# Green Asia Report Series

# No.5

## Rice Ratooning for Low-Input Rice Cultivation

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# Rice Ratooning for Low-Input Rice Cultivation

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## Abstract

"Sustainable agriculture" focuses on farming that emphasizes environmental protection, economic stability, and social responsibility. It employs various methods and technologies to ensure sustainable food production for future generations. With population growth, climate change, and environmental issues intensifying, promoting sustainable agriculture is crucial for achieving the United Nations' Sustainable Development Goals (SDGs). However, several challenges impede the widespread adoption of sustainable practices. A major challenge is the destabilization of the international food market, which can make small-scale farmers' incomes unstable, potentially hindering investments in sustainable agriculture and efforts to reduce environmental impact. Additionally, climate change directly affects crop production, leading to decreased yields and declining quality, while increasing the risk of disrupting agricultural ecosystems.

In the Asia-Monsoon region, the aging and departure of farmers have led to a significant shortage of agricultural labor, posing a major obstacle to sustainable agriculture. For instance, in Japan, the average age of agricultural workers is rising, and there is a notable decrease in new farmers. This decline can hinder the dissemination of new agricultural technologies and proper farmland maintenance, potentially undermining sustainability. Consequently, there is a pressing need for new agricultural technologies that reduce labor and resource inputs while enhancing productivity. Technological innovation in agriculture is crucial to achieving the SDGs.

This report delves into "ratoon rice cropping," an agricultural technology aimed at enhancing understanding of its characteristics and challenges. Ratoon rice cropping involves cultivating rice repeatedly using new shoots (ratoon) that sprout from the stubble after the first crop (main crop) harvest. This method eliminates the need for plowing, puddling, seedling, and transplanting for the second crop, thereby reducing associated materials and labor. Additionally, the growth period of the ratoon crop is significantly shorter than that of the main crop, requiring less effort for fertilization and water management. In some regions, the short growing period of the ratoon crop allows for harvest before the flood season, contributing to regional food security.

To successfully implement ratoon rice cropping, selecting varieties that produce numerous tillers from the stubble after the main crop's harvest is essential. Since ratoons begin developing before the main crop's harvest, cultivation management must consider ratoon development from the main crop stage. For instance, fertilization to promote ratoon growth and soil drying during harvest to encourage rooting are effective measures.

Challenges to ratoon rice cropping include low and unstable yields and the need for effective cultivation techniques. A significant issue is the decreased regeneration rate and reduced yields due to mechanical harvesting damage during the main crop's harvest. Additionally, because ratoon rice grows from the same plant as the main crop, it is susceptible to the same diseases.

Despite these challenges, introducing the low-input ratoon rice cropping system instead of conventional double rice cropping offers numerous advantages. Ratoon cropping is highly labor-efficient and reduces environmental impact, allowing farmers to produce rice while cutting costs and labor hours. Additionally, it conserves water resources and reduces greenhouse gas emissions, playing a key role in both climate change adaptation and mitigation.

However, outside certain regions in China, ratoon rice cropping has not seen significant adoption. To promote its wider dissemination, it is crucial to enhance information and technical support for farmers, develop varieties suited to ratoon cropping, and refine cultivation techniques. Ongoing research is expected to drive advancements in both variety improvement and cultivation management practices.

## 1: Introduction

Rice is typically seen as an annual plant, completing its life cycle with a single sowing and harvest. However, many *Oryza sativa* varieties in the Asia-Monsoon region, including Japan, exhibit perennial traits. A cultivation method leveraging this is called "ratooning," where new shoots or "ratoons," emerge from the stubble base after the first harvest. This method is also used in crops like sugarcane, pineapple, and banana.

Since the 1930s, Japan has explored double rice cropping to increase food production. However, the short interval between harvesting the first crop and planting the second led to excessive labor demands and competition for labor. To address these issues, research on ratoon rice cropping began (Yamamoto, 1973). This method uses new shoots sprouting from the stubble after the main crop harvest, eliminating the need for sowing and transplanting, and significantly reducing labor and costs for seeds, seedlings, and transportation. Additionally, the growth period for ratoon rice is shorter than the main crop (Vergara et al. 1988), allowing for more efficient fertilization and water management. However, due to Japan's climate, suitable regions for ratoon cropping are limited, and declining rice demand has further restricted its use, confining ratoon cropping to warmer areas like Kochi Prefecture.

In recent years, the aging population and the outflow of agricultural workers have led to severe labor shortages in the Asia-Monsoon region, including China, Indonesia, Thailand, Korea, and Japan (Ngadi et al. 2023; Szabo et al. 2021). In Japan, the average age of agricultural workers is nearing 70, and abandoned paddy fields are increasing (MAFF, 2018). Additionally, the international food market has been disrupted by various factors (FAO, 2022), whereas fertilizer and feed prices have risen due to supply chain issues and increased demand (World Bank, 2022). Abnormal weather patterns and climate change are also significantly impacting food security (IPCC, 2022). In this context, interest in ratoon rice cropping is growing, as it has the potential to reduce labor and costs (Zhang et al. 2023) while minimizing environmental impact (Shen et al. 2021).

Despite challenges like low yields and the need for refined cultivation techniques, ratoon rice cropping could become a viable strategy for sustainable rice farming in the Asia-Monsoon region if these obstacles are addressed. It has the potential to significantly enhance regional food security. Therefore, research and dissemination efforts to overcome these challenges will be increasingly important.

This report highlights "ratoon rice cropping" as a promising technology for sustainable rice farming in the Asia-Monsoon region. It begins by examining the benefits and challenges of ratoon rice cropping, followed by an in-depth discussion of the physiological and morphological traits crucial for cultivation management.

The report then reviews current research findings and cultivation techniques, concluding with future prospects. The goal is to explore how ratoon rice cropping can enhance agricultural productivity and sustainability while identifying potential future developments.

## 2: Overview of ratoon rice cropping

### 2.1: Research on ratoon rice cropping in Japan

Professor Takeo Yamamoto of Aichi University of Education, a pioneer in ratoon rice cropping research in Japan, has been dedicated to this field since the late 1960s. He focused on optimizing rice double cropping based on the physiological growth characteristics of rice. His achievements are compiled in "Ratoon Rice Cropping," which systematizes the principles and applications of this method (Fig. 1). In 1985, at the university's experimental field, using the Hamaminori variety, a yield of 10 t $ha^{-1}$ (main crop 6.4 t $ha^{-1}$ and ratoon crop 3.6 t $ha^{-1}$) was achieved.

**Figure 1: Experimental field for ratoon rice cropping in Japan**
(Source) Reproduced from "*Rice Ratoon Cropping*" by Yamamoto (1973). Year of photography unknown

According to Yamamoto (1973), the oldest record of ratoon rice in Japan is the expression "one cultivation and reharvest from the Tenmu era in 'Nihon Shoki', where it was called 'Hitsuji' or 'Hikobae.'" However, in modern times, it was not pursued for food production due to low yields. With the spread of rice double cropping, early maturing varieties and early cultivation were introduced, making ratoon crops noticeable after the main crop harvest. Interest in using ratoon rice for cultivation and fodder grew, leading to research in various experimental fields around 1965. However, interest waned due to the 1969 rice production adjustment policy and decreased demand. Consequently, ratoon rice cropping was limited to warmer areas like Kochi Prefecture.

In recent years, ratoon rice cropping has regained attention due to the increasing need for cultivation technologies that address labor shortages caused by the aging and departure of farmers in the Asia-Monsoon region, including China, Indonesia, Thailand, South Korea, and Japan (Ngadi et al. 2023; Szabo et al. 2021). Additionally, the growing demand for agricultural technologies that minimize environmental impact while aiding climate change adaptation and mitigation ( Zou et al. 2024; Qi et al. 2024) has heightened awareness of the importance of improving labor productivity and promoting sustainable agriculture. In China, where ratoon rice cropping is most advanced, the cultivated area has reached 1.08 million hectares (Yu et al. 2022).

Ratoon rice cropping leverages global warming to boost crop productivity. In 2023, the global average annual temperature was the highest in 174 years (WMO, 2023), significantly affecting rice quality in Japan. Rice cultivation typically requires an accumulated temperature of 1,500°C–2,500°C, depending on the region and variety. Rising temperatures due to global warming can shorten the growing period, making ratoon rice cropping more feasible. This technique benefits from the positive effects of global warming on crop growth. Nakano et al. (2020) demonstrated this potential by achieving a yield of 14.7 t $ha^{-1}$ (main crop 9.8 t $ha^{-1}$, ratoon crop 4.9 t $ha^{-1}$) using the high-yielding variety at an experimental field in Fukuoka Prefecture.

Ratoon cropping can enhance labor and land productivity, reduce environmental impact, and address climate change. Future research and the expansion of this technique in the Asia-Monsoon region are expected to further its development.

### 2.2: Strengths and weaknesses of ratoon rice cropping

Ratoon rice cropping enhances labor and land productivity by cultivating axillary buds from the stubble of the initial crop after harvest. Unlike traditional double cropping, it significantly reduces the time and costs associated with seeds, seedlings, and transplanting, allowing for a short harvest. Previous research has identified the following strengths and weaknesses of ratoon rice cropping:

| Strengths | Weaknesses |
|---|---|
| • No need for plowing, seedling production, or transplanting<br>• Shorter growth period, reducing labor, water usage, and agricultural material input costs<br>• High productivity per unit area within a short period<br>• Seed production retains genetic characteristics across multiple seasons | • Yield is generally low and unstable<br>• Many varieties have weak ratoon ability, requiring careful selection before cultivation<br>• Uneven maturity due to variation in heading is likely<br>• Pests and diseases from the main crop easily affect the ratoon crop<br>• Cultivation management remains underdeveloped and immature |

**Improvement of labor and land productivity**

The primary advantage of ratoon rice cropping is that it eliminates the need for seeding, seedling production, and transplanting. Although mechanization in Japanese rice farming has significantly reduced the working hours for plowing, transplanting, and harvesting the processes of seedling, seedling production, and transplanting still rely heavily on human labor, accounting for 27% of the working hours. These operations become less efficient as the scale of farming expands (MAFF, 2018). Ratoon rice cropping removes these labor-intensive steps, thereby reducing labor costs and improving work efficiency.

Additionally, ratoon rice grows rapidly, shortening the cultivation period by 40%–50% compared to the main crop. This reduces the need for operations like water management and fertilization, saving 30% of labor time compared to conventional rice double cropping (Yuan et al. 2019).

**Mitigation and adaptation for climate change**

Ratoon rice cropping is a cultivation technique that aids in water resource management and mitigates global warming. Unlike conventional double cropping, it does not require plowing, significantly reducing water usage. In water-scarce regions, ratoon rice cropping can serve as a water-saving system. Additionally, reducing machine operating time for plowing and water management lowers carbon dioxide ($CO_2$) emissions, whereas shortening the flooding period decreases methane ($CH_4$) emissions from paddy fields (Yu et al. 2021). Thus, ratoon rice cropping is effective for both climate change mitigation and adaptation. Moreover, depending on the region, it allows for harvesting before the typhoon or flood season, reducing yield loss risks and enhancing regional food production.

**Physical properties and texture of ratoon rice**

Ratoon rice has unique physical properties and textures compared to the main crop. The shortened growth period affects starch synthesis, altering the rice's physical properties and texture. Texture, including chewing sensation, tongue feel, and crunchiness, is crucial for consumer preference. Ratoon rice absorbs water well and tends to be less hard, sticky, and elastic than the main crop (Zhang et al. 2021). Consequently, it offers a different texture and processing characteristics, potentially meeting new consumer needs and creating market opportunities.

**Challenges of ratoon rice cropping**

While ratoon rice cropping offers numerous benefits, it also faces several challenges. A primary challenge is increasing and stabilizing yield. Although the panicle number per unit area of ratoon rice slightly increases compared to the main crop, the number of spikelets per panicle decreases significantly, making it difficult to boost spikelet numbers through cultivation management. Additionally, in midlatitude regions, the accumulated temperature and solar radiation during the ratoon rice cultivation period are much lower than during the main crop, creating unfavorable growth conditions.

To overcome these challenges, ongoing research and development are essential for improving varieties and advancing cultivation techniques. In the future, ratoon rice cropping is expected to become a more attractive option for a larger number of farmers.

## 2.3: Usefulness of ratoon rice cropping

### Low-input rice cropping system

Ratoon cropping is a sustainable cultivation technique that simultaneously enhances productivity and reduces environmental impact by improving resource and energy use efficiency and increasing yield per unit of water.

In single cropping, the costs of inputs such as diesel, electricity, and labor are much lower in ratoon crop cultivation than in main crop cultivation, although the total yield of the ratoon crop is lower than that of the main crop (Fig. 2a). In double cropping, input costs are also lower in rice double cropping (Rice-Ratoon rice) than in conventional double rice cropping (Rice-Rice) (Fig. 2b).

Thus, ratoon cropping offers significant economic and environmental advantages and holds great potential as an alternative agricultural technology to conventional double rice cropping.

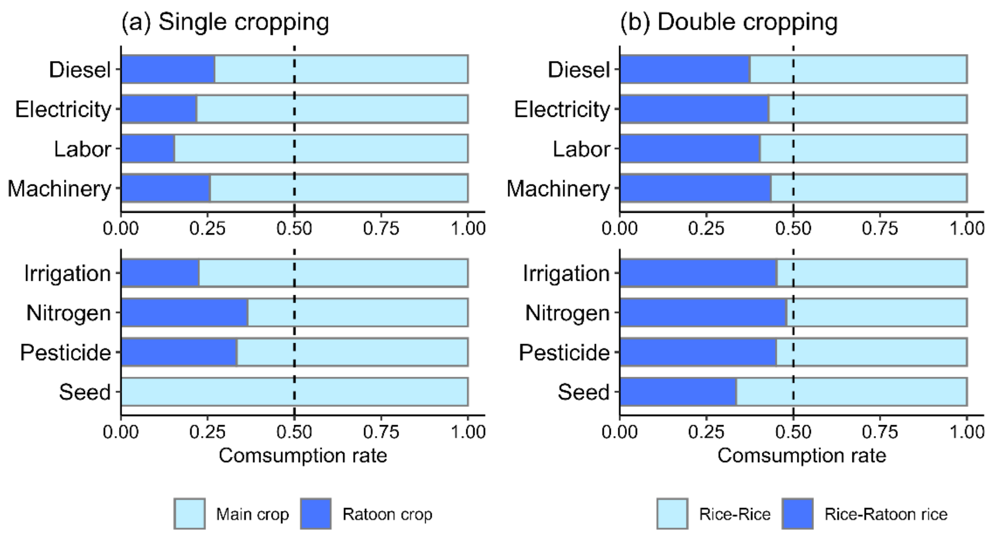


**Figure 2: Resource input ratio for each crop, assuming the total is 1.**

(Source) Yu et al. (2021); Yuan et al. (2019); Shen et al. (2021); Xu et al. (2022)

(Note) Rice-Rice refers to the double rice cropping, where two separate rice crops are planted and harvested within the same year. Rice-Ratoon rice involves harvesting the first rice crop and allowing the stubble to regrow for a second harvest. Resource inputs per unit area are adjusted based on yield levels, with the combined total input for both crops is set to 1 to calculate input ratios.

**Avoidance and mitigation of yield loss risk due to natural disasters**

In flood- and typhoon-prone regions, ratoon rice cropping can shorten the planting period, reducing the risk of yield loss due to natural disasters (Fig. 3). This approach is expected to enhance food security in these areas.

In the regions of Masarawag, Minto, and Mauraro in Albay Province, Philippines, ratoon rice cropping has been traditionally practiced. Here, the risk of crop loss during double rice cropping reaches 40%–80% during the typhoon season from October to December. Consequently, ratoon rice cropping, which allows for harvest before the onset of typhoons, has become widely adopted (FAO, 2013).

Another successful example of ratoon cropping is found in Le Thuy district, Quang Binh Province, Vietnam. This floodplain region often experiences stagnant river water during the rainy season. Historically, farmers tried to mitigate flood damage by using early-maturing varieties or advancing the sowing period, but these measures were insufficient to prevent losses. Since the introduction of ratoon cropping in 2003, however, farmers have been able to ensure harvests before the floods arrive (Sen & Bond, 2017). Today, ratoon rice cropping is practiced in all paddy fields within the floodplains of Le Thuy district.

These examples illustrate that ratoon rice cropping is an effective technique for mitigating the risks posed by natural disasters like typhoons and floods.

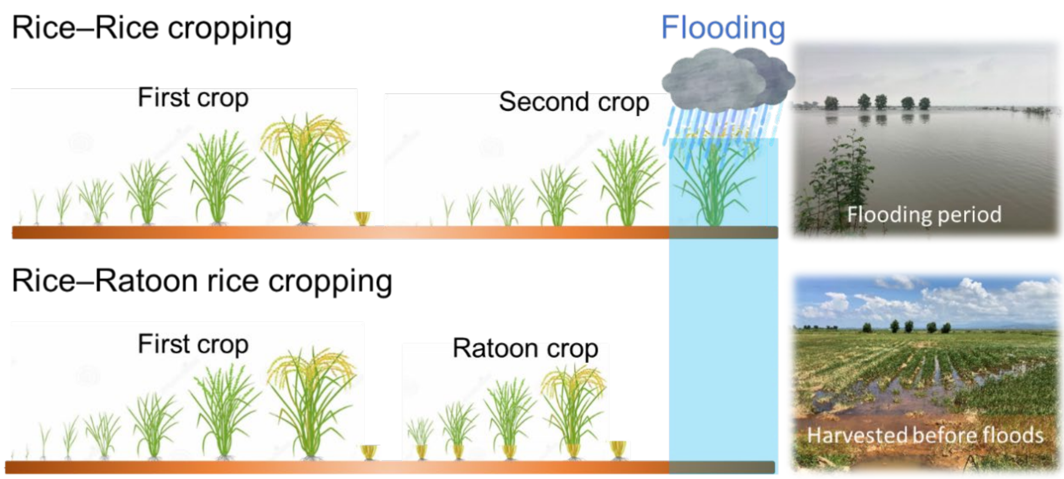


**Figure 3: Ratoon cropping enables harvest before the flood season**

(Note) Paddy fields in Le Thuy district, Vietnam, during the flood season
(Photos) Taken before and after the flood by JIRCAS

## 3: Physiological and morphological characteristics of ratoon rice

### 3.1: Growth and yield characteristics of ratoon rice

**Ratoon rice productivity**

The ratoon ability of rice is a complex trait influenced by both genetic and environmental factors (Wang et al. 2020), and its mechanism is not yet fully understood. Generally, the yield of ratoon rice tends to increase as the yield of the main crop increases (Fig. 4). However, depending on the region and cultivation conditions, the relationship between the yields of the main and ratoon crops can vary; there may be positive, negative, or no correlation at all. Although many studies have focused on rice varieties with high ratoon ability and their characteristics, differences in genetic and environmental factors often lead to varying research outcomes.

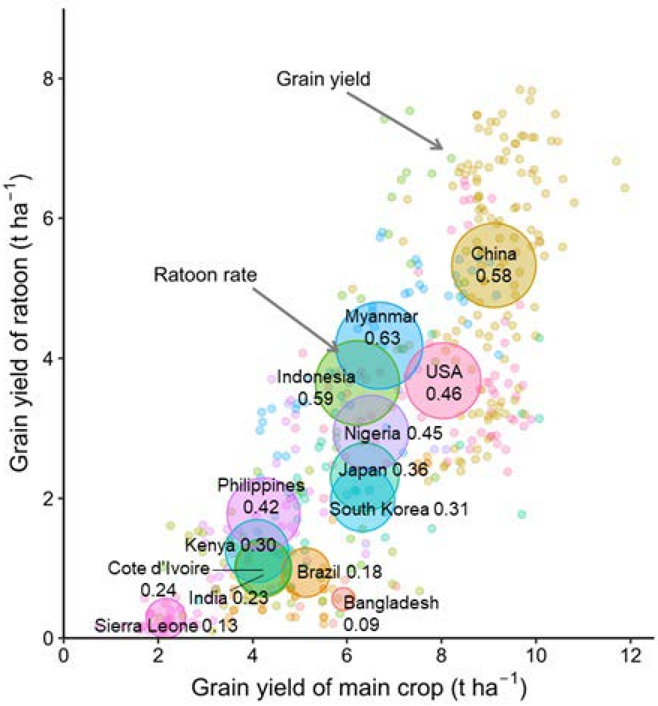


**Figure 4: Relationship between grain yield per unit area for the main crop and ratoon crop, and ratoon rate**

(Source) Shiraki et al. (2024)

(Note) Yield data are extracted from 51 research papers. Small dots represent grain yield, whereas large circle areas and numbers indicate the ratoon rate by country (ratoon rate = ratoon rice yield / main crop yield).

**Yield morphology of ratoon rice**

Ratoon cropping, which utilizes rice stubbles after the main crop harvest, changes the role of yield components. Although the main crop follows a "panicle weight type," with each panicle holding many grains, ratoon cropping shifts to a "panicle number type," characterized by many small panicles (Fig. 5). Consequently, ratoon rice adopts a "panicle number type," where the number of effective tillers (panicles) becomes the key yield factor. Therefore, successful ratoon cropping selecting varieties with high ratoon ability and implementing cultivation practices that enhance ratoon potential to ensure sufficient effective tillers.

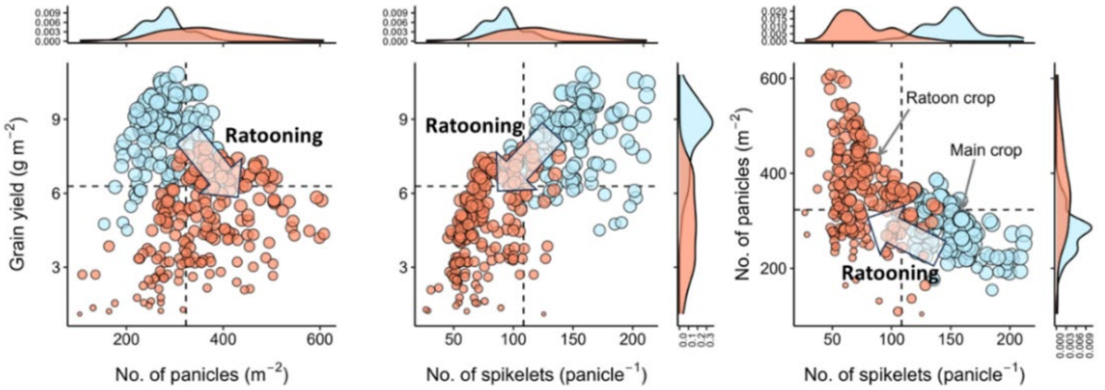


**Figure 5: Differences in yield, spikelet number, and panicle number between main and ratoon crops**

(Source) Shiraki et al. (2024)

(Note) The dashed line represents the overall average value for each trait.

## Rice ratoon characteristics

The ratoon rate (final growth amount of ratoon crop/main crop) of yield-related traits shows a similar trend across each trait, although regional variations exist (Fig. 6). Ratoon rice tends to increase stem and panicle numbers by 19% each compared to the main crop. However, plant height and spikelet numbers decrease by 23% and 48%, respectively, and the growth period is shortened by 41% (median value). Consequently, the low yield of ratoon crops is due to a slight increase in panicle numbers and a significant decrease in spikelets. To improve ratoon crop yields, strategic cultivation management based on ratoon rice characteristics is essential.

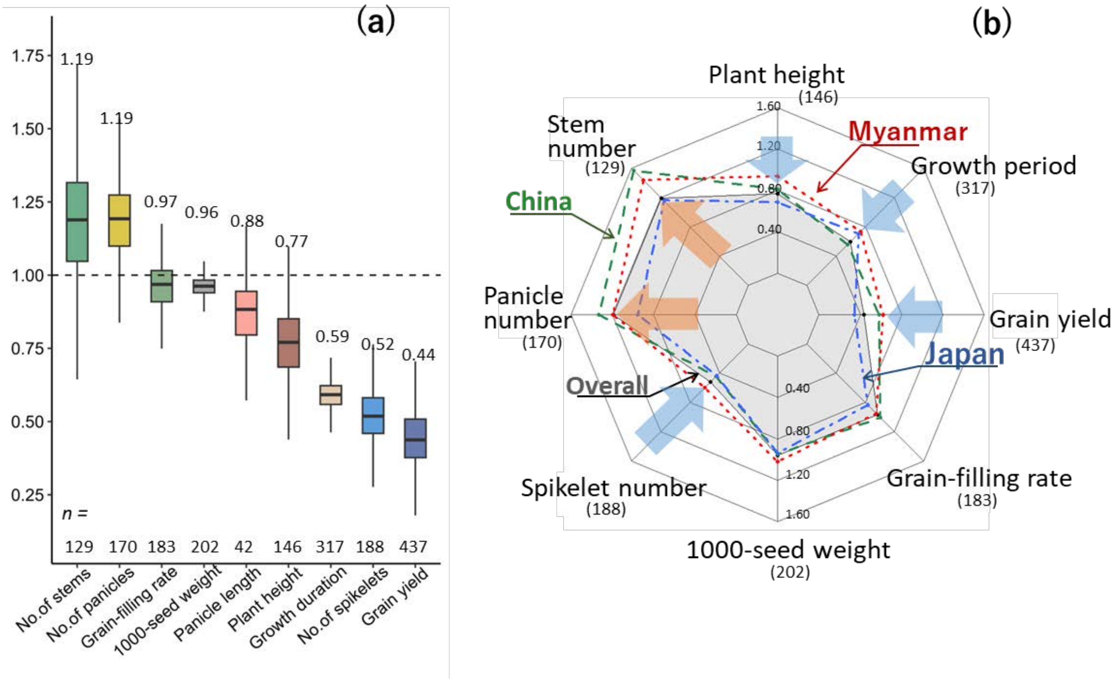


**Figure 6: (a) Ratoon rate (ratoon crop/main crop) for yield-related traits (b) Comparison of ratoon rates across Japan, China, and Myanmar, and the overall average**

(Source) Shiraki et al. (2024)

(Note) (a) The radar chart shows median ratoon rates. The value "*n*" represents the number of data points. (b) Numbers in parentheses indicate the number of data points. China has the widest dissemination of ratoon rice cropping, while JIRCAS has conducted numerous ratoon rice studies in Myanmar.

## Genetic and environmental factors in rice ratoon characteristics

Genetic factors (such as productivity and maturity) and environmental factors (including regional characteristics, nitrogen application, and cutting height) differently impact ratoon crops (Fig. 7). Nitrogen application significantly influences the axillary buds of the stubble. Among yield-related traits, ratoon tillers are most susceptible to genetic and environmental differences. Conversely, 1000-seed weight, grain-filling rate, growth period, and spikelet numbers show minimal differences between main and ratoon crops, indicating these traits are less affected by variations in varieties and cultivation conditions.

The ratoon ability of tillering is the most manageable aspect in terms of variety selection and cultivation management. By choosing varieties with high ratoon ability and applying appropriate fertilization before and after the main crop harvest, the regeneration and elongation of axillary buds can be promoted. However, controlling spikelet numbers and grain-filling rates remains challenging with current varieties and cultivation practices. To improve ratoon crop yields, it is crucial to understand the impact of genetic and environmental factors on rice regeneration and manage cultivation to maximize ratoon ability. This understanding enables effective management of ratoon rice cropping, thereby stabilizing and increasing yields.

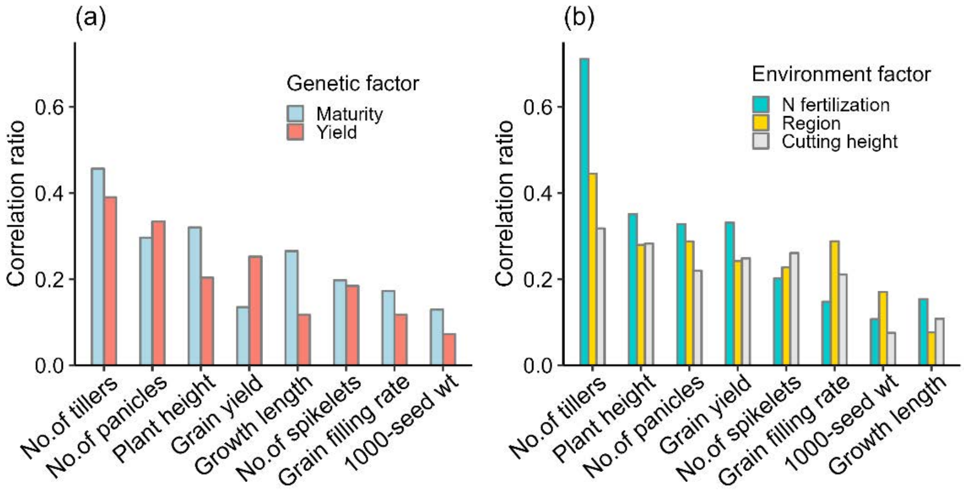


**Figure 7: Impact of (a) genetic and (b) environmental factors on the ratoon rate for yield-related traits, including varieties and cultivation management**

(Source) Shiraki et al. (2024)

(Note) Correlation ratios are interpreted as follows: Less than 0.1 indicates "no correlation," 0.1 or more indicates "correlation," and 0.25 or more indicates "somewhat strong correlation." Groupings are as follows: (a) Yield categories are low (average 4.0 t $ha^{-1}$), medium (average 6.5 t $ha^{-1}$), and high (average 9.0 t $ha^{-1}$); (b) maturity stages are early (average 110 days), medium (average 130 days), and late (average 147 days); (c) regional characteristics include South/Southeast Asia, East Asia, America, and Africa; (d) nitrogen application rates are low (less than 100 kg N $ha^{-1}$), medium (100 to less than 300 kg N $ha^{-1}$), and high (300 kg N $ha^{-1}$ or more).

## 3.2: Unique growth phases of ratoon rice

In the main crop, rice growth transitions clearly from the vegetative phase to the reproductive phase. This transition marks the cessation of leaf primordial differentiation at the stem's growth point and the beginning of panicle differentiation. During the reproductive phase, stem node differentiation is completed, the number of internodes is determined, and internode elongation begins. In contrast, in ratoon rice crops, vegetative and reproductive growth proceed simultaneously in a competitive manner (Yamamoto, 1973) (Fig. 8).

This simultaneous progression occurs because the axillary buds, destined to become ratoon rice, begin panicle differentiation before the main crop is harvested. Differentiation progresses faster in the lower nodes, whereas the development speed is a factor in the upper nodes (Yoshida & Hozono, 1995; Xu et al. 2020). The degree of differentiation varies substantially depending on the variety and cultivation conditions, but it remains unclear whether genetic or environmental factors have a greater influence.

Therefore, since the growth phases of ratoon rice differ substantially from those of the main crop, cultivation management based on the development of axillary buds is required from the main crop stage.

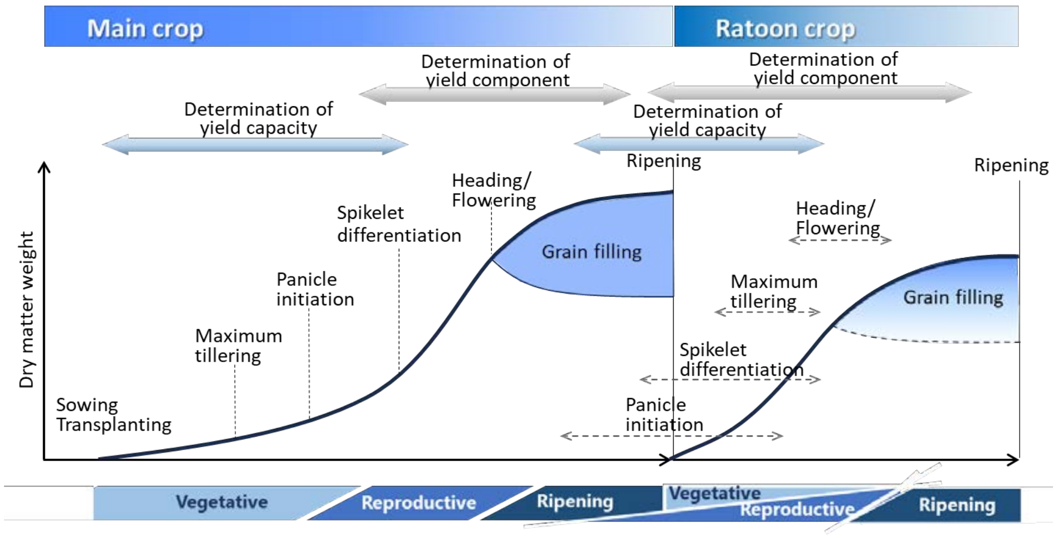


**Figure 8: Progression of total dry matter weight in main and ratoon crops during grain formation and maturation**

### 3.3: Physical properties and texture of ratoon rice

Ratoon rice efficiently translocates photosynthetic products to grains (Huang et al., 2020), directly influencing its physical properties and texture. The amylose content of starch in ratoon rice is approximately twice as high as that in main crop rice, increasing from 8.4–9.9% to 14.9–16.4% (Table 1), with a correspondingly significant decrease in the proportion of amylopectin. Moreover, an increase in the proportion of short-chain amylopectin and a decrease in long-chain branches disrupt the ordered structure within starch molecules, resulting in a significant reduction in relative crystallinity. Furthermore, despite these structural changes, the water solubility index has been reported to be lower than that of starch from main crop rice (Deng et al. 2021).

Changes in the physical properties of ratoon rice impact its texture and processing characteristics. For instance, its lower pasting temperature allows for easier heating and shorter cooking times. Viscosity changes affect the texture postcooking; ratoon rice has lower peak and breakdown viscosities, indicating weaker stickiness during cooking. However, it shows increased final and setback viscosities, suggesting maintained stickiness postcooking (Zhang et al. 2021).

The unique properties and texture of ratoon rice have potential applications in developing new food products and industrial uses. Leveraging these attributes could expand culinary diversity and advance the food industry by creating novel foods and processed products utilizing ratoon rice's specific qualities.

**Table 1: Comparison of components between the main and ratoon crops**

| Crop | Starch (%) | Amylose (%) | Protain (%) | Fat (%) | Ash (%) |
|---|---|---|---|---|---|
| Qy-MC | $81.5 \pm 1.4^{b}$ | $9.9 \pm 0.05^{b}$ | $8.4 \pm 0.06^{b}$ | $0.28 \pm 0.01^{a}$ | $0.30 \pm 0.01^{a}$ |
| Qy-RC | $80.4 \pm 3.5^{b}$ | $16.4 \pm 0.08^{d}$ | $7.9 \pm 0.05^{b}$ | $0.38 \pm 0.02^{c}$ | $0.29 \pm 0.04^{a}$ |
| Flyx-MC | $81.5 \pm 0.3^{b}$ | $8.4 \pm 0.09^{a}$ | $8.5 \pm 0.04^{b}$ | $0.35 \pm 0.01^{b}$ | $0.30 \pm 0.01^{a}$ |
| Flyx-RC | $75.7 \pm 1.4^{a}$ | $14.9 \pm 0.05^{c}$ | $7.9 \pm 0.05^{a}$ | $0.28 \pm 0.01^{a}$ | $0.40 \pm 0.01^{b}$ |

(Source) Zhang et al. 2021

Qy and Flyx refer to the varieties Quanyou822 and Fengliangyouxiang1, respectively. MC and RC denote main crop and ratoon crop, respectively. Data are presented as mean ± standard deviation. Means within the same column sharing the same letter indicate no significant difference ($p < 0.05$).

## 4: Cultivation techniques of ratoon rice cropping

Effective ratoon rice cropping requires focused cultivation management during the late growth stage of the main crop and the early growth stage of the ratoon crop. After the main crop's heading, axillary buds at the upper nodes begin to differentiate. By the main crop's harvest, some buds have already formed panicles, whereas others may start elongating or heading.

In ratoon rice cropping, cultivation management must consider the simultaneous progression of vegetative and reproductive growth phases during the main crop stage. The rice plant type shifts from a "panicle weight type" in the main crop to a "panicle number type" in the ratoon crop, where the number of panicles significantly impacts yield. Therefore, enhancing the regenerative capacity of axillary buds, promoting their elongation, and ensuring the formation of effective tillers from the main crop stage is essential for stabilizing and increasing yield in ratoon rice cropping.

### Basic principles of cultivation management

- Implement fertilization management throughout the main crop's growth stage to enhance axillary bud development and germination.
- Maintain optimal soil oxidation conditions during the main crop harvest to stimulate rooting and sprouting in ratoon rice.
- After reirrigation, apply fertilizer to promote axillary bud elongation and improve tillering.

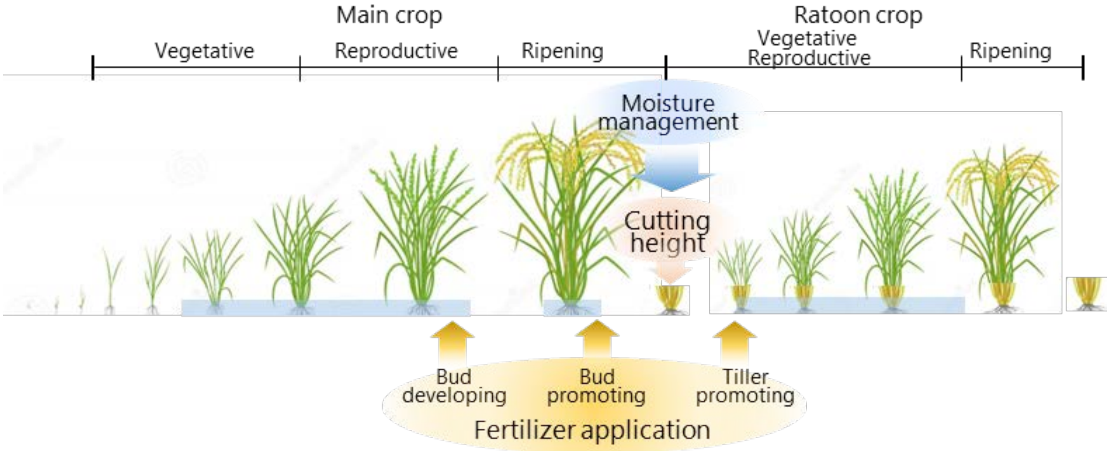


**Figure 9: Cultivation management strategies for the late growth stage of the main crop and the early growth stage of the ratoon crop**

### 4.1: Basic principles of variety selection

Selecting varieties with superior ratoon ability from axillary buds is crucial for successful ratoon rice cropping after harvesting the main crop. Despite extensive research into variety selection adapted to cultivation conditions, the availability of varieties with strong ratoon ability remains limited.

Varieties with excellent ratoon ability exhibit characteristics such as high dry matter production, root activity at maturity, shorter plant height with high yield potential, increased panicle density per unit area, and abundant spikelet numbers. However, some reports suggest that varieties with fewer panicles and spikelets might demonstrate higher ratoon ability (Cai et al. 2019; Lin et al. 2020; Jichao & Xiaohui, 1996; Dong et al. 2017).

Conducting cultivation trials to identify suitable varieties is essential for establishing a ratoon rice crop. However, due to the lack of clear selection criteria, it is recommended to choose the optimal variety by evaluating the following principles and observations:

**Basic principles for variety selection**

- **Ratoon ability**: Choose varieties with a high regrowth rate per plant after the main crop harvest.
- **Maximization of total yield**: Opt for high-yielding varieties to maximize overall yield from both the main and ratoon crops. Varieties with strong source-sink capacity tend to have superior ratoon ability and yield potential.
- **Disease and pest resistance**: Because ratoon rice shares the same genetic makeup as the main crop, it is equally susceptible to pests and diseases. Therefore, prioritize varieties with strong resistance to minimize crop loss.
- **Quality**: Although high yield is crucial, consider key attributes such as taste and texture when selecting varieties to meet market or consumer preferences.
- **Maturation period**: Choose varieties with a maturation period that aligns with the heading safety limit for ratoon crop development. For example, in Japan, the main crop should be harvested by mid-August. Late-maturing varieties may result in a shorter period of ratoon rice compared to early-maturing ones.

### 4.2: Ratoon ability and optimal harvest time for rice ratooning

The ratoon ability of axillary buds is significantly influenced by the amount of nonstructural carbohydrates (NSC) and nitrogen concentration (N) in the stubble. Changes in their quantitative balance play a crucial role in regulating axillary bud differentiation and growth (Yang et al. 2021). The relationship between the accumulation of N and NSC in the stem affects the differentiation and growth of axillary buds. When evaluating ratoon ability using the regeneration ratio after harvest, the number of new tillers is typically lowest from the milky-ripening to dough-ripening stages and rapidly increases approaching yellow-ripening (Fig. 10). During the milky and doughy ripening stages, assimilates are directed toward the panicle, reducing stored nutrients in the stem and lowering ratoon ability. At full ripening, assimilate translocation stops, and surplus nutrients reaccumulate in the stem, thereby enhancing ratoon ability (Yamamoto, 1973).

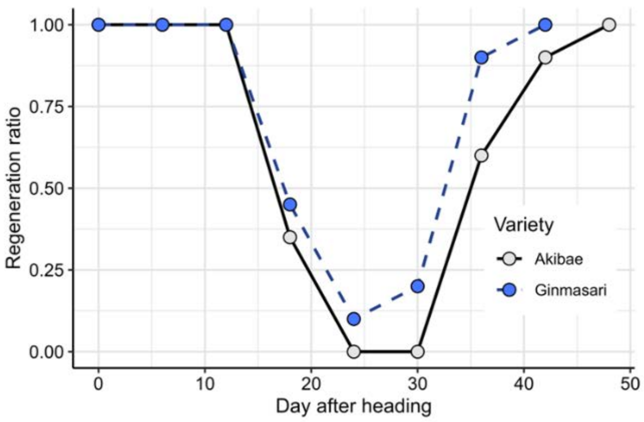


**Figure 10: Changes in the regeneration ratio following the main crop's heading**

(Source) Yamamoto (1973)

The optimal harvest time for the main crop is at or just after the full ripening stage, aligning with peak ratoon ability. Some studies suggest harvesting the main crop about a week earlier than usual or when 85%–90% of the grains are golden yellow, though conclusive data is lacking. Therefore, although the optimal harvest time generally poses no issues, adjustments should consider varietal differences and cultivation conditions, focusing on the developmental status of axillary buds and the maturity stage of the main crop.

Lower cutting heights have been observed to extend the vegetative growth period during ratoon cropping. This is because the panicles at lower nodes are at a less advanced differentiation stage compared to those at upper nodes, leading to a prolonged vegetative and reproductive phase up to the main crop harvest. Therefore, the cutting height for ratoon cropping may be determined by the progress of panicle differentiation at various nodal positions at the main crop harvest.

## 4.3: Water management before and after the main crop harvest

In ratoon cropping, a higher regeneration ratio in the early growth stage (the ratio of tillers in the ratoon crop to the main crop) tends to increase dry matter weight and grain yield. Effective water management is crucial. Soil drying promotes root development, whereas flooding encourages stem elongation. Water management before and after the main crop harvest should aim to create soil moisture conditions that promote both axillary bud elongation and root growth (Fig. 11, 12).

**Figure 11: Soil drying after the main crop harvest promotes rice regrowth**
(Photo: JIRCAS, 2020)

At the main crop harvest, a moderately dry state (oxidative conditions) is desirable for rice root physiology. Drying the soil increases oxygen content, stimulating root respiration and promoting root growth. Water stress activates amylase in the stem, breaking down starch and increasing soluble sugars, which are nonstructural carbohydrates. Additionally, plant hormones such as zeatin and zeatin riboside may increase, promoting axillary bud differentiation and growth, thus enhancing ratoon ability (Zhang et al. 2022).

In the soil, easily decomposable nitrogen compounds increase, forming a rhizosphere that enhances the supply of inorganic nitrogen. This interaction between soil moisture management and fertilization reduces rolling damage caused by mechanical harvesting of the main crop, thereby reducing yield loss (Zheng et al. 2022).

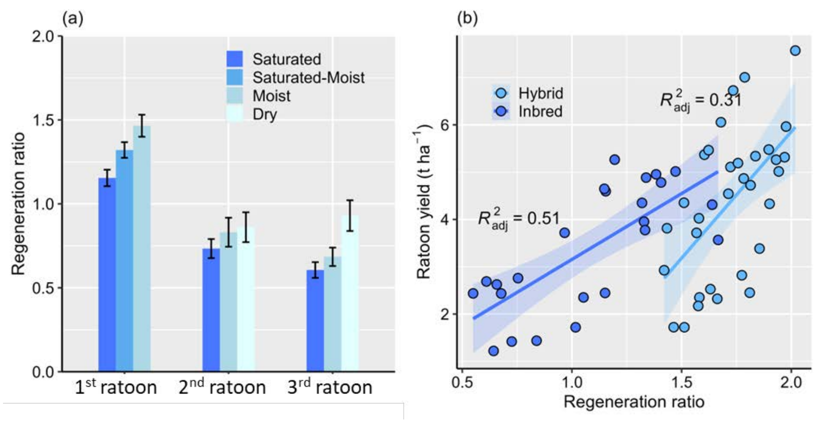


**Figure 12: (a) Effect of soil moisture management on the regeneration ratio (b) Relationship between regeneration ratio and ratoon yield**
Sources: Shiraki et al. (2020); Chen et al. (2018)

### 4.4: Fertilization in ratoon rice cropping

Fertilization is crucial in rice cultivation and varies with the plant's growth stages. The tillering and panicle formation stages are particularly important. Axillary buds of the ratoon crop begin cell differentiation and growth after the main crop heading. Both vegetative and reproductive growth progress simultaneously after the main crop's harvest. Therefore, fertilize both main and ratoon crops simultaneously without delay. After the grain-filling stage of the main crop, it is essential to promote the re-accumulation of assimilates in the stem and prepare for panicle differentiation and elongation. Previous studies suggest applying fertilization for the ratoon crop 2–3 times (Fig. 13). In high-fertilization cultivation, yields of the main and ratoon crops can be negatively correlated (Zhou et al. 1995; Xu et al. 2005). Increased nutrient accumulation in the stem promotes differentiation and induces early heading in the ratoon crop. Since the ratoon crop is influenced by the growth conditions of the main crop, unified fertilization management is challenging and requires attention to multiple factors from the main crop stage. Fertilization content and timing vary depending on the variety and soil conditions, so it is recommended to determine the optimal fertilizer application through trial cultivation.

#### Timing of fertilization

- **After the main crop's heading**: Improve the grain filling rate and ratoon ability by promoting tiller growth. Recommended application timing: 10-13 days (Yamamoto, 1987) or 15-20 days after heading (Sun et al. 1982; Nakano & Morita, 2008).
- **Fertilization before harvest of the main crop**: To induce tiller differentiation and promote elongation. Recommended timing is 6-8 days before harvest (Yamamoto, 1987) or 25-28 days after heading (Ling et al. 1989).
- **Fertilization after harvest of the main crop**: To promote stem elongation, tillering, and nutrient supply for panicle development. Recommended timing: 2-5 days (Turner & McIlrath, 1988) or 6 days after harvest (Yamamoto, 1987).

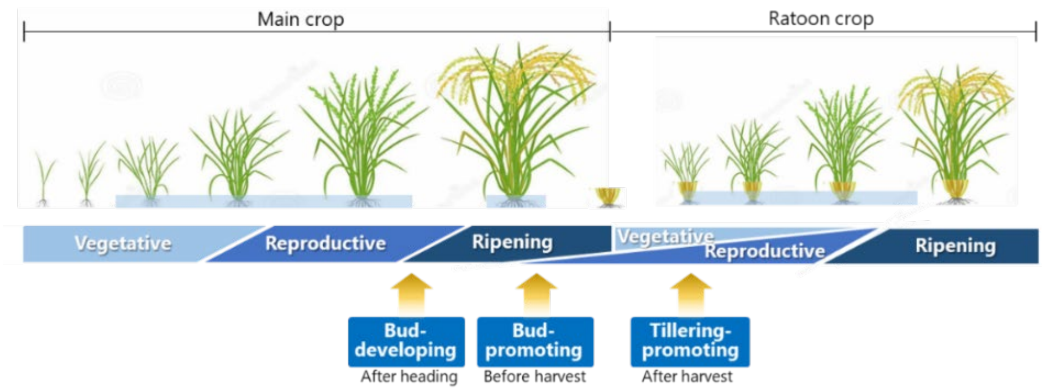


**Figure 13: Optimal nitrogen application timing for ratoon rice cultivation**

## 4.5: Development of perennial and early maturing rice varieties

### Development of perennial rice varieties

In China, efforts to maximize the benefits of ratoon rice have led to the development of perennial varieties. "Perennial Rice 23 (PR23)" was developed through hybridization between the annual high-yielding indica variety RD23 (*Oryza sativa*) with the African wild rice (*Oryza longistaminata*) (Zhang et al. 2023) (Fig. 14). RD23, widely cultivated in Southeast Asia, is valued for its high yield and marketability. PR23, designated as a government-recommended variety, is expected to improve labor productivity and sustainability in rice cultivation.

Perennial wild rice typically allocates more assimilates to vegetative growth and propagation, resulting in lower seed production. However, *Oryza longistaminata* can reproduce both vegetatively through rhizomes and by seed. PR23 leverages this trait, significantly reducing labor and cultivation management costs by half from the second year onward, compared to annual varieties, offering a promising solution to labor shortages and improving overall productivity.

Nevertheless, the adoption of PR23 presents several challenges. Continuous cropping and reduced tillage can lead to nutrient imbalances in the soil and increased risk of pests and diseases. Additionally, if yields decline, removing the rhizomes that have proliferated deep in the soil due to ongoing cultivation poses a greater burden than replanting (Stokstad, 2022).

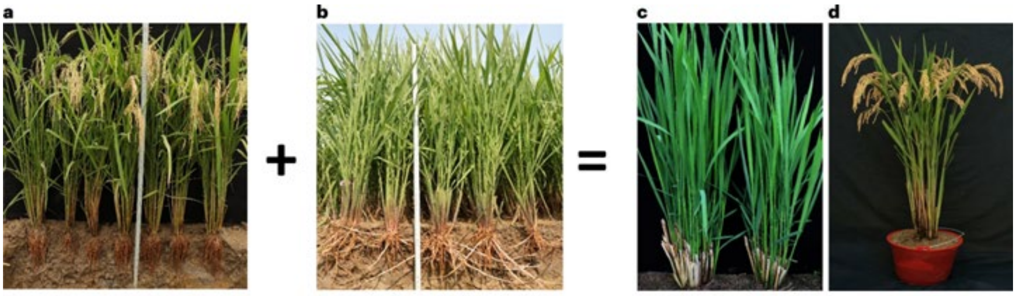


**Figure 14: Breeding of perennial rice varieties**

(Source) Zhang et al. (2023)

Note: (a) Annual variety RD23 (*Oryza sativa*); (b) Perennial variety (*Oryza longistaminata*); (c) PR23, perennial rice selection showing excellent regrowth above ground; (d) Ratoon rice crop of PR23

### Development of high-ratooning early maturing rice varieties

The development of high-ratooning, high-yielding early-maturing varieties is a key approach to improving the feasibility of ratoon rice cropping systems. Due to their shorter growth cycles, early-maturing varieties enable multiple cropping within a single year, enhancing land productivity and resource use efficiency (Liang et al. 2024).

Early-maturing varieties also provide farmers with the flexibly to select varieties based on market demands and specific cultivation conditions for each cropping cycle. Additionally, their introduction enhances the adaptability of ratoon cropping in regions with limited planting periods, such as temperate zones, and in areas prone to water shortages (Dou et al. 2016; Zhijun et al. 2024). By utilizing high-ratooning and early-maturing varieties, rice farming can achieve greater operational flexibility through an approach distinct from that of perennial rice varieties.

# 5: Future issues and developments

## 5.1: Development of rice varieties with high ratoon ability

Historically, productivity improvements in ratoon rice cropping have relied on agricultural techniques and knowledge such as fertilization, water management, and harvesting methods. This reliance stems from the limited availability of varieties with high ratoon ability (Wang et al. 2020). To increase and stabilize yields in ratoon rice cropping, developing rice varieties with high ratoon ability is crucial. PR23, introduced in Section 4.5, is a perennial rice crop that propagates nutritionally through rhizomes and seeds, exhibiting characteristics distinct from conventional rice cropping systems.

Rice ratoon ability is a complex trait influenced by factors like soil moisture, fertilization, and cutting height. It is generally controlled by additive genetic effects, where multiple genes contribute additively, rather than by a few specific genes (Wali & Mhadevappa, 1996). This complexity makes gene-level analysis challenging, rendering improvement and breeding strategies for ratoon rice cropping inefficient. However, recent discoveries of quantitative trait loci and specific genes related to ratoon ability, such as "rice ratoon ability 3 (RRA3)," have advanced our understanding (Hu et al. 2022; Yao et al. 2023).

RRA3 is a homolog of the NRX1 gene in Arabidopsis thaliana, encoding a protein with disulfide bond reduction activity related to ratoon ability and leaf senescence suppression. RRA3 interacts with *Oryza sativa* HK 4 (OHK4), a cytokinin receptor in rice, and inhibits its dimerization, thereby suppressing cytokinin signal transmission. This suppression potentially decreases ratoon ability and limits the elongation of axillary buds, which develop into ratoon rice (Yao et al. 2023).

Through this mechanism, it is hypothesized that RRA3 can suppress excessive axillary bud growth, conserve energy and nutrients, secure the vegetative growth period, and ultimately increase yield. The understanding of rice ratoon ability is gradually being elucidated, suggesting that variety improvement with enhanced ratoon ability may be achievable in the near future.

### 5.2: Understanding of rice nutritional propagation mechanism

There are no studies discussing ratoon rice cropping from the perspective of nutritional propagation. Rice ratooning is a cultivation method that propagates nutritionally from the stubble after the main crop harvest. This method exhibits distinct characteristics in growth development and yield components compared to the main crop propagated by seeds. Specifically, ratoon rice through nutritional propagation has a significantly shortened vegetative growth period, and the number of spikelets per panicle is halved compared to the main crop propagated by seeds.

Similar to perennial wild rice that propagates nutritionally, ratoon rice may prioritize assimilation allocation to the regeneration and development of stems and roots, reducing resources for seed production. The molecular mechanisms involved in nutritional propagation include genes, hormones, and environmental factors, and are more complex compared to seed propagation, with many aspects still not understood (Bessho-Uehara & Amano, 2023). Advances in molecular biology and genetic engineering hold the potential to elucidate these mechanisms. Identifying key genes and signaling pathways involved in axillary bud activation, assimilate redistribution, and allocation could significantly advance yield improvement techniques and the development of rice varieties with enhanced ratoon ability.

### 5.3: Yield loss due to mechanical harvesting

Yield loss due to mechanical harvesting is a major challenge in ratoon rice cropping. When large harvesting machines pass over the field, the stubble is crushed, causing physiological damage to the rice plants and leading to a yield loss of 20%–50% (Peng, 2023; Zheng et al. 2022). The extent of yield loss depends on factors such as planting method and cutting height. In the broadcast sowing method widely used in the Asia-Monsoon region, rice hills are small, and their roots are shallowly embedded in the surface soil, making them more susceptible to machinery damage. This often prevents the plants from reaching maturity, reducing the yield from ratoon rice cropping with mechanical harvesting by half compared to manual harvesting (Fig. 15).

To address this issue, various studies have focused on improving harvesting methods, stubble recovery techniques after machine passage, distributing machinery weight, developing varieties resistant to rolling damage, and fertilizing to strengthen plant stems. Despite these efforts, many challenges remain, and these technologies have yet to be fully implemented (Zou et al. 2024). Further research and development are needed to solve the problems associated with mechanical harvesting.


**Figure 15: Harvest conditions of ratoon rice crop and damage to rice during mechanical harvesting of the main crop**
(Photo) JIRCAS (2023)
(Note) Farmer's field of ratoon rice cropping in Le Thuy, Vietnam

### 5.4: Pest, disease and animal control

Since ratoon rice grows from the same plant as the main crop, it is more susceptible to the same pests and diseases. The stubble remaining after the main crop harvest can become breeding grounds for planthoppers, which spread rice leaf stripe disease. The small brown planthopper, a vector for this virus, migrates to Japan from northern Vietnam and southeastern China on seasonal winds. Recently, the shift to hybrid rice varieties in the Indochina Peninsula and China has intensified insecticide use, leading to the increased the planthopper population with drug resistance, exacerbating the damage (Matsumura, 2014).

Insect-borne diseases such as rice stripe disease transmitted by the small brown planthopper are passed transovarially, making them difficult to eradicate quickly and necessitating long-term control measures. Consequently, local governments in Japan are increasing vigilance against rice leaf stripe disease and recommending prompt plowing after the main crop harvest. Implementing ratoon rice cropping requires thorough planthopper control, including the use of planthopper-resistant varieties and pest management for minimizing the risk of outbreaks.

Birds, such as sparrows, and rodents, is another serious issue in ratoon cropping systems. The staggered harvest period of ratoon rice, which differs from conventional rice cropping, tends to concentrate on bird damage, especially in areas with few surrounding rice fields. Sparrows, for example, are attracted to ratoon rice fields, where they feed on the grains and can cause substantial yield losses. Similarly, rodents such as rats damage the stubble and consume grains, further contributing to yield reductions.

To address these challenges, bird nets and deterrent measures have proven effective against avian pests, while regular field monitoring and timely intervention are essential for controlling rodent populations. A systematic and integrated pest and wildlife management approach is necessary to ensure the stable production of ratoon rice and minimize losses from by pests, diseases, and wildlife damage.

### 5.5: Dissemination of ratoon cultivation technology and its challenges

Ratoon cropping has been recognized as a promising alternative to conventional double rice cropping due to its potential to reduce labor requirements and environmental impacts. However, its adoption remains limited in many regions, and significant barriers continue to hinder its widespread dissemination.

One key challenge is the insufficient transfer of technology and technical guidance to farmers, which has led to unstable and low yields. Many farmers face difficulties in accessing effective solutions to improve productivity, limiting their ability to achieve consistent results (Fig. 16). For instance, in central China and Vietnam's central provinces, attempts to introduce ratoon cropping before the 1990s faced constraints due to unstable yields and limited water resources (Wang et al. 2023; Sen & Bond, 2017). Furthermore, before 2014, in Vietnam's central regions, governmental policies gave low priority to ratoon cropping within provincial rice production targets. This resulted in insufficient water allocation for ratoon cropping, further restricting farmers' adoption efforts.

The promotion of agricultural mechanization has also posed challenges. Although mechanized harvesting improves efficiency, it often damages stubble, leading to substantial yield losses in ratoon cropping. This issue is exacerbated by the continued use of traditional broadcast sowing methods, which result in shallow rooting and increased susceptibility to mechanical damage. Furthermore, the lack of proactive technical guidance from extension workers has hindered farmers' understanding of ratoon cropping's value and practical potential.

To accelerate the adoption of ratoon cropping, strengthening information dissemination and technical support for farmers is essential. This includes targeted farmer training programs, demonstration plots showcasing successful ratoon cropping practices, and clear, practical guidelines tailored to local conditions. Concurrently, it is crucial to address existing technical limitations through the development of high-yielding ratoon varieties and the refinement of cultivation techniques to stabilize yields.

Ratoon cropping offers a labor-saving, low-input rice production system that supports to sustainable agriculture. It also serves as an adaptation and mitigation strategy for climate change, helping to reduce water use and lower greenhouse gas emissions. To promote its adoption, effective collaboration among research institutions, government agencies, and farmer organizations is essential. By aligning dissemination efforts with farmers' needs and local conditions, ratoon cropping can become a viable solution for sustainable and productive rice farming.

**Figure 16: Variations in growth conditions among farmer's fields in ratoon rice cropping**

(Note) Farmer's fields in Le Thuy district, Vietnam

(Photo) JIRCAS (2023)

### 5.6: Enhancing economic feasibility through cost benefit analysis of market value and externalities

Although ratoon rice cropping reduces labor requirements and production costs, its economic viability depends on regional climate, farm scale, and labor availability, making it unsuitable for every rice production system. Consequently, it is imperative to collect and analyze region-specific farm management data to determine break-even points and assess profitability.

Ratoon rice cropping differs from conventional double cropping not only in having a shorter growing season and distinct harvest timing but also in exhibiting unique quality attributes—such as a higher amylose content compared to the main crop (Zhang et al. 2021). These characteristics necessitate a careful evaluation of market trends and consumer preferences, along with the development of supply strategies that align with demand.

Enhancing the added value of ratoon rice is critical for its long-term sustainability. Although ratoon cropping promotes efficient resource utilization and reduces environmental impact, current market mechanisms do not adequately reflect these benefits (Conner, 2004), thereby limiting farmers' ability to secure prices that correspond to the product's enhanced value. Increasing consumer and market awareness through regional branding and targeted marketing strategies is essential for achieving appropriate price recognition.

Demonstrating the economic advantages of ratoon rice cropping is vital for wider farmer adoption. This can be achieved through trial cultivations and comprehensive data collection on region-specific profitability, supplemented by practical support measures such as subsidies, technical training, and the establishment of stable buyer networks. Moreover, future research should include detailed profitability comparisons across diverse agricultural conditions and comprehensive evaluations using True Cost Accounting (von Braun & Hendriks, 2023) to assess both the environmental externalities and overall economic feasibility of ratoon versus conventional double rice cropping.

### 5.7: Deployment in the Asia-Monsoon region

Ratoon rice and perennial rice technologies have attracted significant global attention, as demonstrated by discussions at the 6th International Rice Congress in Manila, Philippines, in October 2023. Originally developed to rapidly increase food production, ratoon cropping has recently gained renewed interest in the Asia-Monsoon region, driven by severe agricultural labor shortages, the pressing need to enhance productivity, and environmental benefits such as water conservation and greenhouse gas emission reductions that underscore its potential in climate change mitigation (Yu et al. 2021).

Given the diverse climatic conditions and socio-economic backgrounds across the Asia-Monsoon region, the effective deployment of ratoon cropping necessitates the development and dissemination of adaptive technologies tailored to local challenges (Saito & Ichikawa, 2014). Variations in rainfall and water resources require adjustments in planting schedules and water management practices, while regional differences in pest and disease prevalence call for customized varietal selection and pest control measures. In addition, establishing mechanisms for sharing both successful and unsuccessful case studies, along with building international research networks, is essential to facilitate the rapid adoption of advanced technologies and to drive context-specific improvements.

Finally, policy support and economic incentives are key to promoting widespread adoption. Implementing ratoon cropping may require infrastructural enhancements—such as the development of irrigation and drainage systems—where government subsidies and technical assistance can play a pivotal role. Furthermore, nurturing model farmers and providing economic incentives that recognize the environmental benefits of ratoon cropping will further encourage its uptake. Collectively, these integrated measures are expected to accelerate the diffusion of ratoon cropping in the Asia-Monsoon region, thereby contributing to sustainable agriculture and addressing regional agricultural challenges.

## 6: Prospects on ratoon rice cropping

Japan's food self-sufficiency rate was 38% in 2021, with the government target of 45% by 2030. However, dietary changes, an aging population, and shifting household structures have led to a steady decline in rice consumption. Additionally, in low-productivity paddy fields, especially in mountainous regions, field abandonment is progressing. Once abandoned, resuming rice cultivation becomes difficult due to blocked irrigation and drainage channels and overgrown weeds.

Rice is not only a staple food but also a valuable for industries like healthy foods, cosmetics, and industrial products. Beyond its role as a food staple, rice holds great potential for diverse applications. Ratoon rice cropping, with lower production costs, could expand its industrial uses. For applications where taste is not a priority, the increased production efficiency of ratoon cropping could enhance supply, making it highly suitable as an industrial raw material. In bioplastic production, for example, rice-derived products with quality the same as petroleum-based plastics have already been commercialized. Additionally, finely ground rice husks have gained attention as raw materials for nutritional foods and cosmetics, presenting an innovative solution for the effective rice utilization.

Looking ahead, ratoon cropping has the potential to create new added value in agriculture. In industrial applications where taste is not a primary concern, the high production efficiency of ratoon cropping could serve as a key advantage, contributing to the diversification of agricultural economies. To fully realize this potential, the promotion and further refinement of ratoon cropping technologies will be essential. Advances in breeding programs and cultivation techniques that enhance yield stability and production efficiency will further broaden the applicability of ratoon cropping, offering new opportunities for regions facing agricultural challenges.

Ratoon cropping is expected to play an increasingly vital role in enhancing food security while supporting the development of sustainable agricultural systems and strengthening regional economies. Realizing its full potential will require a comprehensive strategy that integrates research and development, targeted policy support, widespread technology dissemination, and consumer awareness initiatives.

## Author contribution statement

Conceptualization, S.S., L.T.H.S.; writing - original draft, S.S.; writing - review and editing, S.S., L.T.H.S.; visualization, S.S. All authors have read and agreed to the published version of the manuscript.


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