standard iron-coated seeds are those prepared with pregerminated seeds, with an iron coating ratio of 0.5, and with iron materials of 10 to 25% iron concentration. When packing seeds into mesh bags after coating, the guideline for keeping the temperature rise to 10°C or less above room temperature is a thickness of 10 cm for an iron concentration of 10%, and 5 cm for 25%.

Iron concentration in iron materials, degree of oxidation heat, heat dissipation guideline, and coating strength. Example of iron coating ratio 0.5

Iron concentration %	Temperature increases of coated seeds in mesh bags	Heat dissipation guideline Thickness of the mesh seed bag in cm	Coating Strength	
			Pregerminated seeds	Dried seeds
0 to 10	Small	10	Large	Weak
25	Medium	5	Large	Medium
50	Large	3	Large	Large
90 to 100	Extremely large	1	Large	Extremely Large

The measure of heat dissipation is the thickness of the coated seeds when packed in a mesh bag, etc. When wet, the water also acts as a binder, increasing the strength of the coating.

Seeds with an iron coating ratio of 0 to 1.0
Immediately after coating

Seeds with an iron coating ratio of 0 to 1.0
After oxidation and drying (conventional method)

Iron coating ratio and amount (kg) of materials. Example for 1 kg of seeds (dry weight)

Iron coating ratio		0. 1	0.5	1.0
Mixture	Iron materials (kg)	0.1	0.5	1.0
	Calcined gypsum (kg)	0. 01	0. 05	0. 1
Mixture of iron materials and calcined gypsum (kg)		0.11	0.55	1.1
Calcined gypsum (kg) used to finish the coating		0. 01	0. 05	0.05

Calcined gypsum is mixed with the iron material at 10 %. Mixed products are also available commercially. The amount of calcined gypsum used for finishing coating is 10% of the weight of the iron material, but if the iron coating ratio is 0.5 or more, the amount should be reduced to about 5%.

The iron coating ratio and iron concentration are adjusted according to the conditions of the field to be direct seeded. Under favorable conditions, the iron coating ratio can be reduced to around 0.05 which is still effective in stabilizing the establishment of seedlings. A small iron coating ratio makes coating work shorter and easier, reduces oxidation heat generation, and significantly reduces material costs. On the other hand, if the wind is strong after sowing, the water on the rice field surface will be shaken, floating the rice seedlings easily, and when the water drains, it will be more susceptible to damage by sparrows.

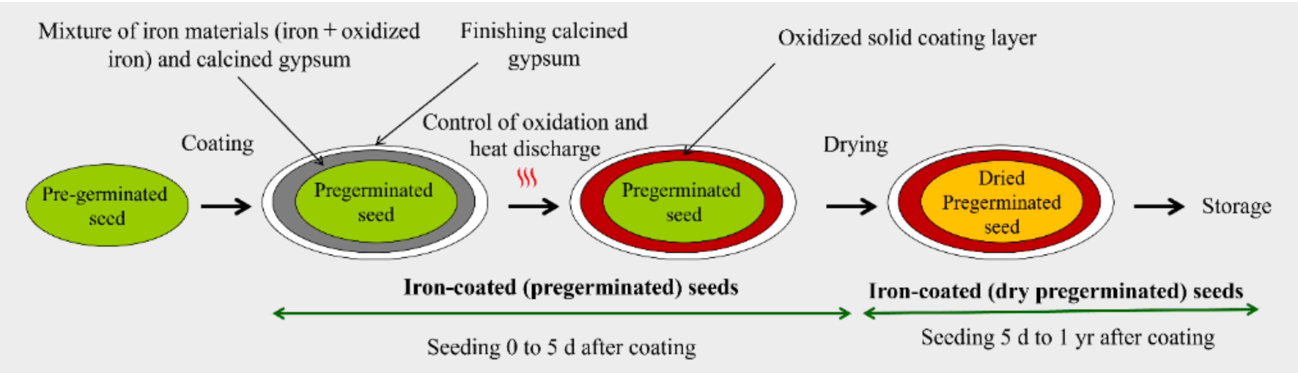
The iron coating ratio can be increased up to about 2. It is stable in water and strongly inhibits the damage caused by sparrows. However, it takes time to coat, generates more heat due to iron oxidation, increases material costs, and makes the seed hopper heavier.

1.4 Workflow from seed preparation to seeding

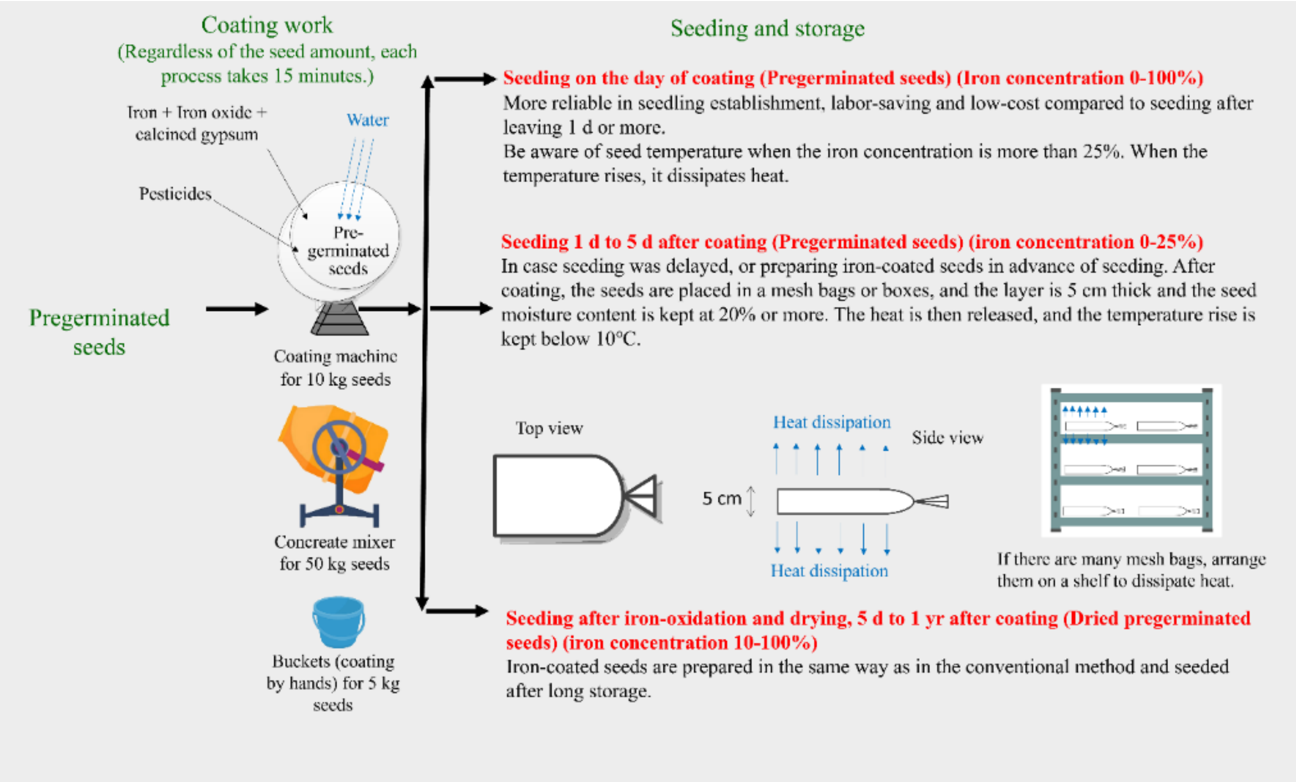
Pregerminated seeds are coated and sown immediately after coating work, and any remaining seeds are sown a few days later or after a year of storage, making it labor-saving, and flexible. In other words, only the amount needed on the day of sowing is coated and sown, and if sowing is interrupted or delayed due to an emergency or weather conditions, the seeds are stored in a mesh bag or thinly spread out until sowing. Conversely, the seeds are coated in large quantities in advance of the sowing time, and sown thereafter for the periods of 1 year.

The recommended order of seeding time after coating, based on the certainty of success of direct seeding and labor saving, is as follows:

Sowing on the same day > Sowing on the next day to 5 days later >
Sowing after 5 days to 1-year storage



Relationships between iron oxidation in iron coatings, desiccation of pregerminated seeds, and seeding time.



Relationship between coating, iron concentration, storage and seeding timing

- Seeding on the day of coating: Direct seeding is possible regardless of the iron concentration. The coated seeds are sown as pregerminated. The important thing to note is that when the iron concentration is high, sow before the seed temperature rises. If the iron concentration is around 10%, there is little heat generation and there is little concern about the seeds' temperature rising.
- Seeding 1 day to 5 days after coating: If the oxidation heat is weak, the seeds can be kept pregerminated by placing them in a mesh bag or piling them up to 5 to 10 cm in thickness. The iron concentration suitable for this seeding is between 10 and 25%.
- Seeding 1 day to 1 year after coating: When the oxidation heat is strong, heat dissipation is critical, the coated pregerminated seeds being dried up. This is the same working system as conventional coating technology in which the iron concentration is 90 to 100%. When the iron concentration is around 50%, there is less risk of damaging the seeds due to oxidation heat compared to conventional methods, and problems such as delayed germination and hardening of the coating layer are mitigated.

For example, the workflow for preparing 1 hectare of iron-coated seeds in an area of western Japan where the rice water weevil, a common pest appearing at an early stage, causes infestations in May is as follows (the standard practice with an iron concentration of 10% and with iron coating ratio 0.5):

(1) Soak 50 kg of seeds (dry weight) to prepare pregerminated seeds. If the water temperature is around 20 to 25°C , soak the seeds for 2 to 3 days.

(2) Weigh out 27.5 kg of mixed iron materials (iron, iron oxide, and calcined gypsum) (25 kg of iron and iron oxide + 2.5 kg of calcined gypsum) and 2.5 kg of finished calcined gypsum. Prepare the pesticide (for example, 550 mL of seed treatment agent Yoval Seed FS).

(3) Iron coating of pregerminated seeds should be completed in 15 minutes.

i. Drain the seeds, place them in a concrete mixer, and add the seed treatment agent while rotating (work time 1 minute).
ii. Add the mixed iron materials in 3 batches. Spray with water. (10 minutes)
iii. Add the finishing calcined gypsum in three to four batches (5 minutes). No water spray.

(4) When seeding on the day of coating: Place the finished iron-coated seeds into mesh bags or containers and transport them to the field for seeding.
(5) When seeding on the next day to 5 days later: On the day of coating, place the iron-coated seeds in a mesh bag (or mesh box) with a 5 to 10 cm thickness. In the evening of the same day, lightly stir the iron-coated seeds in mesh bags or boxes in order to allow the moisture contained inside the mass of seeds to escape. This is because the condensed water will come out of the seeds. After this, leave the coated seeds in mesh bag or box to rest with a 5 to 10 cm thickness, away from direct sunlight and wind, until seeding (approximately up to 5 days).
(6) When coated seeds need to be stored for more than 5 days: dry the seeds (moisture content 14% or less) by spreading them thinly or using a bulk dryer, then store them in a dark, dry place at room temperature.

2 Preparation of iron-coated seeds

2.1 Materials

(1) Get iron powder, iron oxide powder, and calcined gypsum, each with properties suitable for iron coating. Weigh and mix.
(2) You may get a mixed product (i.e., premixed product, product made of iron powder and iron oxide powder mixed with calcined gypsum, not including the finishing calcined gypsum), although it is costly.
(3) Weigh out the finished calcined gypsum.
(4) Because moisture not only oxidizes iron but also deteriorates calcined gypsum, materials and mixtures should be stored sealed tightly in a dry place.
(5) Follow the Fire Service Act, because fine iron powder (single element) is considered a flammable material.

Use plastic bags or a concrete mixer for efficient mixing.

2.2 Preparation of pregerminated seeds

Soak the seeds to pregerminate. When the temperature is low, heat them with a germination machine.

The best time to germinate the seeds is when they are in a pigeon-breasted state, when the embryo can be seen through the husk and when they have slightly germinated and can be used for coating. If the tips of coleoptile emerged from the seeds are not broken during coating, they are fine.

2.3 Coating work

Coat the pregerminated seeds. The total time required is 15 minutes (±5 minutes) per coating, regardless of the amount of seeds. Coating with the mixture of iron materials and calcined gypsum with water spray for 10 minutes, followed by finishing with calcined gypsum with no water spray for 5 minutes. Coating over a long period of time may damage the seeds.

(1) Drain off the excess water before placing the seeds in the coating machine. Hang the mesh bag with the seeds for a few minutes or place it on a pallet. Take the drained seeds out of the bag and place them in the coating machine.
(2) When the seeds are to be treated with pesticides, they are poured in the coating machine. The time required for the treatment is about 1 minute.
(3) Add about 1/3 of the total amount of the mixture of iron materials and gypsum.
(4) Once the mixture has settled around the seeds, add more mixture and repeat, spraying with water as needed.
(5) When the mixture adheres to the rotating plate of the coating machine, scrape it off quickly with a spatula, etc. If it is difficult to scrape it off, spray water on the area where it has adhered to remove it.
(6) Once all the mixture has been applied to the seeds, spray with as much water as possible. If the seed surface is evenly covered with iron material, then you haven't sprayed enough. The trick is to spray enough water so that the iron continues to oxidize even after the coating process is complete. The guideline for when to stop spraying water is to observe the movement of the seeds inside the turntable: when the seeds inside the turntable flow smoothly, it is a sign of a shortage of water to be sprayed; when the flow changes from smooth to a state in a ragged/wavy pattern, it is a sign of a little too much water and that it is time of stop watering.
(7) No more water spraying afterwards. Add the finishing calcined gypsum in three or four small applications. Rotate for a few minutes to allow the coating to harden. The guideline for the application of the finishing calcined gypsum is 5 minutes.

Relationship between the amount of water spray and surface of seeds being coated
Example of iron material with an iron concentration of 12.5%

The seed surface showing insufficient water spray The surface is evenly covered with iron material. The coating is uniform and looks good, but the amount of water spray is insufficient. Currently, the seeds flow smoothly in the coating machine or concrete mixer, indicating insufficient water conditions.

Moderate amount of water spray The surface of the intact seeds, i.e. husk, will start to become visible. At this point, the seeds that flowed smoothly in the coating machine or concrete mixer will start to crumble (flow in a wavy manner). This is when the amount of water is just right.

If you spray more water on seeds that have already been sprayed with the right amount of water, the amount of water sprayed will be excessive, causing the area of husk to spread and the uniformity of the coating to become uneven.

For preparation of iron-coated seeds, moderate to excess water is better than insufficient water.

This is the appearance of the seed surface when finishing calcined gypsum is added to seeds with a slightly excessive amount of water. The gypsum absorbs the excess water, eliminating the sticky and lumpy feeling and reducing the uneven appearance of the coating.

Here is what the seeds looked like the day after coating. The iron particles have rusted and turned a light brown.

Insufficient water spray will result in insufficient oxidation of the iron particles and increased amounts of iron material will flake off from the seed surface.

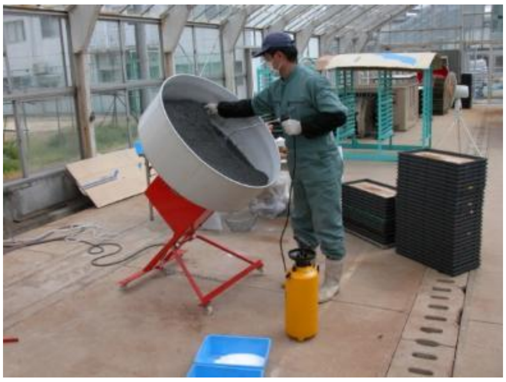
Even with a little more water, iron-coated seeds grow well.

⚠️ Wear protective glasses, a dust mask, and gloves when working for coating. Also, wash the machine with water as soon as possible after coating is finished. If rusty iron is strongly attached to the rotating plate, add gravel and water, and stir and wash it.

💡 Iron, iron oxide, calcined gypsum and the mixtures of these should be stored in sealed plastic bags away from moisture. If iron oxidizes, or calcined gypsum absorbs moisture and deteriorates, coating will no longer be possible.

Seed coating can be accomplished in a variety of ways.

If you have a few kilos of seeds, you can coat them by hand using a bucket.



The coating machine can process 1 to 10 kg of seeds.

When using a concrete mixer, the internal mixing blades are removed. The amount of seeds that can be processed at one time is about a few kilograms to 80 kg according to the size of the concrete mixer.

This is a procedure to coat a large amount of seeds at once using a large concrete mixer. A large manual or electric pressurized sprayer is also used.

(1) The seeds soaked in the mesh bag are placed on a pallet or the like to drain the excess dripping water. 40 to 80 kg are placed in a 110 L concrete mixer. The mesh bag in the photo contains 20 kg of soaked or pregerminated seeds. The coating time is approximately 15 minutes.

Seeds at the bottom of the drum may not be stirred properly. Stir with a long-handled ladle or shovel. Spray a little excess of water.

(2) The concrete mixer is turned on and the mixture of iron materials and calcined gypsum is poured in. Water is sprayed in. The movement of the seeds is controlled by changing the angle of the drum.

(3) The key is to spray lots of water. If the surface is powdery, there isn't enough water.

(4) Finally, pour in the finishing calcined gypsum to cover the surface of the coating seeds. Do not spray water after starting to pour the finishing calcined gypsum.

(5) Pack into mesh bags or large containers.

2.4 Post-coating care (until the seeding date)

When sowing on the day of coating

The seeds are transported in containers, buckets, net bags, etc. to the field and sown.

When seeds are not sown on the day of coating

Wet iron-coated seeds (pregerminated seeds) can be stored for 5 days in mesh bags or boxes packed to a depth of 5 to 10 cm. If stored for a long time, the moisture content of the seeds will decrease and the germination rate will decrease.

The coated pregerminated seeds are stored in net bags to both release heat and prevent from drying out. When the coated pregerminated seeds (2.5 kg or 5.0 kg in dry rice weight equivalent) are placed in a net bag which is common for seed storage (40 x 60 cm), the thickness is 5 cm (left photo) or 10 cm (right photo).

The recommended thickness of the mesh bag is less than 10 cm at 10% iron concentration and less than 5 cm at 25% iron concentration, although the thickness changes according to the room temperature and other conditions.

To prevent moisture contained in the germinating seeds from escaping and condensing, and to allow heat to escape from the surface of the mesh bag, a gap is left between the bags and the floor.

On the day of coating, the coated-pregerminated seeds contain a lot of moisture. Therefore, if left overnight, a large amount of condensed water will be produced. Also, the seeds may germinate inside the mesh bag. To avoid this, lightly

knead the mesh bag only in the evening on the day of coating to expose the seeds inside to the outside air and evaporate the moisture. This is not necessary from the following day onwards. Leave the seeds in a dark place until sowing.

When the seed amount is large, mesh bags common for combine harvesting are used and placed on a pallet.

Caution: If iron-coated seeds are spread out directly on a polyethylene tarpaulin or floor, moisture and temperature control will be poor. Do not expose the iron-coated seeds in mesh bag or box to direct wind from a fan, etc.

2.5 Key points for long-term storage and drying

When you plan to seed iron-coated seeds one week after coating, or to prepare them in advance of seeding, you dry and store them in the same way as conventional iron-coated seeds. It is important to note that the lifetime of dried pregerminated iron-coated seeds varies depending on the variety and seed source.

If the quality of the seeds is high (germination percentage 95 to 100%), they can be stored for several months by air drying, or for over a year if dried with hot air (35°C) in a mass production machine. If the quality of the seeds is low, the germination percentage will drop as much as 10% when they are dried after pre-germination, so they are not suitable for long-term storage. When the quality of the seeds is low, they should be sown in the pregerminated state after iron coating.

The water in the coating layer acts as a binder. Therefore, the iron-coated seeds with pregerminated seeds are resistant to the drop test but not with those with dried pregerminated seeds. In dried iron-coated seeds, iron rust is the main binder. When the iron concentration in the iron material is 10%, there is little rust, so the seeds are more likely to break during storage and transportation, and when sowing. At 25% or more, this problem is reduced, and at 50% or more, the coating layer is hard and strong.

The iron in coated seeds oxidizes, generating heat. When iron-coated seeds are exposed to the atmosphere, they dry, and the oxidation of iron gradually slows down and stops as the water in the coating layer is lost. The degree of heat generated will depend on the type and concentration of iron. When the iron concentration is 25%, it may be necessary to spread the seeds thinly to dissipate heat, and at 50%, this is essential. The temperature of the seeds should not exceed 40°C.

When the iron concentration is below 25%, the iron-coated seeds could be oxidized and dried, being stored in a mesh bag. When the concentration is more than 25% and the oxidation heat is large, the iron-coated seeds should be accommodated, oxidized, and dried in a thin box, like a nursery box as shown in the photos below. Or you may use the mass production system developed in conventional iron coating.

Place sticks between the seedling boxes to ensure there is enough space between them to prevent heat build-up. Using seedling racks or containers for transporting seedlings makes the process easy and efficient.

Wind dries the seeds out quickly and slows down oxidation. Low temperatures (below 10°C) also slow down oxidation.

When the water evaporates because the seeds are spread thinly, and there is little oxidation (rust), spray water on the seeds in the seedling tray. The coated seeds will absorb the water. As a guideline, spray enough water so that no water accumulates in the seedling tray.

Allow the heat to escape and dry again. If the iron concentration is high, the coated seeds will be a rust-brown color. If the iron concentration is low, the color will be gray to black.

Even if the surface appears dry, the inside of the seed is often moist and will take a long time to dry out.

After one week, stack the seedling boxes. Keep them like this until the planned day of sowing.

Note: If iron-coated seeds that are not completely dry are placed in a bucket or mesh bag, the seeds will be damaged and will not be able to be stored for long periods of time.

For long-term storage, it is convenient to use a conventional iron-coated seed mass production machine, which can complete the oxidation and drying process in two days.

2.6 Germination test

By measuring the germination percentage of seeds before and after coating, it is possible to determine at what stage the germination rate decreased when direct seeding fails. A decrease in germination immediately after coating or during subsequent storage occurs when the quality of the seeds used for coating is poor, when heat is trapped during coating and the seeds become too hot, or when the seeds are not dried sufficiently after coating.

100 seeds, either before or after coating, into a disposable plastic Petri dish, add a sufficient amount of water (about 20 mL of water for a Petri dish that is 9 cm in diameter and 20 mm high), and leave them at 25 to 30°C for one week. Then count the seeds that have germinated and those that have not, and calculate the germination rate.

No water changes are necessary during the test, as water spoilage is due to poor seed quality.

Instead of a Petri dish, you can use anything, such as a supermarket food tray, a disposable cup, or a plastic bottle.

When temperatures are low, place the plants in an incubator or seedling container.

3 Field preparation

3.1 Paddy fields suitable for direct seeding

Direct seeding and transplanting have different water management and pest control ecology, so direct seeding is best introduced in a cluster, separately from transplanting fields.

When direct seeding iron-coated seeds, surface water is drained at the time of coleoptile emergence and reflooded after rooting and 1st to 4th leaves. The surface drainage is essential for stabilizing seedling establishment.

Therefore, it is important that fields suitable for introducing direct seeding meet the following five conditions:

- Leveling
- Moderate permeability (water depth loss of 10 to 20 mm per day)
- Open drains or ditches (quick inflow and outflow)
- Tall and sturdy ridges
- Being able to introduce and drain water when needed

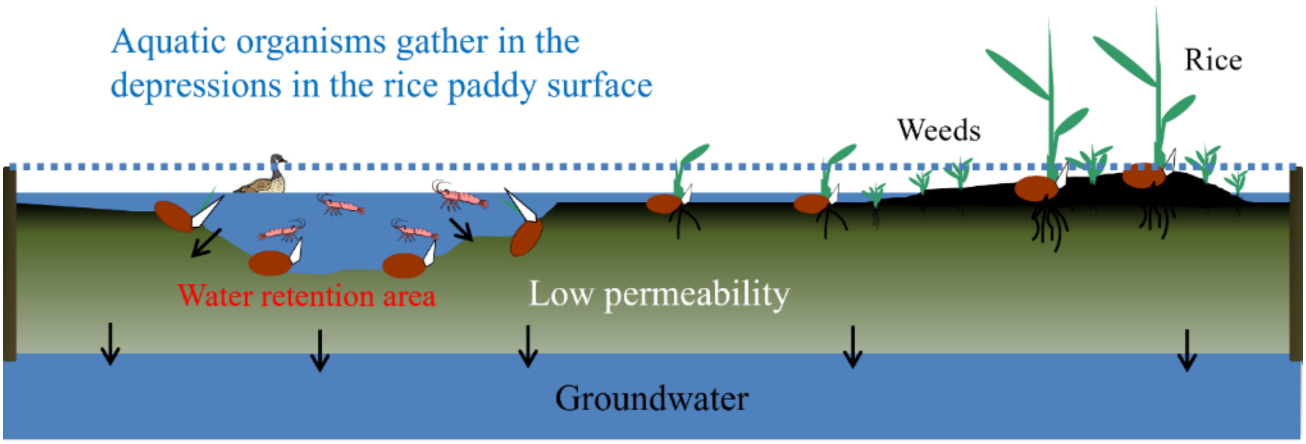
3.2 Paddy fields where direct seeding fails, and where it is successful but lacks labor-saving properties

Introducing direct seeding to paddy fields that have been used for transplant cultivation for many years would require a lot of effort in water management and weed control. The points to note are as follows:

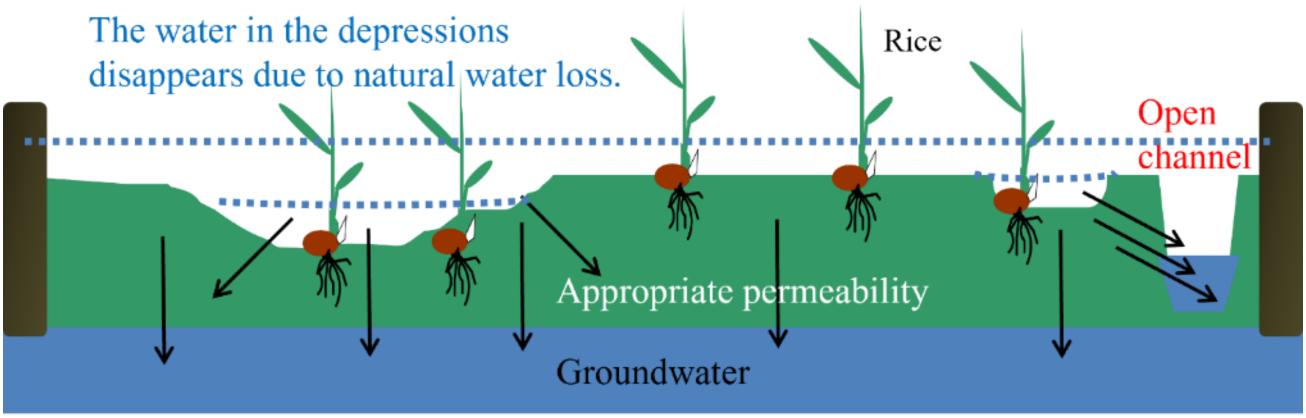
Even if the water is drained, stagnant water remains in the depressions, which results in poor seedling establishment due to growth inhibition caused by soil reduction, damage by pests and diseases, disturbance by aquatic organisms, the arrival of birds and damage caused by feeding, and excessive increases in water temperature during high atmospheric temperatures.

Meanwhile, the protruding parts in the field crack and weeds grow. Rice emergence and early growth are also uneven, making it difficult to find out the optimum time for the herbicide application.

If the ridges are low and prone to collapse, the field water level cannot be maintained, which reduces the effectiveness of herbicides.



Paddy fields that are uneven, have low permeability due to over-plowing, have no open channels or furrows, have low and weak ridges, and cannot add water when needed are unsuitable for direct seeding.



In paddy fields that are appropriately leveled and permeable, and have open channels, ditches, and high, sturdy ridges that allow for quick inflow and outflow when needed, direct seeding can be carried out labor-saving and stable, and high yields can be expected. In such paddy fields, forced drainage can be avoided, herbicides work well, and damage from pests and diseases is reduced.

3.3 Key points for preparing paddy fields for direct seeding

(1) Moderate puddling

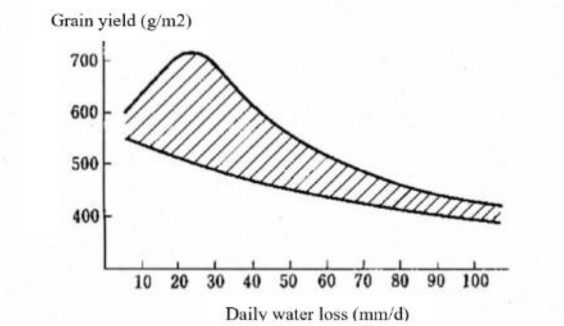
Puddling has the following effects:

- Leveling the soil surface
- Improving water retention
- Suppressing the growth of weeds and weedy and volunteer rice
- Increasing fertility

In recent years, for environmental conservation reasons, it has been recommended to flood the soil at a shallow depth, then rotovate and level the soil, and puddle with moderate strength. Operators are recommended to bear in mind the following points:

- It is difficult to level a large field by puddling alone, and in some cases, too much effort is put into leveling, resulting in over-puddling and reduced permeability.
- When leveling large field, it is effective to use a laser leveler before the land preparation. However, the use of a laser leveler is not essential.
- In paddy fields with a daily water loss of 10 mm or more, even if there is water stagnating in a 2 to 3 cm depression, the water will disappear after 2 to 3 days.

A moderate daily water loss is useful for labor saving and healthy growth of the root system. It was reported that the maximum grain yield is obtained with a daily water loss between 20 and 30 mm.



Relationship between grain yield of rice and daily water loss (Isozaki, 1957) Shaded area indicates data variability.

Maintaining a daily water loss of 20 to 30 mm with moderate puddling leads to labor savings, low costs, and high yields. Excessive puddling creates turbid water and pollutes the aquatic environment.

(2) Open ditches - Installation, merits and demerits

If open drainage ditches are prepared, water can be removed even if it becomes stagnant due to over-puddling.

Installation and merits A trencher or backhoe is used. The wheel tracks made by a tractor or cultivator can also be utilized for the drainage. Open ditches allow water to be quickly let in and out, making it possible to spray herbicides at the right time. They are also useful for the seedlings to keep the root system healthy and prevent lodging.


Open channel construction using a trench digger


Open channel construction work using a backhoe

The key to introducing open ditches is to install them only in paddy fields where they are necessary. They do not necessarily have to be framed open drains that go around the entire field, and in many cases I- or L-shaped drains are sufficient. The important thing is to make sure they are connected to a drainage outlet.

After installing the open ditches, puddle the field with shallow water (about 80% of the soil is exposed). Puddle the soil to a distance of 50 cm from the open drain, and do not sow seeds to the edge of the open ditch. Also, spread the excavated soil thinly in the field.


Drying of seedlings in direct-seeded rice fields. If there is an open ditch, the occurrence of stagnant water can be prevented even if the soil is puddled in excess.

The open ditches will remain after the harvest. They will be repaired as necessary during the off-season in preparation for spring.

Demerits When the soil rises, weeds grow and the area for rice planting is reduced.

4 Fertilizer and agricultural chemicals

This section outlines the specific requirements for fertilizer and chemical application in direct-seeding rice cultivation, emphasizing key differences from traditional transplanting methods.

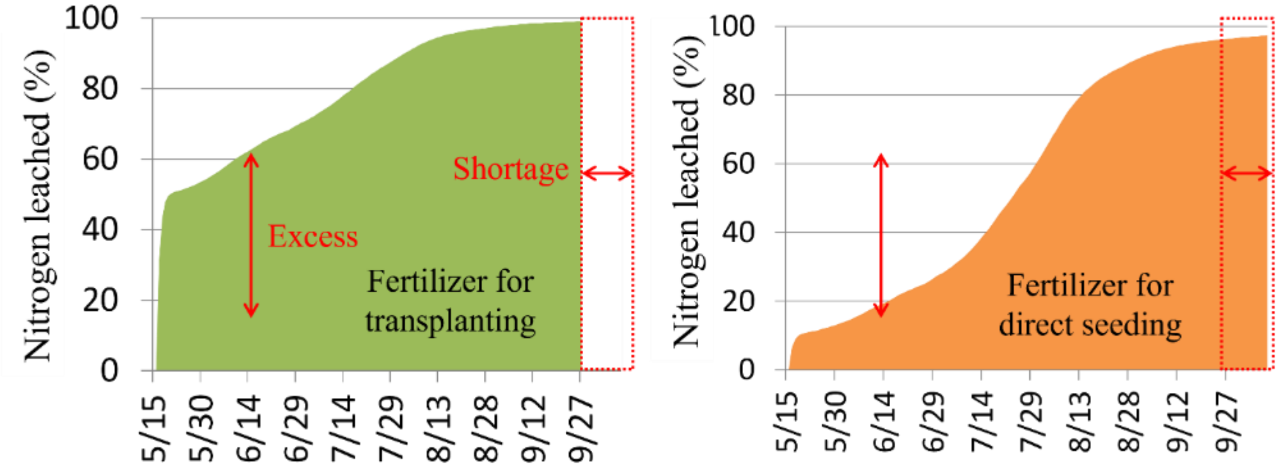
4.1 Fertilizer

The fertilizer strategy for direct seeding is fundamentally based on labor-saving and delayed nitrogen release. Since the primary benefit of this method is reduced labor, a one-shot basal fertilizer system that eliminates the need for top dressing is typically preferred.

Seeding method	Recommended application method	Rationale
Row and hill seeding	Side-dressing	Places fertilizer near the seed/row to minimize loss.
Broadcast seeding	Full-layer application	Uniform distribution across the field.

The key difference is the one-shot basal fertilizer use. Unlike transplanting, direct-seeded rice uses nutrients stored in the endosperm for the first month after sowing. Therefore, fast-acting nitrogen is unnecessary in the early stages.

- Requirement: Use fertilizers specifically designed for direct seeding that contain a high proportion of slow-release nitrogen.
- Goal: The fertilizer's effective period must be extended to compensate for the harvest time, which is typically 7 to 10 days later than transplanting.



If transplanting fertilizer is mistakenly used for direct seeding, the following severe problems can occur due to excessive nitrogen in the early stage:

- Fertilizer loss: Nitrogen is wasted before the plant needs it.
- Excessive tillers: Leads to thin, weak stems.
- Lodging risk: Plants become highly prone to collapse (lodging) during the ripening period.
- Late-stage deficiency: Nitrogen runs out prematurely, resulting in low yields and poor grain quality.

Direct seeding fertilizer is formulated to ensure the nutrient supply (especially nitrogen) is maximized in the latter half of growth, which is crucial for maximizing the yield and quality.

Labor-saving fertilization techniques are required. To further reduce labor, consider the following methods for additional nitrogen application (often used to counteract high-temperature damage):

- Pouring into irrigation water: a highly effective, labor-saving way to apply liquid nitrogen.
- Aerial spraying by drones: practical for large fields, utilizing specialized liquid fertilizers.

Cost and soil fertility

One-shot fertilizers are typically more expensive. To mitigate this cost and improve long-term sustainability:

- Recommendation: apply fully matured compost and organic matter to increase overall soil fertility and organic matter content.
- Soil reduction benefit: since iron-coated seeds are typically sown on the soil surface, the risk of seedling injury from soil reduction (a subsurface issue) is significantly lower compared to underground seeding methods.

4.2 Agricultural chemicals

Due to differences in the crop establishment process and pest ecology, agricultural chemicals registered for transplanting may not be suitable for direct seeding.

Mandatory Check: Always confirm that any product used is specifically registered for direct seeding and, if applicable, for forage rice (WCS) use. Refer to the "Rice Fermented Forage Production and Feeding Technical Manual" (Japan Grassland and Livestock Seed Association) for detailed guidance on WCS crops.

(1) Herbicides

Weed control is the most challenging aspect of direct seeding because rice and weeds germinate simultaneously, drastically limiting the optimal application timing.

Cultivation stage	Basic strategy
Pre/post-seeding	Early-stage herbicides (applied before or immediately after sowing).
Post-development	Combine with early-middle stage one-shot herbicides (applied after the main leaves develop).

Emphasis on timing:

- The effect of standard herbicides is often weakened in direct seeding to avoid injuring the germinating rice seed. This is why sufficient puddling (plowing/tillage before seeding) is crucial to suppress initial weed emergence.
- Critical guidelines: To prevent weeds that survived puddling from taking hold, the time between puddling and seeding should be kept very short, ideally 1 to 3 days.

Dealing with infestation:

- New developments: highly effective early-middle stage one-shot herbicides have been developed that are effective even when barnyard grass has grown slightly large after drying, potentially eliminating the need for early-stage applications.
- Mid-to-late stage: if there is a heavy infestation of weeds during the surface drainage period (seedling establishment stage), mid-late-stage herbicides (e.g., Clincher Bath Liquid or Areil SC) are effective for rescue treatment.

(2) Insecticides and fungicides

The iron coating of the seeds provides a baseline defense against seed-borne diseases and some pests.

- Seed disinfection: in areas with low endemic disease occurrence, seed disinfection may be omitted due to the iron-coating effect.
- Early growth protection: controlling common pests and diseases (rice blast, rice water weevil, rice leaf beetle, etc.) from seeding to establishment is critical for a stable stand.

Application methods:

Application type	Target pests/diseases	Examples of agents used
Seed treatment (during iron coating)	Early and mid-stage pests (rice blast, rice water weevil, planthoppers).	Yoval Seed FS, Routine Seed FS, Evergol Seed FS, Lumispans FS.
Box treatment agents (row/hill seeding)	Common early-stage pests.	Granular box treatment agents (common in transplanting) can be applied simultaneously using the seeding machine's granular spreader attachment.
Broadcast granules (post-establishment)	Rice water weevils, leaf beetles, blast, sheath blight, planthoppers, and stink bugs.	Applied across the entire field after the seedlings are established.
Apple snails	Apple snails (Pomacea canaliculata).	Metaldehyde, ferric phosphate, thiocyclam, or cartap granules registered for snails.

5 Seeding

5.1 Seeding time & cold risk

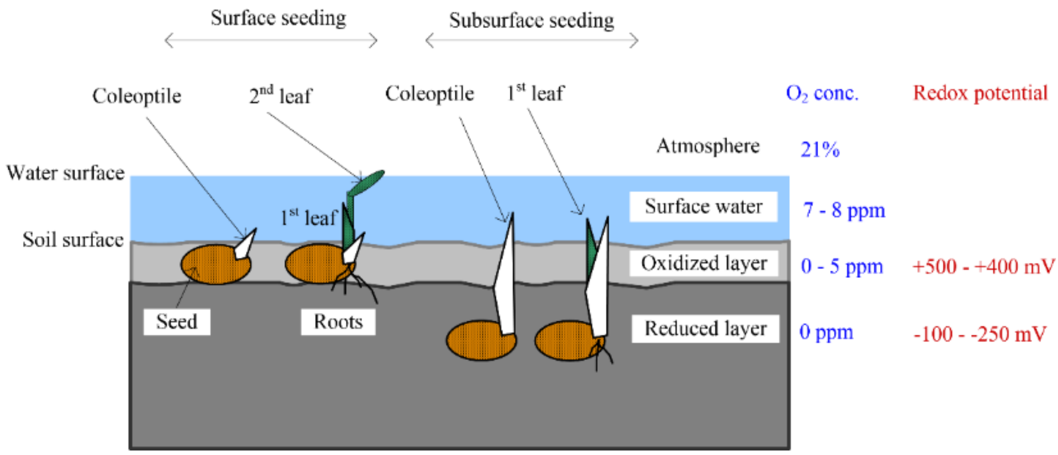
The germination and initial growth of rice is controlled by the temperature. It is cold in the temperate zone where planting is spring, but not in the tropics. When farmers switch from transplanting to direct seeding in the temperate zone, seeding time affects establishment and harvest times. In general, later seeding ensures easier establishment but delays harvest.

Seeding time	Relationship with transplanting	Time required for seedling establishment	Ease of early growth of rice	Harvest time (approximate)
Late seeding	After transplanting	1 to 2 weeks	Easiest (due to high temperatures)	Later than transplanted rice
Regular seeding	Just before or after transplanting	2 to 3 weeks	Easy	10 days after transplanted rice
Early seeding	When seedlings start to be raised for transplanting (3 weeks before)	3 to 4 weeks	The most difficult (because of the cold temperatures)	10 days after transplanted rice

5.2 Seeding method: a surface is required

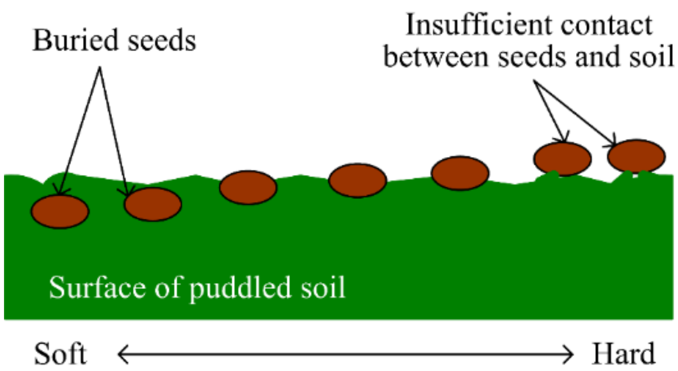
Seeds have buoyancy in water and tend to float. In America where soil puddling is not practiced, seeds are sandwiched between clods or particles of soil created by rough plowing and do not float, which is called "water seeding". In Asia where puddling is commonly practiced, seeds are broadcast after draining the puddled fields and do not float, which is called "wet seeding". Iron coating increases the seed specific gravity, reducing floating. It is common in the direct seeding of America, Asia, and iron coating, that seeds remain in the oxide layer on the soil surface. Because of the presence of oxygen, the first leaves and roots grow.

Sowing the seeds under the surface of flooded soil has the advantage that the seeds do not float. However, there is a high risk of the seeds dying due to lack of oxygen or reduction damage. To avoid these problems, the seeds are coated with oxygen generator calcium peroxide, sown at a precise depth of 10 to 20 mm, followed by intensive drainage to avoid the damage by the soil reduction. Subsurface seeding requires a highly sophisticated seeding machine to place the seed underground in puddled soil. Water seeding is not practiced for subsurface seeding. Practicing subsurface seeding is limited in Japan.



The ideal relationship between iron-coated seeds and soil surface is the state of being approximately half of the seed should be visible on the soil surface. It is practiced in water and wet seeding in puddled and non-puddled soils.

- Soil contact is key: Insufficient contact with the soil surface hinders water absorption. In this case, extend the flooding period to promote closer soil contact.
- Drainage/drying: Seeds that are shallowly buried will sprout upon surface drainage/drying.
- When sowing into dry fields, pressing the seeds down after sowing can increase establishment by about 10%.



Precaution: Never expose iron-coated seeds to direct sunlight for long periods before sowing, as the coating can become extremely hot and damage the seeds.

5.3 Selecting a seeding method (hill/row vs. broadcast)

Hill and row seeding is suitable when you need precise plant spacing to reduce the disease/lodging risk, use fewer seeds, or mimic the appearance of transplanted rice. On the other hand, broadcast seeding is preferred for faster operation and utilizing existing machinery (e.g., power spreaders).

	Hill or row seeding	Broadcast seeding
Machines to be used	Dedicated seeding machine	Power sprayers, boom sprayers or broadcasters attached to the riding-type management machine, unmanned helicopters, drones, etc.

Seed rate	Approximately 40 kg/ha	Approximately 50 kg/ha
Merits	Stable seedling establishment (planting density) ★ • Manual weeding possible • Suitable for varieties prone to lodging • The appearance is similar to planting transplanted seedlings. • Side fertilization is possible (labor-saving, increasing fertilizer use efficiency) • It is possible to cut furrows when sowing, making it easy to drain the field at the seedling establishment stages	• Fast working speed • Water seeding is possible (Enhances herbicide efficacy, saving water) • Various machines can be used. Manual sowing is also possible in small areas.
Disadvantages	• Slow seeding speed • Water removal is required when seeding, wasting water and labor. • A dedicated direct seeding machine is required • Seed rate adjustment is limited to the machine's settings.	Seedling establishment (planting density) cannot be controlled with high precision ★ • Cannot weed by hand • Not suitable for varieties prone to lodging • An open channel or ditch is required • Fertilization is done to all layers, which is time-consuming.

★ With hill and row seedings, the spacing is fixed, so even if the seedling establishment percentage is very poor (for example, 15%), it does not significantly hinder cultivation and the appearance will not be adversely affected.

★ If the seedling establishment percentage drops significantly, cultivation becomes very difficult due to the poor appearance and in many cases cultivation is discontinued.

5.4 Hill/Row seeding procedure

(1) Seeds are sown using a special machine capable of surface sowing.

(2) The iron-coated seeds are allowed to fall naturally onto the rice field surface without the need for furrows or covering with soil.

(3) In a flooded state, it is difficult to determine the driving position (the precise position of seeding machine in the field in case GPS is not used). Since the seeds are moved by the water current, the water is temporarily removed.

(4) To reduce the amount of water drained, adjust the amount of water used during plowing. If the amount of water is too much, start draining in the evening of the day before seeding to create a suitable condition of the field for the seeding next morning.

(5) After hill or row seeding, the field is reflooded with water to suppress weed emergence.

Hill seeding machine for iron-coated seeds

At the same time as seeding the iron-coated seeds, fertilization and pest control can be applied (side dressing, herbicides, insecticides and fungicides).

It is equipped with a drainage ditch cutter.

The state of the rice field immediately after sowing. The photo is on the hard surface of soil. Iron-coated seeds, herbicide (small white dots), and fertilizer applied as side dressing (in the furrows) can be seen.

5.5 Broadcast seeding procedure

(1) Seed the seeds onto standing water approximately 5 cm deep between 1 to 3 days from the day after puddling.

(2) If the water is forcibly drained immediately after plowing, the seeds will sink too deep and will not establish well. Seed in flooded conditions.

(3) A variety of seeding machines can be used for broadcasting.

(4) When broadcasting, open channels or drainage ditches should be cut to prevent stagnant water from forming.

(5) Be careful not to let iron-coated seeds or pesticides drift into neighboring rice fields.

Power spreaders come in a variety of nozzle shapes, with the plain cylindrical (black) and spiral (blue) types unlikely to damage the coating, but the types that can spray both far and near at the same time (red) can.

If iron-coated seeds break during broadcasting, fragments may fly into the operator's face. Wear safety glasses and a mask.

When using a power spreader, seed from the periphery of the field. When using for the first time, put half of the iron-coated seeds into the power spreader and make two revolutions to spread evenly over the entire surface. It can be used for direct seeding in flooded and dry fields.

In large fields, shouldering a power spreader and broadcasting is laborious, so it is also effective to use rice transplanting machines and riding management machines. In addition to a power spreader, boom sprayers and fertilizer broadcasters can also be used.

When broadcasting seeds using an unmanned helicopter, the water depth (5 cm) is ensured at the seeding time to prevent the soil surface from being exposed by wind pressure.

Drone broadcasting in rice terraces is an easy direct seeding method. It also ensures safety for workers when the ridges are weak and narrow, particularly in terraced fields.

5.6 Determining the seed rate

High and stable yields in direct seeding are achieved with 100 to 150 established seedlings per m^2. To manage costs, the target minimum is 100 seedlings / m^2. Producers switching from transplanting must ensure sufficient establishment to prevent yield reduction.

Calculation formula

Number of seedlings established (no / m^2) =

Number of seeds seeded sown (no / m^2) x Seedling establishment (%)/100

The number of seeds sown / m^2 is converted into the seed rate (kg dry seeds or iron-coated seeds / ha) based on the weight of a single seed.

Seedling establishment percentage factors

Seedling establishment percentage typically ranges 30 to 70% for iron coated seeds (dry pregerminated seeds) in puddled fields (50±20%).

- Regional variation: Seedling establishment tends to be higher in eastern Japan (50 to 70%) and lower in western Japan (30 to 50%) due to factors like soil reduction and pest/disease frequency.
- Seeding method: Non-puddled flooded or dry-field direct seeding often shows 10 to 20% higher than puddled fields. Iron-coated seeds generally have a higher seedling establishment than intact or dried pregerminated seeds.
- Mitigation: Seed treatments, especially with early-stage pest control agents, increase and stabilize the seedling establishment.
- Risks: Damage from birds and golden apple snails (Pomacea canaliculata) can significantly reduce the seedling establishment.

Note: Taking weather conditions into consideration, the seeding rate is set to be high so that more than 100 seedlings / m^2 can be established even if unexpected problems occur.

Required seed rate example (targeting 100 seedlings / m^2)

Assuming a normal variety (e.g., single seed weight 25 mg), a seedling establishment percentage of 50% requires seeding 200 seeds / m^2, which is equivalent to 50 kg of dry rice seeds/ha.

Relationship between the seedling establishment percentage and seeding rate required to ensure 100 seedlings/ m^2

Seedling establishment (%)	Seed rate (kg / ha)
30	80
40	63
50	50
60	42
70	36

Setting up the hill seeding machine

For hill seeding, the seed rate is determined by the row spacing (30 cm), the hill spacing, and the number of seeds per hill.

Key adjustment: Adjusting the number of seeds per hill is crucial, as a difference of one seed per hill is approximately a 10% difference in the seed rate. Example of the target seed rate 4 kg/ha

Hill spacing (cm)	Seed no. / hill
14	7
16	8
18	9
21	10

6 Surface drainage at the emergence/seedling establishment stages

6.1 Purpose of surface drainage

In direct seeding, especially in poorly drained areas, seedlings are highly susceptible to damage from various factors between seeding and establishment, leading to poor and uneven stands. These disturbances include soil reduction, pests (like rice water weevils, golden apple snails), diseases, aquatic organisms, and excessively high water temperatures due to high air temperatures.

Surface drainage is a crucial technique used to prevent or mitigate these problems.

6.2 Timing and duration

The drainage period should generally start as early as 2 days after seeding and conclude as late as 3 weeks after seeding, which is when seedling establishment is complete. During this time, it is vital to eliminate stagnant water.

6.3 Water management condition

Surface drainage vs. drying out: Surface drainage is a traditional water management practice for surface-sown seedlings, similar to raising nurseries for transplanting. It is different from the practice of "drying out" the field for "underground" or "subsurface" seeding (e.g., for oxygen-release coated seeds or anaerobic-tolerant varieties).

Soil condition: With surface drainage, the surface is drained, but underneath it remains saturated with water. Even if the surface dries, only slight cracks should appear.

- Ideal state: Keep the seedlings fully watered (wet enough that water pools around footprints). While water should pool in the furrows made during sowing, it is best for the water to drain immediately around the seeds.
- Seed observation: As the seeds are visible on the soil surface during this period, you can easily observe their growth, such as the appearance of the coleoptiles and the first leaf.

6.4 Regional differences in management

Management practices should be adjusted based on the regional climate, as the primary disturbances differ between warm and cold regions.

Region	Primary Disturbances	Management Strategy	Rationale
Warm Regions	Pests (e.g., golden apple snails) and high water temperature in stagnant water	Start drainage earlier.	Mitigate immediate threats from pests and heat.
Cold Regions	Slow germination and growth; high susceptibility to low temperatures at the coleoptile elongation stage	Start drainage later than in warm regions.	The water retains heat, which favors the early growth of seedlings.

6.5 Key benefits of surface drainage

Surface drainage provides multiple benefits for direct-sown rice:

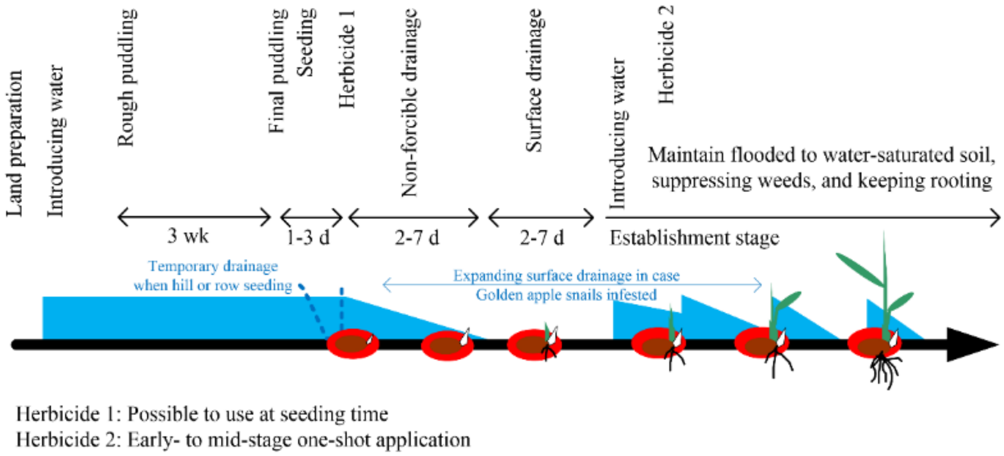
- Improved establishment: prevents poor seedling establishment and uneven early growth.
- Protection: prevents damage from pests, diseases, and aquatic life, as well as herbicides.
- Heat control: prevents seedling death due to an excessive temperature rise in stagnant water on hot days.
- Waterfowl deterrence: prevents waterfowl from entering the field and causing a disturbance.
- Soil health: protects seedlings from damage caused by a decrease in soil redox potential.
- Lodging resistance: promotes root spread into the underground, which increases the plant's

resistance to lodging (falling over).

The ideal condition for drying seedlings is to keep them fully watered (wet enough that water pools around the footprints). Water should pool in the furrows made when sowing, but it is desirable for the water to drain around the seeds.

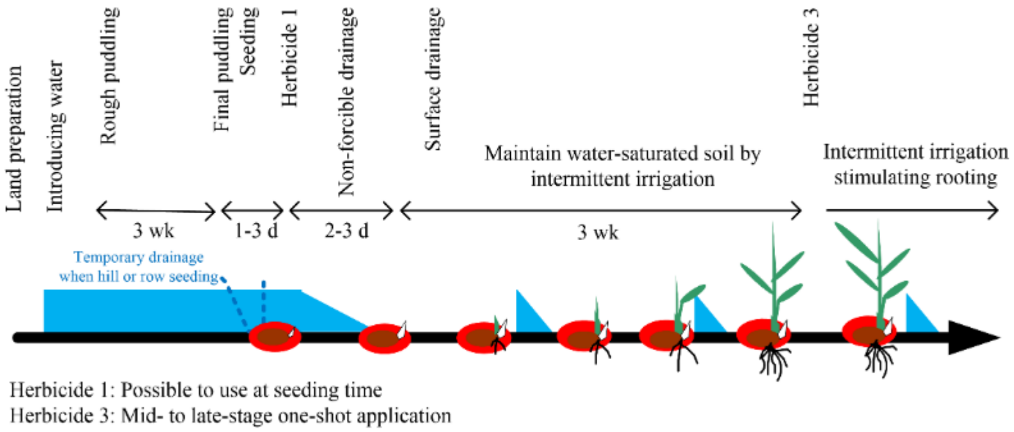
In surface seeding, many of the seeds are visible on the soil surface, especially during the periods of surface drainage, and you can observe the growth of the seeds. The photo shows the coleoptiles growing and the 1st leaf appearing, 1 to 2 days after the drying process began.

7 Direct seeding in puddled fields



Basic pattern of direct seeding of iron-coated seeds in puddled fields

Shortening the surface drainage period may reduce weed infestation, thereby lowering the number of herbicide applications.



Basic pattern of direct seeding of iron-coated seeds in puddled fields

Prolonging the surface drainage period, and its extension not only reduces poor seedling establishment but also reduces lodging susceptibility.

The method of direct seeding with iron-coated seeds in puddled fields is characterized by weed suppression without early drainage (in the broadcasting method).

7.1 Broadcasting (water seeding)

7.1.1 Land preparation and puddling

Phase	Action	Timing and remarks
Land preparation	Leveling, installation of open ditches, suppressing weeds	From after the harvesting in autumn to early spring
Rough Puddling	Weak puddling	3 weeks before final puddling. Effective in weed suppression.
Final Puddling	Adequate intensity of puddling with shallow water depth	1 to 3 days before seeding

7.1.2 Seeding and initial water management

- Seeding: broadcast iron-coated seeds onto the puddled water.
- Herbicide application: Apply herbicide 1 to 3 days after puddling (at seeding time) Delaying seeding strengthens weeds.
- Initial water: Do not drain the puddled water This is the main advantage, as the water suppresses weed growth Replenish water if the level naturally decreases.

7.1.3 Crucial drainage timing

- Start drainage when: The tips of the white coleoptiles become visible on the surface of the seeds.
  - Warm season: Approximately 2 days after sowing.
  - Cold season: Approximately 7 days after sowing.
- Special considerations:
  - Low temperature (<17°C): Delay drainage until the 1st leaf elongates, or maintain full water, as the coleoptile is sensitive to cold.
  - Late frost (spring): Flooding is required.
- Risk of delayed drainage: If drainage is delayed too long, roots may grow above the soil surface, causing seedlings to float and fail to root.

7.1.4 Surface drainage period

- Purpose: To allow rice plants to take root in the soil.
- Start/End Timing:
  - Start: Immediately after the puddled water has been drained.
  - End (Re-watering): When the rice plants have taken root and the 1st or 2nd leaves are visible.
- Duration: Varies significantly based on conditions:
  - Cold or low pest/snail damage: Approx. 2 days.
  - Warm seasons: Approx. 7 days.
  - Golden apple snails infested paddies: Approx. 3 weeks. Extension is also necessary if pest/aquatic organism damage is observed.
- Water replenishment: The soil surface must be kept moist. Replenish water (usually once a week) when the surface dries out and begins to crack (typically 5 to 7 days after drainage starts) .
- Weed control (during drainage): If weeds become rampant, use a clincher bath or similar herbicide application during the drainage period.

7.1.5 Establishment and post-drainage water management

- Watering (Post-drainage): After the rice plants have fully emerged and pest/snail damage has decreased, re-water the field.
- Herbicide 2: Apply herbicide 2 (Early- to mid-stage one-shot application). Maintain water after application to suppress weeds.
- Mid- to late-stage: Once the rice plants cover the field, switch to intermittent irrigation to keep the field slightly dry. This is done to encourage deep rooting and increase tolerance to lodging.

  Note: This differs from transplanting, where fields are constantly flooded to suppress weeds. Direct seeding uses a denser planting rate (5 kg/10 a) than transplanting.

7.2 Hill and row seeding after temporarily removing the puddling water

- Procedure: water is temporarily drained only during machine operations (seeding, side-row fertilization, herbicide 1 application) and then immediately re-entered.
- Drawbacks: requires temporary drainage, which wastes labor and water, potentially causes pollution, and increases the tendency for weed growth.
- Advantages: despite the drawbacks, this method offers many advantages (e.g., precise plant spacing, fertilizer application).

7.3 Wet seeding

- Adaptability: direct seeding after puddling is highly flexible, allowing adjustments to iron coating ratios and concentrations as needed.
- Application to wet seeding (popular method in Asia): Iron-coating technology may improve the widely practiced wet seeding method (seeding pregerminated seeds after forced drainage).
  - Low coating ratio: A coating ratio as small as 0.1 is possible because floating seedlings are less likely.
  - Benefits: Easily and quickly coated at low cost. Alleviates problems such as the need for precise field leveling, timing issues, seeds being washed away by water/rain, and damage by birds.

8 Direct seeding in non-puddled fields

Iron-coated seeds can be directly sown in flooded or dry fields without plowing or puddling. The most suitable locations are the fields with a high water-holding capacity (i.e. little water leakage).

The advantages are that no plowing or puddling is required, which allows for greater labor savings and cost reduction, as well as more stable seedling establishment.

The disadvantages are that its application is limited to paddy fields that do not require plowing and have good water retention, and that it requires more frequent use of herbicides and higher amounts of fertilizer. In addition, care must be taken to prevent the emergence of volunteer rice (the seeds dropped in previous rice crops) and weedy rice.

8.1 Direct seeding in flooded, non-puddled conditions

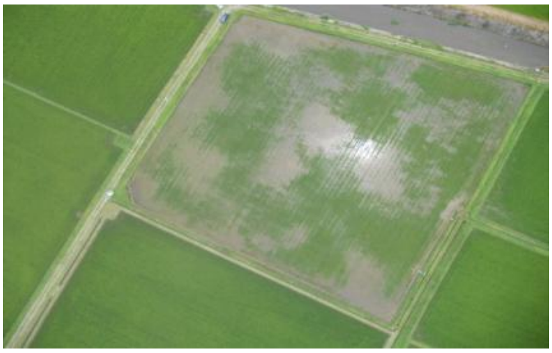
This is the same as water seeding in the United States where the land is prepared in dry soil. (In Asia, puddling is common because the soil is wet during the land preparation due to the monsoon rains.)

8.2 Dry seeding

The difference from conventional dry seeding is that it is surface seeding and that it is flooded for at least half a day after seeding. In conventional direct seeding, the seeds absorb water in the soil supplied from rainfall and germinate, but iron-coated seeds are surface seeded and do not absorb enough water from the soil.

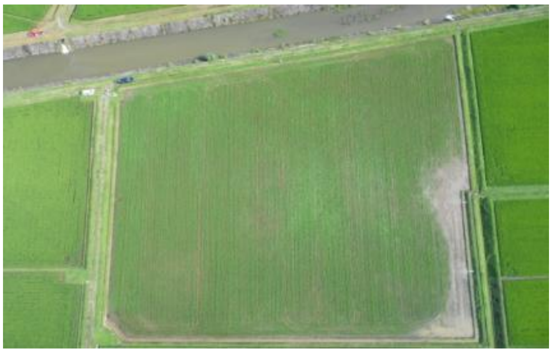
On the other hand, if rainfall occurs immediately before sowing, conventional dry seeding cannot be carried out, but dry seeding of iron-coated seeds can be carried out by switching to non-puddled, flooded direct seeding.

8.3 A case study where puddling was replaced by non-puddling



Direct seeding in flooded water after puddling. Waterlogged areas occurred and seedling establishment was poor. It is difficult to level a 1-ha field by plowing and puddling, and waterlogged areas could not be avoided due to excessive puddling (2011). As a result, poor seedling establishment caused by rice water weevils occurred widely.

Before seeding, the field was leveled with a laser leveler, and then iron-coated seeds were directly sown in flooded water without puddling (2012).

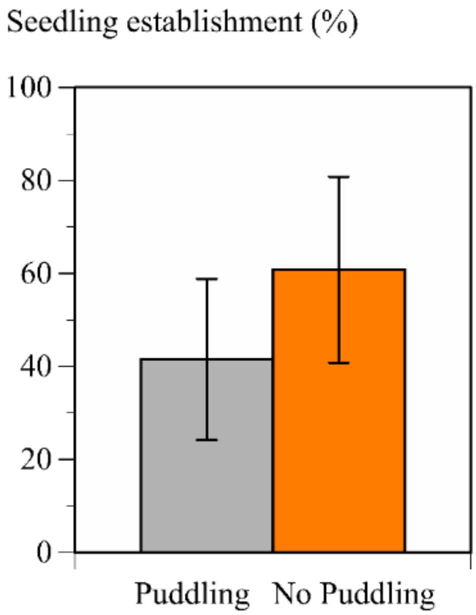


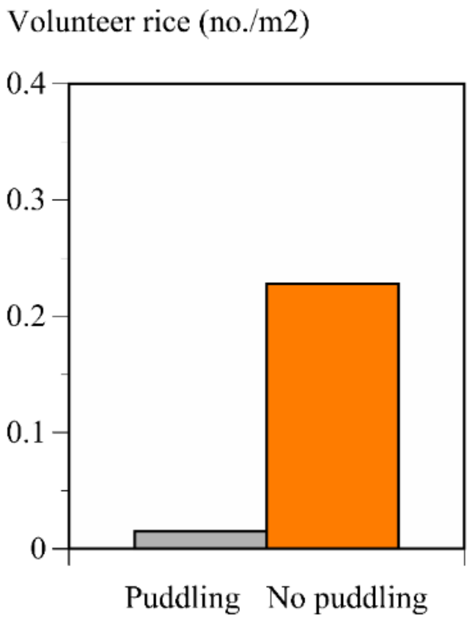
As a result, there were almost no stagnant water areas, little soil reduction or pests appearing, and seedling establishment was stable (2012). Water management leads to the reduced use of pesticides in cultivation.

In non-puddled rice fields, water can be added and seeds can be sown in the same way as in puddled rice fields. The photo shows an example of using a hill seeder.

When seeding iron-coated seeds directly into dry fields, after broadcasting them in the field, water is introduced and the soil is left submerged for at least half a day to allow the seeds to absorb the water and be in good contact with the soil.

8.4 Effect of non-puddling on the seedling establishment percentage and occurrence of volunteer rice





The seedling establishment percentage tends

Under non-puddled conditions, volunteer rice to be higher under non-puddling conditions (Fukuyama City, Hiroshima Prefecture).

is likely to occur (Fukuyama City, Hiroshima Prefecture).

To prevent the occurrence of volunteer or weedy rice, it is important not to drop the rice grains during harvest, and to conduct seeding late, using Roundup to kill any weeds that may be growing just before seeding and flooding, and then seed iron-coated seeds on the surface without tilling.

When volunteer or weedy rice occurs in non-puddled or dry seeding, introduce puddling then, direct seed or transplant.

9 Damage to the seedling establishment by birds

Iron coating reduces bird damage during the seedling establishment. The damage occur differently depending on the bird species, so different measures are required.

When iron coating is not used, the damage from sparrows is prevented by flooding (which attracts ducks) and that from ducks is by draining (which attracts sparrows), making it difficult to take effective measures. With iron-coated direct seeding, drainage may suppress damage from both ducks and sparrows. Although draining fields stimulates weed infestation and delays the growth of seedlings at low temperature, it is necessary to prioritize the measures against birds over weed and low temperature because of the seriousness of bird damage.

<Sparrow>

Because the coating layer becomes hard as the increase in iron concentration, it takes longer for the sparrows to break it and eat the seeds.

When the seed rate is small, damage by birds will result in a lack of seedlings and a drop in yield. When the seed rate is around 50 kg/ha, even if there is some bird damage, there is little risk of a lack of seedlings.

The damage may decrease as the coating ratio and iron concentration increase, and vice versa.

<Greenfinch>

Iron coating is also effective for reducing the damage caused by greenfinches. Because they cause more damage than sparrows, the iron coating ratio and iron concentration should be increased more than for sparrows.

<Spot-billed duck>

The damage caused by ducks occurs when the direct- seeded fields are flooded after seeding. When the field is drained, they do not come.

Damage is greater when the water is deep. Damage also occurs at night. If the water on the rice

field remains turbid, and the seeds have disappeared after seeding, there is a possibility that ducks have been coming at night.

<Crow>

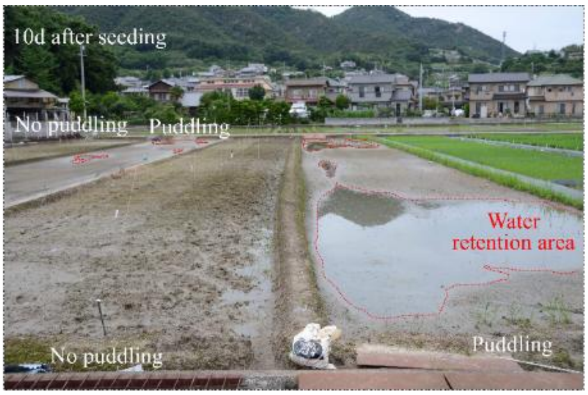
The damage caused by crows has not been fully confirmed, but there have been reports of them flying in flocks and causing mischief, such as wiping out seedlings or uprooting them.

If flocks of crows are seen flying into or around the direct seeded fields, it is important not to leave them alone, but to flood them if they are surface-drained, or to stretch fishing line around or in the center of the field.

Thus, the damage caused by ducks, sparrows, and greenfinches can be overcome by adjusting the iron coating ratio and iron concentration and/or through surface drainage. However, the issue of the damage caused by crows has not been solved yet.

10 Damage to the seedling establishment by soil reduction

The surface drainage at emergence protects the seeds from damage due to soil reduction, because the seeds are exposed directly to atmospheric oxygen.



In non-puddled fields, permeability is high and water does not accumulate. On the other hand, excessive puddling reduces permeability and creates stagnant water.

In the ill-drained portions of field, no seedlings are established. In non-puddled fields, rice grows, but many weeds also appear.

In the stagnant water area, there are many dead seeds and seedlings failed in anchorage (rooting). Some of them will recover and rise up by extending the periods of surface drainage.

Soil reduction retards rice growth, and many seeds die due to infection.

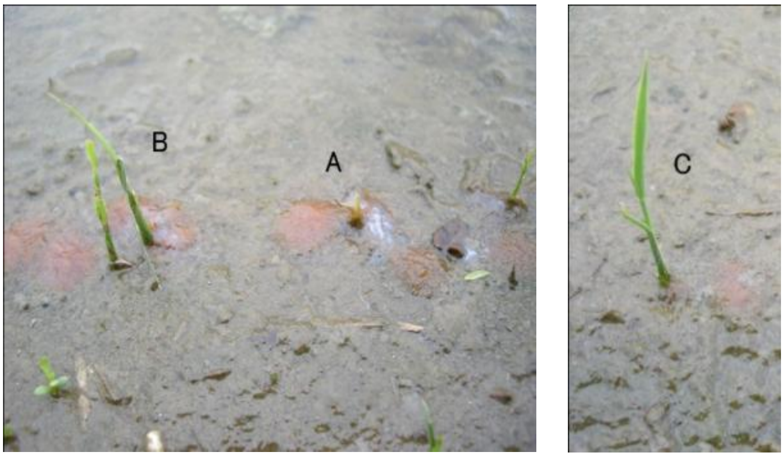
Seedlings grow vigorously in non-puddled paddy fields. On the other hand, in puddled paddy fields, root growth is inhibited due to the reduction, especially in the stagnant water areas. The failure of rooting causes many seedlings to fall over on the surface of the fields.

The countermeasures are to puddle with appropriate strength and to install open channels to prevent stagnant water from occurring.

11 Damage to the seedling establishment by pests and aquatic organisms

When iron-coated seeds are direct-seeded, damage from rice water weevils, snails, golden apple snails, midges, horseshoe shrimp, and seedling rot (*Pythium bacteria*) has been confirmed. Such problems have been reported in rice production in general, therefore, they are not particular to iron coating. They can be solved by water management and proper use of pesticides.

When direct seeding with iron coating is practiced in abandoned rice fields in mountainous areas and in rice paddies adjacent to forests, the extent of damage varies depending on the seeding time. In severe cases, no seedlings establish at large scales. On the other hand, direct seeding with iron-coated rice has been often successful in rice fields surrounded by the fields with transplanting where pests and diseases have been adequately controlled. Thus, pests and aquatic organisms should be properly controlled to achieve stable seedling establishment with iron-coated seeds.



Seedlings damaged after seeding

A: Damage immediately after emergence, B: Damage during the development of the leaves, C: Rice with minimal damage (Photo taken in a field 3 weeks after sowing, with a seedling establishment percentage of 30%). With direct seeding, early pest control leads to stable seedling establishment.

Damage caused by rice water weevils

Chironomid

Damage being caused by snails

Seedling rot

A phenomenon that occurs when pests, diseases, or disturbances caused by aquatic organisms occur.

- Germination or emergence was confirmed 3 to 5 days after seeding, but the seedlings subsequently lost their vitality, became pale, fell over, or withered while still standing. The seeds were observed not to have germinated. The seeds ran out midway through.
- One week after seeding, the coleoptiles have unfolded and the 1st and 2nd leaves are growing, but

they look as if they have been bitten off by something.

- The seeds were sown on the surface, but after a week they had sunk into the soil and could no longer be seen.
- There is absolutely no rice or weeds growing on the surface of the rice fields one to three weeks after seeding.

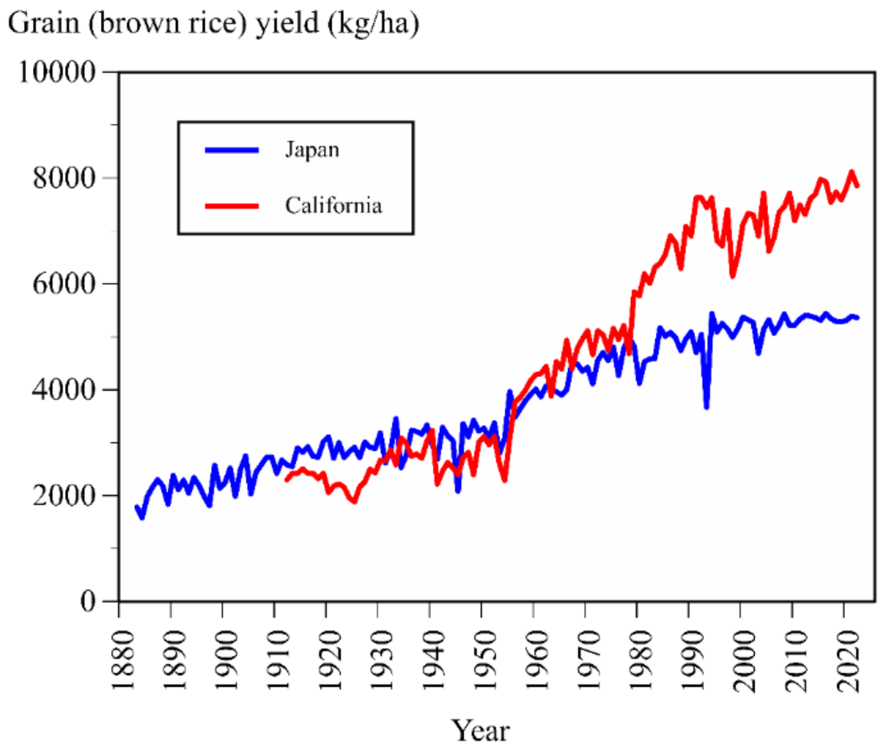
Measures against pests and aquatic disturbances

Improving water management and extending the drainage period are effective countermeasures. When this is difficult, pesticides should be used.

- The damage can be reduced by surface drainage, especially when the term of drainage is extended.
- Switch from water seeding to wet seeding.
- Water seeding without puddling or dry seeding can solve this problem.
- The use of seed treatment agents (pesticides) during coating is labor-saving and very effective. The application of pesticides after seeding into the fields is also effective. Appropriate use of pesticides will ensure seedling establishment even if surface drainage is not practiced.
- Once poor seedling establishment has occurred, it is too late to administer pesticides. Prevention is better than cure.

1 2 Key points for achieving high yields with iron-coated seeds

Some people believe that direct seeding cannot produce high yields, but the yield in California, which uses water seeding without puddling, was the same as Japan's transplanting until 1980, but has since increased and is now 1.4 times higher. This shows that it is possible to produce higher yields with water seeding than with transplanting.



Comparison of yields between California and Japan (using data from the Ministry of Agriculture, Forestry and Fisheries of Japan and the United States Department of Agriculture) The main planting method in California is non-puddled, water seeding of pregerminated seeds, while in Japan it is transplanting.

If directly seeded with iron coating, and grown properly, it will produce yields that are the same as or several percent higher than those produced by transplanting.

Comparison of transplanting and iron-coated surface seeding of Koshihikari

(Test paddy field after yield survey in September 2005)

Transplant (water end side)

Iron coating (center)

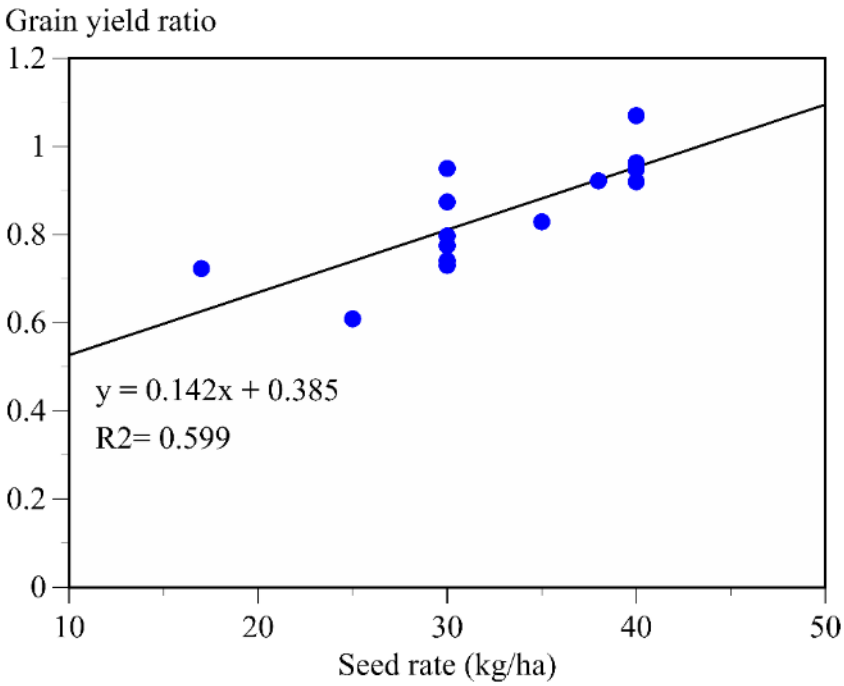
Iron coating (water inlet side)

The average brown rice yield over the three years from 2003 to 2005 was 4,930 kg/ha when transplanted and 5,280 kg/ha when iron-coated seeds are row-seeded on the soil surface after puddling. The seed rate was 62 kg seed dry weight/m^2 (232 seeds/m^2), with a seedling establishment percentage of 60.9% (141 seedlings/m^2).

High-yielding varieties, which are characterized with big panicles and few tillers, requires dense planting for high grain yield. When transplanting machines are used, the row spacing is mostly fixed by 0.3 m and the hill spacing is limited between 0.14 m and 0.18 m, so dense planting is difficult, but with direct seeding, it is easy to increase the plant density just by increasing seed rate.
The key points for achieving stable, high-yield with iron-coated direct seeding are as follows:

12.1 Optimization of seed rate

The grain yield in the direct seeded rice fields with iron-coated seeds (on-site farmers' fields) is the same as that of transplanted rice fields, or tends to be about 10% lower. The main cause is an insufficient seed amount. Other reasons include inadequate water and fertilizer management and failure to control weeds. To increase the yield, it is necessary to fully understand the difference between transplanted and direct seeded cultivation.
High grain yields are achieved with a seedling density of 100 to 150/m^2 in direct seeding in general. However, in many areas of the farmers' fields where iron-coated direct seeding has replaced transplanting, yields have declined to only 90% of that of transplanting, with the seedling density of 60 to 80/m^2, which had been caused by the decrease in seed rate from the 50 kg (seed dry weight)/ha (the recommended seed rate for iron-coated seeds) to 20 to 30 kg/ha (conventional seed rate for the nursery of transplanting).



Relationship between seed amount and yield in large-scale demonstration fields conducted nationwide in Japan by Zennoh (2015)

The yield ratio indicates the ratio of grain yields of iron coating to transplanting. The seed rate of iron coating is expressed as the weight of dry seeds. All sites were tested using fertilizers specifically designed for direct seeding.
The average seed rate was low at 3.2 kg/10 a, and the yield was only 84% of that of transplanted. It is estimated that a seed rate of 43 kg/ha would produce the same yield as transplanted, and a seed rate of 50 kg/ha would produce a yield 10% higher than transplanted.

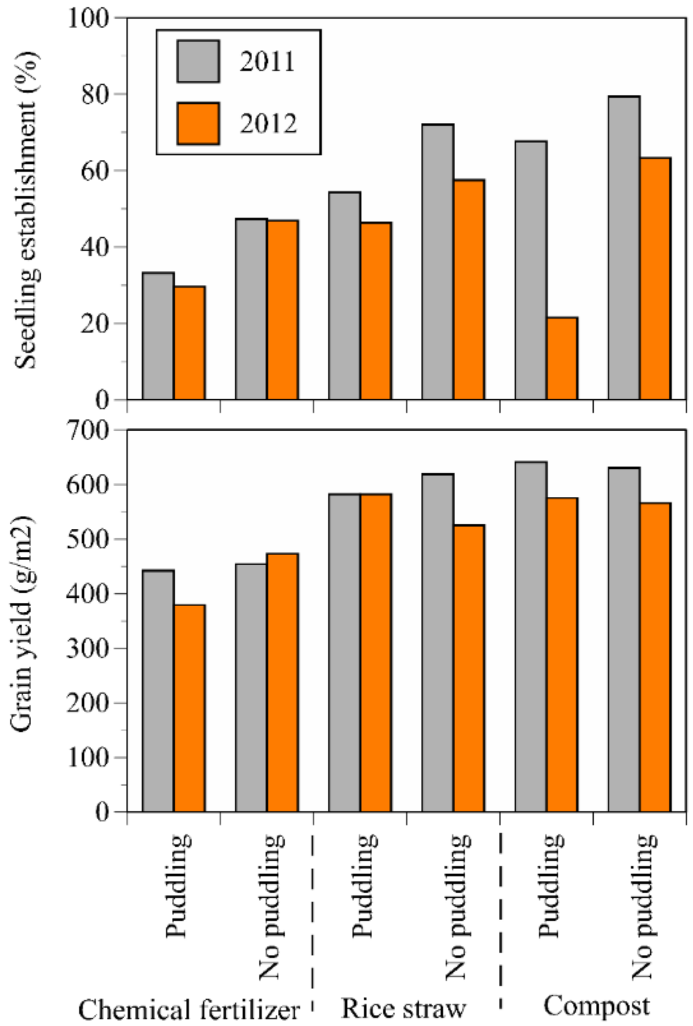
In addition, there are cases where the seed rate was intentionally reduced due to concerns about reducing the lodging problem, although the effect of this is far smaller than the effect of optimizing water and fertilizer management or introducing lodging-resistant varieties.

12.2 Improvement of water management

Improper water management leads to unstable seedling establishment, failure to control weeds, and increased lodging, which reduces yields. In order to suppress the emission of greenhouse gases and to increase root activity in order to prevent the occurrence of white immature grains due to high temperature damage, keeping the soil oxidized through alternate wet and drying would also lead to higher yields of iron-coated direct-sown rice.
The installation of open channels for drainage is effective in labor-saving, proper, and rapid water management in direct seeded fields, particularly after puddling. In high water-holding fields with little water leakage, light or no puddling is used. Also, after the seedlings have established and the rice plants have covered the surface of the field and are outcompeting the weeds, it is important to extend the intervals between watering and keep the field watered and dry to encourage root growth and dry the soil.

12.3 Fertilization management

When direct seeding iron-coated seeds, applying organic matter or compost will increase yields.



Seedling establishment and yield of iron-coated seeds in puddled and non-puddled flooded direct seeding in fields continuously treated with chemical fertilizer, rice straw, and cow manure compost (paddy field at the Western Japan Agricultural Research Center of the National Agriculture and Food Research Organization)

12.4 Yield of conventional vs. newly developed iron-coated seeds

Direct seeding of the new iron-coated seeds can produce higher yields than conventional methods.

Germination, field establishment and yield of three iron-coated seeds
(Akisakari variety, Mihara City, Hiroshima Prefecture, sown on May 25, 2023)

	Iron coating (pregerminated seeds)	Iron coating (dried pregerminated seeds)	Conventional iron coating (dried pregerminated seeds)
Date of coating	5/25	3/14	3/14, 4/28
In petri dish			
Germination (%)	93.7	91.9	94.0
Germination rate (d)	0.55	1.82	2.5
18 days after seeding			
Seedling establishment (%)	51.4	52.7	48.8
Seedling height (cm)	12.9	12.2	11.4
Single seedling wt. (mg)	31.9	24.8	20.2

Seedlings started tillering (%)	53.7	26.1	15.0
117 days after seeding			
Plant wt. (g / m^2)	1,697	1,579	1,490
Brown rice yield (g / m^2)	609	583	535

The relative merits of iron-coated seeds in terms of labor-saving in seed production, rapid germination, and yield are as follows in our experience to date:
New iron coating (pregerminated seeds) ≥ New iron coating (dry pregerminated seeds) ≥ Conventional iron coating (dry pregerminated seeds).

13 Sustainability

The area under rice cultivation is large, and any change in the cultivation method will have a significant impact on the environment. Therefore, when introducing direct seeding cultivation, careful consideration of the sustainability is required. Here, we have listed some points to consider when introducing direct seeding of iron-coated seeds, particularly regarding environmental issues.

13.1 Safety of the coating materials

Iron, iron oxide, and calcined gypsum are applied to the fields every year when we employ the direct seeding with iron-coated seeds. The negative impact on the environment, however, would be small for the following reasons:

- The iron, iron oxide, and calcined gypsum used are natural or derived from them.
- When iron-coated seeds are seeded in a field, the amount of iron added is 25 kg/ha (seed rate 50 kg/ha, iron coating ratio 0.5).
- Iron is naturally contained about 7% in the soil of rice fields, which is large in amount. To increase soil fertility, it is recommended to apply soil improvement materials containing iron at the annual application of 340 kg of iron/ha. The amount used in this technology is 1/13 of that amount.
- Then, we may expect the soil ecosystem is little affected by the iron brought about by iron-coated seeds.

13.2 Reduced use of chemical fertilizer

Because direct seeding of iron-coated seeds is a surface seeding method, the seeds are less susceptible to the soil reduction damage as compared to the underground/subsurface seeding method. Compost and organic matter can be applied and utilized to increase the soil fertility, reducing the amount of chemical fertilizer use.

13.3 Reduced use of agricultural chemicals

You can choose to use or not use pesticides and herbicides as needed.

- The frequency of herbicide use is higher for direct seeding than for transplanting in general. It depends on the occurrence of weeds, but generally it is about four times for dry direct seeding, two times for flooded direct seeding, and once for transplanting. If the germinated seeds are iron-coated and then sown without plowing, it is thought that it is possible to reduce the frequency to the same level as for transplanting.
- Because iron-coated direct seeding is surface seeding, no oxygen suppling chemicals are required.
- It is confirmed that direct seeding with iron coating suppresses the occurrence of seed-borne

diseases. This is a natural phenomenon caused by the effect of active oxygen generated when iron rusts. This allows the use of seed disinfectants to be omitted.

- The prevention of bird damage by iron coating is confirmed. There is no need to use chemical repellents.
- For pest control, seed treatment or field control agents are used only when necessary. Seed treatment has a smaller impact on the environment than the application to the entire field. Improving water management, especially surface drainage, is effective for pest control during the seedling stage, which eliminates chemical pesticide use.

13.4 Water resource conservation

In rice paddies, whether puddling is carried out properly or not plays a crucial role in the conservation of water resources. In fields where the water-holding capacity is low with high soil permeability, puddling plays an essential role in saving water. On the other hand, in the fields which locate lower positions in toposequences and where water permeability is low, puddling creates inadequate drainage, making water control difficult. Because iron-coated seeds can be seeded both in puddled and non-puddled fields, land preparation could be carried out properly on the basis of the fields' water-holding capacity, contributing the water resource conservation.

Water seeding of iron-coated seeds saves water because the puddling water is not forcibly drained as is popularly conducted in conventional wet seeding in many Asian countries. In addition, because the puddled water contains a large amount of nutrients and clay, water pollution caused by their runoff can be avoided.

13.5 Global warming (methane emission) countermeasures

Alternate wet and drying of rice fields (AWD) is assumed to be useful in the suppression of methane emission. AWD may have good compatibility with the water control of iron-coated direct seeding which requires the improvement of rooting to achieve high grain yields.

13.6 Suppression of weedy rice emergence

The occurrence of weedy rice is a serious problem in direct seeding. More than 20 years have passed since the start of cultivation of iron-coated seeds, but no occurrence of weedy rice has been reported. One of the reasons why weedy rice emergence is suppressed could be the puddling followed by water seeding of iron-coated seeds.

Thus, it seems that the introduction of iron coating in the rice direct seeding may contribute to sustainability in various ways. Further studies are required to confirm this.

14 Intellectual property rights and technical guidance

This manual incorporates technology that is protected by Japanese Patent No. 7092423 and Chinese Patent No. ZL 2022 1 1548935.4. We kindly request your cooperation in respecting these intellectual property rights. For users in Japan and China, the technology is legally protected in your countries. For researchers, producers, and manufacturers in other countries, we would ask that you consider the intellectual property is in use for the sake of farmers and consumers of rice worldwide. For specific technical details, licensing information, coatings, cultivation methods, or partnership inquiries, please contact the author.

Reference materials

Inoue, H., Yamauchi, M., and Miyagawa, H. 2009. Control of seed-borne diseases of rice seedlings by coating seeds with iron. (In Japanese, with English abstract.) Jpn. J. Phytopathol. 75:164–169.

Kurihisa, H. 2009. Damage of seedling establishment by rice water weevil in the direct seeding of iron-coated seeds of rice plants. Agricultural Research Highlight of Kinki, Chugoku, and Shikoku District of Japan. (In Japanese.) Natl. Agric. Food Res. Org.

Matsuura, S., K. Takemoto, M. Tojo, and M. Yamauchi. 2012. Reduced seedling growth on rice caused by Pythium arrhenomanes after direct sowing of iron-coated seeds. (In Japanese, with English abstract.) Jpn. J. Phytopathol. 78:301–304.

Miyagawa, H., Yamauchi, M., Inoue, H. 2013.The control of seed-borne diseases of rice seedling by iron-coating seeds in a mass production machine. Ann. Rept. Kansai Pl. Prot. 55: 23-30.

Sato, T., S. Azuma, and T. Ichikawa. 2011. Effect of the amount of iron coating, seeding depth and water management after seeding on emergence and seedling establishment of rice direct-seeded in a submerged paddy field in Hokuriku Region. (In Japanese, with English abstract.) Jpn. J. Crop. Sci. 80:157–164.

Takimura, Y., and S. Hoshino. 2010. Injury of seedling establishment by pond snails in the direct seeding of rice with iron coating. Agricultural Research Highlight of Kinki, Chugoku, and Shikoku District of Japan. (In Japanese.) Natl. Agric. Food Res. Org.

Japan Patent 4441645 Manufacturing method for iron powder coated rice seeds (Inventor: Minoru Yamauchi, Patent holder: National Agriculture and Food Research Organization) Application date: 2004/1/6

Japan Patent 5717110 Manufacturing method of non-aggregated single particle iron-coated rice seeds. (In Japanese.) (Inventor: Minoru Yamauchi, Patent holder: National Agriculture and Food Research Organization) Application date: 2013/5/13

Japan Patent 7092423 Direct seeding method for rice seeds and coating method for rice seeds (Inventor: Minoru Yamauchi, Patent holder: Minoru Yamauchi) Application date: 2022/1/28

China Patent ZL 2022 1 1548935.4 Direct seeding method for rice seeds and coating method for rice seeds (Inventor: Minoru Yamauchi, Patent holder: Minoru Yamauchi) Application date:2022/12/05

Yamauchi, M., Domon, M., Kano, M and Fujiwara, I. 2008. Technology of mass production of iron-coated seeds. (In Japanese.) New Technol. in Kinki, Chugoku, and Shikoku District 7:22–24.

Yamauchi, M. 2012 Direct seeding of rice crop in flooded paddy fields suing iron-coated seeds. Jpn. J. Crop Sci. 81: 148-159

Yamauchi, M. 2017. A Review of Iron-Coating Technology to Stabilize Rice Direct Seeding onto Puddled Soil. Agronomy J. 109:739-750

Yamauchi, M., Shiomi, S., Higuchi, R., Yamakawa, S., Muraoka, K., Nakanishi, K., Abe, H., Higashino, H., Tanaka, T., Yamamoto, S., Ishihama, N., Kanda, F., Ono, H., Iwata, K. 2018 Manual for direct seeding of rice using iron-coated seeds 2018 1-57 National Federation of Agricultural Cooperative Associations

Yamauchi, M. 2019 Labor-saving, stable, high yield and environmental harmony in iron-coated direct seeding of rice. Soil Improvement Eco-Farming (Tsuchidukuri to Ekonougyou) 51: 27-34

Yamauchi, M., Homma, T., Morimoto, S., Ogata, S., Satou, H. 2022 Iron-coated seeds of rice with suppressed heat damage associated with iron oxidation and rapid emergence, which can be sown just after coating. In: Abstract 254th Meeting Crop Sci. Soc. Japan. p. 21.

Yamauchi, M., Ogata, S., Homma, T., Morimoto, S., Katajima, K., Kawara, N., Asonuma, H., Okubo, T., Hidaka, H., Satou, H. 2023 Expanding seeding time of iron-coated seeds of rice from just after coating to several months as affected by iron contents in coating layer. In: Abstract 256th Meeting Crop Sci. Soc. Japan. p. 40

Yamauchi, M., Ogata, S., Homma, T., Morimoto, S., Sato, H., Katajima, K., Kawara, N., Asonuma, H., Okubo, T., Hidaka, H. 2024 Simplification of seed preparation and improvement of initial growth of rice direct seeding technology with iron coating. In: Abstract 257th Meeting Crop Sci. Soc. Japan. p.138

Yamauchi, M., Saeki, T., Takashima, K., Furuzono, S., Kubota, R., Hasegawa, T., Nagatomo, M., and Fujita, Y. 2024 Broadcasting improved iron-coated seeds with drone in terraced rice fields in Kyushu mountains. In: Abstract 258th Meeting Crop Sci. Soc. Japan. p.4

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