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**REVIEW**

# Research and Control Techniques for Volunteer Rice

**Youichi OHDAIRA***

Central Region Agricultural Research Center, National Agriculture and Food Research Organization, Jo-etsu, Japan

## Abstract

Recently, the Japanese government policy has recommended the cultivation of multipurpose high-yield paddy rice cultivars for animal feed (not only in the form of brown rice but also of whole crop silage (WCS) and others) in response to the decrease in demand on palatable rice for human consumption in Japan. However, when palatable cultivars are cropped in the following year of cultivations of high-yield cultivars for animal feed, the seeds of the high-yield cultivars are often left in the paddy field and grow as volunteer rice in the next crop season over winter, resulting in decrease in grain yield and lowering the quality of the palatable rice. Up to date, many ecological studies on overwintering ability of rice seeds have been carried out, and several key techniques on how to reduce volunteer rice were developed. This review summarizes ecological characteristics of volunteer rice, and describes effective countermeasures with cultural method, herbicides, lime nitrogen, and premature harvest (for only WCS).

**Discipline**: Crop Science
**Additional key words**: Herbicide, Lime nitrogen, Tilling, Wintering

## Introduction

Rice consumption by Japanese people has been steadily decreasing by 0.1 million tons per year in Japan (MAFF 2022). Overproduction results in decrease in rice prices, negatively affecting farmer's income. To avoid such situation, the Japanese government and Japan agricultural agency try to decrease rice production to meet the demand and supply in the market. However, the increase in fallowing or abandoned paddy fields leads to the loss of various aspects of paddy fields, such as landscape maintenance and water storage function. On the other hand, Japan is importing huge amount of corns and soybeans from abroad for the purpose of animal feed, resulting in low percentage of food self-sufficiency below 40% (MAFF 2020). Utilization of paddy fields to produce rice for animal feed in the form of brown rice and whole crop silage (WCS), among others, is one of the clues to increase food self-sufficiency. To tackle such issues in paddy rice cultivation and for the purpose of improving food self-sufficiency rates, rice cultivation to produce grains and WCS for animal feed has been promoted as a government policy in Japan. In particular, brown rice for animal feed is expected to have a marked potential demand, and it is also easy for paddy rice producers to transition to this from the production of palatable rice. According to the Basic Policy for Food, Agriculture and Rural Areas, which has been implemented by the Japanese government since 2020, a total production of 0.7 million tons of brown grain is the target for animal feed in 2030. The total production in 2020 was 0.38 million tons, so high yielding is inevitable to boost total grain production. Subsidy in accordance with yield of rice grain for animal feed has been provided (MAFF 2022).

When a palatable rice cultivar is cropped in the following year of a high-yield cultivar for animal feed, some of the seeds that were left in the paddy field before and at harvest can unexpectedly germinate, resulting in its growth as a volunteer rice in the next crop season with

*Corresponding author: yodaira@affrc.go.jp
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the palatable rice cultivar (Fig. 1) (Ohdaira et al. 2006). In Japan, palatable rice is graded according to the quality of the appearance of brown rice. This grading affects the rice price and market branding. When brown rice derived from volunteer rice of a high-yield cultivar mixes into the harvested brown rice of the palatable cultivar, the contamination leads to a degradation of rice quality for palatable rice grains. In addition, yields of animal feed rice are hampered when the producer avoids the cropping of high-yield cultivars and instead cultivates standard-yield, palatable cultivars. Suppressing the cost per product by increasing the yield is important in animal feed rice and WCS cultivation. For this purpose, it is necessary to popularize high-yield cultivars and to take measures against volunteer rice to maintain the brown rice grade of palatable rice.

Japan has a large landmass spanning from north to south, with climatic zones ranging from subarctic to subtropical. To develop control techniques for volunteer rice at a region-wide level, it is necessary to grasp the overwintering ability of seeds that were left in the field in autumn in each region and to devise cultural management control techniques or adopt chemical treatments that can be applied to all regions or tailored to individual regions. This paper focuses on (1) characteristics of shattering and overwintering ability of rice seeds, (2) control methods based on cultural control corresponding to regional characteristics, and (3) region-wide control methods. This paper summarizes the results of studies based on continuous rice cultivation practice, which is the common style of cultivating paddy rice in Japan.

In recent years, the problem of indigenous weedy rice that mixes with palatable rice cultivars has become apparent in Japan (Imaizumi 2018). Weedy rice grains are often colored and have remarkable shattering habits (Sakai et al. 2014, Imaizumi 2018, Aoki 2019, NARO 2019). Control of weedy rice is indispensable for maintaining the brown rice grade of palatable cultivars and multiple countermeasures have been developed toward that purpose (Sakai et al. 2011, 2014; Aoki 2019, NARO 2019). Some of the control techniques developed for weedy rice have yielded more practical results than for volunteer rice. They are referenced in this paper since these are applicable to measures against volunteer rice. In

**Fig. 1. Emergence of volunteer rice in inter row space**

addition to its high shattering habits, weedy rice is prone to severe natural diffusion (Sakai et al. 2014, Imaizumi 2018). Therefore, it is necessary to aim for its complete control. On the other hand, volunteer rice is unlikely to expand, so it would be enough to suppress the emergence of volunteer rice to a level that the yield and grade of brown rice of palatable cultivars are not affected. Therefore, extremely high-cost techniques to control weedy rice have not been the focus of this paper.

The transition from paddy rice to non-paddy field crops is also very effective in controlling volunteer rice. This will be briefly discussed at the end of this paper.

## Research findings and countermeasure techniques that have been developed for controlling volunteer rice

### 1. Characteristics of shattering and overwintering ability of rice seeds

The occurrence of volunteer rice largely depends on the number of seeds that were left in the field and the overwintering ability of these seeds. The degree of the shattering habit of each cultivar is clearly stated in the local records available in Japan. The rice cultivar for animal feed “Moretsu” was widely cultivated for WCS in Miyazaki Prefecture in the first half of 2000 owing to its excellent lodging resistance and high yield (Takeda et al. 2005). However, “Moretsu” had a very high shattering habit, and it often becomes volunteer rice in the next crop season. The subsequent rice cultivar “Minamiyutaka” was better than “Moretsu” with its reduced the shattering habit (Yoshioka et al. 2006). As such, it is important to select cultivars based on their shattering habits. In recent years, rice cultivars with short panicle have been developed for WCS in Japan (NARO 2020). These cultivars also reduce the problem of volunteer rice because much less seeds are dropped into the field.

A study on the overwintering ability of rice seeds was conducted in the western, moderately warm part of Japan (Ohdaira & Sasaki 2011). When seeds of various cultivars were embedded in the field in autumn, the germination rates of the collected seeds in spring tended to be low in cultivars with low seed dormancy. However, when seeds were placed on the field surface in autumn, the effect of the degree of seed dormancy on germination rates in spring is not clear (Ohdaira & Sasaki 2011). In addition, when seeds on the field surface were sequentially embedded from mid-October to December, the germination rate in spring was higher in those that were buried in December (winter) than in those that were embedded in October (autumn) (Ohdaira & Sasaki 2015). These results suggested that the seeds germinated by embedding in soil in autumn under suitable moisture and temperature conditions withered in winter. Section 2- (1), (2) discusses the relationships between the timing of seed burial, changes in air temperature, and the rate of germination after wintering along with a discussion on control by tilling.

In another study conducted in a moderately cold part of Japan, a clear relationship between the degree of dormancy and the rate of germination after wintering was not observed in seeds placed on a field surface or in soil in autumn (Ohdaira et al. 2015). This might have been due to the fact that the level of postharvest autumn temperature was not high enough to promote the germination metabolism.

### 2. Control methods based on cultural control corresponding to regional characteristics

(1) Warm and moderately warm regions

When seeds were sequentially embedded in the soil from mid-October to December in a western, moderately warm part of Japan, the germination rate after wintering tended to be lower for the seeds that were buried early (Ohdaira & Sasaki 2011). In addition, an effective cumulative autumn air temperature of 100°C or higher (lower limit temperature, 10°C) within the year was enough to reduce the overwintering ability of the embedded seeds. Moreover, when seeds were sown on the field surface to create pseudo fallen grains and the soil was tilled by rotary tillers at different times, the emergence rate of volunteer rice in the following year was lower in earlier tilling in autumn. The emergence rate of seedlings from fields tilled in autumn decreased to approximately one fifth compared to those that were tilled in winter or when the seeds were left on the field surface over winter (Ohdaira & Sasaki 2009). These results suggested that the generation of volunteer rice can be reduced by tilling in autumn when obtainable effective cumulative air temperature (lower limit temperature, 10°C) was more than 100°C in warm and moderately warm regions. It also confirmed that the effect of tilling in autumn could be further enhanced by excessive watering immediately after tilling (Ohdaira & Sasaki 2009).

The emergence of volunteer rice in the western, moderately warm parts of Japan peaks around early June (an effective cumulative spring air temperature of 480°C (lower limit temperature, 10°C)) under dry field conditions (NARO 2017). This indicates that the effective control of volunteer rice is possible by using nonselective herbicides that contain chemicals such as glyphosate and paraquat at that time, and then cropping the paddy rice of that year at a later time than usual (Naro 2017, Asami & Tachibana 2020).

(2) Cold and moderately cold regions

In the moderately cold and Pacific-side region, it has been shown that the germination ability of seeds could be reduced to 1/2 to 1/6 by leaving them overwintering on the field surface without tilling in autumn (Okawa & Tsujimoto 2009). This observation was made in an experiment conducted in Miyagi Prefecture, which faces the Pacific Ocean side where seeds are prone to freezing and death due to low temperatures in winter from radiative cooling caused by the cloudless winter weather. In Akita Prefecture, which faces the Sea of Japan side where cloudy and humid weather is frequent and snow covers the ground in winter, the correlation between seeds left on the field surface or in soil and their germination ability after wintering was unclear (Ohdaira et al. 2015). Taken together, in cold and moderately cold regions, tilling in autumn is undesirable, and utilization of region-wide control methods is recommended.

(3) Regionwide control methods

a. Herbicides

The use of herbicides containing specific ingredients that can act before and after transplantation is known to be effective for controlling of volunteer rice and weedy rice in Japan. It has been demonstrated that the use of butachlor as an initial agent is effective in preventing volunteer rice infestation in seed-producing fields in moderately warm regions (Nemoto et al. 1982). In addition, butachlor and pretilachlor have been reported to be effective as initial agents in preventing seedling establishment of volunteer rice in warm (Yano & Ogata 1991) and moderately cold regions (Yamauchi & Hattori 1994, Sato et al. 2006). The control value defined by the following formula can be quantitatively examined for the control effect. Control value = 100 – (percentage of seedling establishment using effective herbicide / percentage of seedling establishment using ineffective herbicide or no treatment) × 100. When an effective herbicide was applied as an initial agent for controlling of volunteer rice during paddy rice transplantation, the control values were 80-86 (Nemoto et al. 1982), 91-97 (Yano & Ogata 1991), 47-89 (Sato et al. 2006), 82-86 (Ohdaira et al. 2013), and 88 (Japan Grassland Livestock Seed Association, 2020). Since the emergence of weedy rice occurs asymmetrically over a long period, controlling this with only initial or early-middle-stage agents is difficult (Saito et al. 2002). The Nagano Agricultural Experiment Station has proposed a control technique for weedy rice with the systematic use of herbicides (Saito et al. 2002, Sakai et al. 2011). Combinations of (a) an initial agent and an early-middle-stage agent, (b) an initial agent and a middle-stage agent, or (c) an initial agent, an early-middle-stage agent, and a middle-stage agent during rice transplantation can perfectly mitigate weedy rice (Saito et al. 2002), while control values of 83-100 (Sakai et al., 2011), and 96-100 (Hosoi et al. 2008) can be achieved.

The growth stage of volunteer rice and weedy rice must be considered when herbicides are applied. The control effect is drastically reduced when effective herbicides are applied after the first leaf stage of volunteer rice and weedy rice (Yamauchi & Hattori 1994, Sakai et al. 2011). Based on herbicide tests conducted on weedy rice, the effective application timing for weedy rice must be “before development” or “before development to the beginning of development (the period of coleoptile emergence)” (NARO 2019). Other factors that influence the effects of herbicides are the ingredients used in the herbicide (Yano & Ogata 1991), the number of puddling times (Sato et al. 2006), and the timing of transplantation (Hosoi et al. 2008).

The Japan Association for Advancement of Phyto-Regulators website indicates herbicide products (including herbicide ingredients) that have shown superior efficacy for weedy rice control and that were proven to be harmless to transplanted rice through rigorous testing (Japan Association for Advancement of Phyto-Regulators 2022). Though the experiment area and the recommended application region are limited for these herbicides, these can be highly effective against volunteer rice using the registered pesticides and paying close attention to the precautions for their use.

b. 4-HPPD inhibitors

In transplanting cultivation, the use of 4-HPPD inhibitors can cause chlorosis in some high-yield cultivars (NARO 2017). Varietal difference has been proven to be based on whether they possess *HIS1* (*HPPD INHIBITOR SENSITIVE 1*) genes or not (Maeda et al. 2019). Taking advantage of this difference, a method had been proposed to control volunteer rice of the high-yield cultivar “Mizuhochikara” (NARO 2019). Since “Mizuhochikara” does not have *HIS1*, volunteer rice could be controlled after a year of cultivating “Mizuhochikara” by applying herbicides that contain 4-HPPD inhibitors prior to the emergence in transplanting cultivation of another insensitive rice cultivar.

Other 4-HPPD inhibitor-sensitive, high-yield cultivars besides “Mizuhochikara” are reported, but it should be noted that the degree of sensitivity varies depending on the cultivar. Moreover, it is necessary to apply the herbicide at the appropriate time as it is less effective when its application is delayed at later than emergence stage.

c. Lime nitrogen

Recently, it has been shown that application of lime nitrogen in the paddy field in postharvest autumn is effective in controlling the emergence of volunteer rice. Depending on the amount of cyanamide and treatment period, the cyanamide contained in lime nitrogen has the ability to break the dormancy and cause subsequent damage to the germination ability of rice seeds (Ohdaira et al. 2014). In Japan, lime nitrogen has been registered as an agricultural agent that causes barnyard grass seeds to break dormancy. It is applied in the field during autumn to break the dormancy of *Echinochloa* sp. seeds, so that they will perish in the low winter temperature. Lime nitrogen has the same effect of breaking dormancy on rice seeds. However, only the breaking dormancy is still insufficient for controlling volunteer rice, and the importance of ensuring that the effect of lime nitrogen leads to the elimination of the germination ability of rice seeds has been suggested (Ohdaira 2021).

The utilization of lime nitrogen also requires further attention. The duration from lime nitrogen application to tilling should be at least 2 weeks according to the field experiment conducted in moderately cold regions facing the Sea of Japan side (Ohdaira et al. 2019, Ohdaira 2021). It has also been shown that immediate tilling after lime nitrogen application did not suppress the emergence of volunteer rice (Ohdaira et al. 2019, Ohdaira 2021). In addition, the effect of lime nitrogen is halved when rice straw residue is present in paddy fields (Ohdaira et al. 2019, Okawa 2019). Herbicides are more effective than lime nitrogen in controlling volunteer rice and weedy rice, and the control value of effective herbicides is more than 90, whereas that of lime nitrogen is estimated to be approximately 80-90 overall (Ohdaira 2021). When lime nitrogen is used in effective conditions, such as when rice straw has been removed, it is assumed that the emergence of volunteer rice and weedy rice can be suppressed to at least 1/5 or 1/10 compared to that with no treatment. Such effects have been confirmed in several parts of Japan, including the moderately cold Akita Prefecture (Ohdaira et al. 2015, Ohdaira et al. 2019) and Miyagi Prefecture (Okawa 2019), the moderately warm Nagano Prefecture (Aoki 2019), and the western moderately warm region Hiroshima Prefecture (Ohdaira et al. 2008, Ohdaira & Sasaki 2008).

It has been reported that when 500 kg $ha^{-1}$ of lime nitrogen is applied to a field before winter in a moderately cold, Pacific-side region, soil ammonia nitrogen in the following spring increases by 40 kg $ha^{-1}$ (Okawa 2019). In a moderately cold region of the Sea of Japan side, when lime nitrogen was applied in autumn, the fertilizer effect calculated from the amount of nitrogen absorbed by paddy rice cropped the next year was 14%-18% (Ohdaira 2021). This meant that when 500 kg $ha^{-1}$ of lime nitrogen is applied in autumn, approximately 15 kg $ha^{-1}$ of basal fertilizer nitrogen can be saved during paddy rice cultivation the following year. In total, 15-40 kg $ha^{-1}$ of basal fertilizer nitrogen could be saved for subsequent rice cultivation if 500 kg $ha^{-1}$ of lime nitrogen is applied from autumn to winter in the previous year (Ohdaira 2021).

d. Premature harvest

The rice cultivar “Leaf Star,” which was adopted as an encouraged cultivar for WCS in Miyagi Prefecture, has small number of spikelets and low fertility due to excessive late heading in moderately cold regions (Utsumi et al. 2014). “Leaf Star” resulted in poor grain filling in moderately cold regions, therefore grains of “Leaf Star” are easily removed during the process of grain sorting by a sieve. Consequently, the risk of contamination of grains of “Leaf Star” into the grains of palatable rice cultivars is very low. In general, this method can be applied to the cultivation for WCS. By using the similar method, it is possible to reduce the problem of volunteer rice (only for WCS) by conducting late cropping using extremely late-maturing cultivars and harvesting before the seeds acquire the ability to germinate.

(4) Other findings and techniques

In general, when rice plants are lodged, huge number of seeds will be left in the field, promoting the emergence of volunteer rice the following year. Delayed harvest has also similar risk. Most high-yield cultivars have excellent lodging resistance, but they can lodge depending on excessive input of fertilizer, meteorological conditions, such as typhoons and heavy rainfall, and the soil bearing capacity during the ripening period. Therefore, appropriate fertilization, water management and harvesting time are important.

It has been shown that the occurrence of weedy rice can be greatly reduced by transitioning from paddy rice to non-paddy field crops and using tillage-based or herbicide control methods (NARO 2019). If transitioning to wheat, the field should be tilled multiple times after the wheat harvest. If transitioning to buckwheat, the field should be tilled multiple times before sowing the buckwheat seeds. If transitioning to soybean, an appropriate foliar treatment of herbicides should be applied as a spray. These are also effective as measures against volunteer rice. In Japan, where the function of paddy fields must be maintained despite the continuous decrease in the demand for rice, the control of volunteer rice by alternating between paddy rice and field crops is a desirable method.

## Conclusion

This paper mainly introduces some research and developed techniques for reducing volunteer rice in the context of continuous cultivation of paddy rice, which has been the common style of cultivation in Japan. These are summarized in Figure 2. Efficient control of volunteer rice can be achieved by combining these techniques in accordance with the regional and varietal characteristics.

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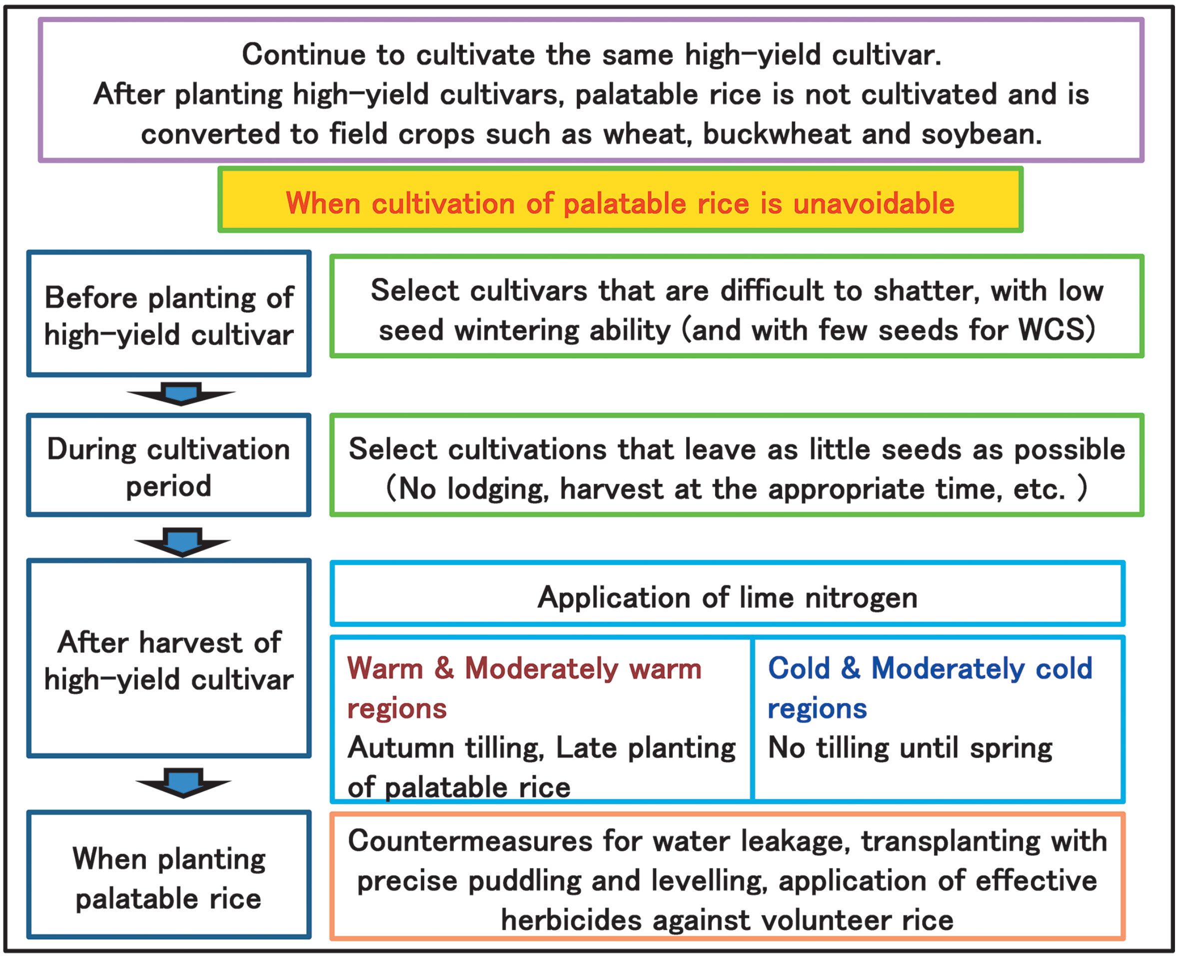


**Fig. 2. Countermeasures against volunteer rice of high-yield cultivars**

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