Rice Ratooning: A Pioneering Strategy for Enhancing Rice Productivity and Embracing Climate Change Adaptation and Mitigation. A critical review

ABSTRACT

The global demand for rice as a primary staple food, especially in Asia, has intensified the need for increased rice production. However, traditional rice cultivation methods such as double-cropping have adverse environmental impacts and are affected by water scarcity due to changing climate conditions. In this context, the ratoon rice system, which involves regenerating a second rice crop from the same plant after the main harvest, offers a promising solution. Ratoon cropping reduces production costs, labor, and water usage while being more environmentally friendly. This review paper aims to explore the best management practices for enhancing ratoon rice system productivity and climate change adaptation. Various strategies are discussed such as optimal varietal selection, timing of sowing and harvesting, establishment techniques, cutting height of the main crop, water and nutrient management, weed control and the use of plant growth regulators. The results suggest that implementing these practices can lead to better ratoon crop yields and economic benefits. Furthermore, sustainability assessments have shown that ratoon rice cultivation can reduce greenhouse gas emissions, making it a more environmentally sustainable option compared to conventional rice cropping methods.

***Keyword**: Ratooning, Global worming potential, Sustainability, Alternate wetting and drying, cutting height, Grain quality*

1. INTRODUCTION

Rice (*Oryza sativa* L.) is commonly known as the "global grain" and is a significant food source for many people, particularly in Asia. It serves as a primary staple food for over half of the world's population. The total estimated area used for rice cultivation worldwide is 165 million hectares, resulting in a production of 502.98 million metric tonnes.In India, rice accounts for 30% of the daily per capita food intake and for more than 3 billion Asians, it can make up as much as 75% of their total calorie consumption [55]. India stands second in rice production, with an area of 45.07 million hectares and a production of 122.27 million tonnes, closely following China [1]. Rice plays a vital role in sustaining agriculture and ensuring food security for over half of India's population [3].

The increase in food production is a significant challenge in the 21st century, especially in developing countries due to rapid population growth and limited resources, worsened by unpredictable climate conditions. Planting a second rice crop using conventional methods damages the soil and puts pressure on the environment due to excessive use of inputs [35] [14].In the past, the tropics benefitted from substantial second rice crop production but this is now becoming difficult due to water scarcity caused by failed rains and reduced reservoir and underground water levels. For example, in the Tunga Bhadra Project irrigation command in Karnataka, the second rice crop has been banned for the last two years because of water scarcity, with the limited available water reserved for drinking purposes. There is uncertainty about the future situation, considering the changing climate, and even if a second crop is possible, growing rice may not be feasible due to its high water requirements. Technologies like ratooning which allow for multiple harvests from the same plant could be a profitable solution in semi and deep-water rice areas during wet seasons. Ratooning not only addresses water scarcity but also tackles issues like labor shortages, fertilizer use and energy consumption. Moreover, by retaining stubbles instead of burning them for a new crop, ratooning reduces air pollution. Additionally, draining fields after the main crop harvest and shallow impounding with aeration help reduce greenhouse gas emissions like methane (CH_4) and nitrous oxide (N_2O) [33].

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There is a need to increase national rice production without causing further environmental damage. To achieve this, more efficient and environmentally friendly methods should be developed while ensuring the growth of rice production continues.

The ratoon rice system offers a promising solution to the challenges mentioned earlier. Ratoon rice cropping involves cutting the rice stem after the main harvest and allowing the stump to regenerate, producing a second rice crop in the same season. This technique has the potential to increase rice production per unit of land area [12].Ratoon rice is known for its efficiency and cost-effectiveness compared to conventional rice cultivation. In tropical areas of Asia, around 30% of rice cultivation is done using the ratoon rice system, covering approximately 26.43 million hectares. This method significantly contributes to total rice production [26].The ratoon rice system has several advantages. It requires lower production costs as there is no need for land preparation and replanting, and fewer fertilizers are needed. Moreover, it shortens the harvest time by 40%, saves up to 60% of water, and reduces production inputs by 38% [19].Compared to traditional double-cropping rice systems, ratoon rice cropping saves labor, time, seeds, and water, and eliminates the need for nursery supplies and land preparation [31]. Labor and seed inputs are significantly reduced, making it a more resource-efficient [25][40]**.**However, there are challenges to widespread adoption of ratoon cropping, as it tends to have lower yields, approximately 40 to 60% of the main crop [55]. The variable grain output hinders its broader use.

Despite this drawback, the ratoon rice system shows great potential in addressing the increasing demand for rice production while conserving resources and being more environmentally friendly. Further research and improvements are needed to maximize its efficiency and overcome yield limitations.Currently, the adoption of ratoon rice farming by farmers is very limited, despite its numerous advantages in climate change adaptation and mitigation. This could be attributed to a lack of awareness and efficient management practices. Given the significant benefits of the ratoon rice system, it becomes increasingly crucial to conduct a comprehensive review and provide suggestions for more effective management practices. The primary objectives of this review paper are to assess the best ratoon management practices of rice that can enhance system productivity and facilitate adaptation to climate change.

2. REDUCTION IN GREENHOUSE GASES EMISSION

Rice cultivation is a major contributor to greenhouse gas emissions, including CH_4 and N_2O, accounting for around 30% and 11% of global agricultural emissions, respectively. Evaluating the sustainability of ratoon rice compared to other rice cropping methods is important. Zhang et al.(2019) conducted a study comparing CH_4 emissions from ratoon rice and double-cropping rice fields at the same location. They found that CH_4 emissions were significantly lower during the ratoon rice seasons compared to the late rice season. Additionally, CH_4 emissions per unit yield were 71% lower in the ratoon rice seasons. Over two seasons, ratoon rice emitted 23% less CH_4 per unit yield compared to double-cropping rice [52].

Peng et al. (2021) reported lower Global Warming Potential (GWP) and greenhouse gas intensity (GWPi) in ratoon rice (RC) compared to conventional rice or main crop (MC). The average GWP of RC was 59.3% lower than MC, mainly due to reduced CH_4 emissions and decreased greenhouse gas emissions from using fewer agronomic inputs. The GWPi of RC was also 23.4% lower than MC, primarily attributed to its lower GWP [36]. Furthermore, Huang et al. (2022) stated that switching from double-season rice to ratoon rice significantly increased the annual net ecosystem economic benefit (NEEB) by 30.95% [21].

3. AGRONOMIC MANAGEMENT STRATEGIES OF RICE RATOON UNDER CLIMATE CHANGE SCENARIO

The cultivation of rice ratoon crops has been known for a long time in certain parts of Asia. However, it has not been widely adopted historically due to its unpredictable and low yields. According to Chauhan et al. (1985), commercial farmers have been hesitant to embrace rice ratooning because of various reasons, such as the lack of suitable ratoon varieties, issues with uneven maturity, disease and insect infestations, absence of location-specific cultural practices, inferior grain quality and uncertainty regarding returns on investment [7].

Recent research has shown that with the implementation of new management strategies, rice ratoon crops can be both productive and profitable. It is essential to adopt optimal practices during both the main and ratoon seasons to ensure the sustainability and productivity of the ratoon rice system. This section presents high-yielding technologies for the ratoon rice system, particularly considering the challenges posed by climate change. These technologies encompass varietal selection, timing of sowing/planting and harvesting of the main crop, main crop establishment and cutting height of the main crop, water management, nutrient management, weed management and the use of growth regulators.

3.1Varietal selection

The success of ratoon crops depends on their adaptability to different day length, temperature, and sunlight conditions compared to the main crops. However, there has been a lack of specific breeding projects focused on ratoon rice varieties. As a result, the varieties used in ratoon rice systems are typically selected from popular varieties already widely used in production.Studies have attempted to identify suitable ratoon rice varieties. For example, Identified four genotypes capable of producing at least 1.5 t ha^{-1} of dry milled grain or increasing the yield by over 50% compared to the main crop in Indonesia. Several varietal traits, including growth duration, regeneration ability and yield potential are important factors to consider when evaluating the sustainability of varieties for ratoon rice practices [4].

Hybrid varieties have shown promise in ratooning, with higher regeneration rates and ratoon yields compared to inbred varieties [39]. Long-duration cultivars have also demonstrated better ratooning ability than short-duration cultivars [9]. Two-line hybrid varieties generally perform better in ratooning compared to three-line hybrid varieties [26].Das and Ahmed (1982) conducted a study in Karimganj, Assam, where they assessed 89 semidwarf varieties that are not influenced by photoperiod for their yields in both main and ratoon crops. Among these varieties, C 3810 exhibited the most favorable results, achieving the highest yield for the main crop (4.1 t ha^{-1} within 124 days) as well as the highest yield for the ratoon crop (2.1 t ha^{-1}within 54 days). Following closely in performance were CR 220-60 and CR 156-5021-307 [56]. Various indices from the main season have been suggested as indicators of high regeneration ability in ratoon crops. For instance, stem thickness, the ratio of leaf to grains during the heading stage of the main crop, stem carbohydrates at harvest and delayed leaf senescence have been linked to better ratooning ability [20] [22]. However, definitive indicators directly related to strong ratooning ability have not been identified yet. More research is needed to better understand and improve the adaptability and productivity of ratoon rice varieties.

3.2Time of sowing/planting and harvesting of main crop

Main and ratoon rice crops experience different day length, temperature and sunlight conditions due to their varying planting dates. However, there has been limited research in this area and these conditions can significantly influence the performance of ratoon crops [7].

Ratoon rice is typically recommended to be grown in regions where there is sufficient thermal energy for single-season rice but not enough for double-season rice [11] [48]. Since thermal energy is generally limited in ratoon rice production, it becomes crucial to optimize the planting date, with an emphasis on early planting. In central China, the main crop is usually harvested between August 5 and 15. Early harvesting of the main crop ensures the success of the ratoon crop as the growth duration and harvesting date of the ratoon crop depend on temperatures in September and October. Higher temperatures during these months result in delayed harvesting and a prolonged growth duration for the ratoon crop, ultimately leading to higher grain yields [41].Similarly, studies in the US and India have shown that planting dates affect ratoon grain yield, with earlier planting resulting in better yields. Planting in September rather than October yielded higher ratoon crops due to lower temperatures affecting ratoon development [57].Overall, the optimum planting date for ratoon rice varies depending on the location and continent. However, in general, early planting is key to achieving successful ratoon crops.

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The stage of maturity or time of cutting the main crop has a direct impact on the yield of both the main crop and the ratoon crop. The best time for cutting the main crop to achieve good ratooning is when the culms are still greenish [14].In India, Lal et al. (2023) found that both the main crop (MC) and the ratoon crop (RC) performed better when planted at the normal planting time (first week of July). The ratoon crop from normal planting recorded 12.9% more panicles and 8.4% more fertile grains per panicle compared to late planting (third week of July). Ratoons from late-planted crops matured earlier, taking only 41–47% of the time needed by the main crop to achieve maturity while normal-planted crops took around 53% of the time. This indicates that timely sowing allows the crop more time to develop panicles and fertile grains. Grain yield was also significantly affected by planting time with the ratoon crop under normal planting yielding 13.6% and 39.7% more grains than the late and very late planting times, respectively [38].

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3.3Main crop establishment

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Direct-seeded rice is a simplified and sustainable method for rice establishment that has the potential to reduce resource consumption and greenhouse gas emissions while maintaining grain yields compared to transplanting [58][60]. Introducing direct-seeded rice into the ratoon rice system to create direct-seeded ratoon rice (DSR-RR) is a promising approach for sustainable development.Previous studies have shown that DSR-RR systems can achieve comparable ratoon season yields and annual yields to transplanting ratoon rice [11]. However, there have been variations in the performance of DSR-RR, with some studies reporting lower ratoon crop yields compared to the main crop [38]. Factors such as poor and uneven crop establishment, weed control issues, and lodging susceptibility in direct-seeded rice could be responsible for the decreased grain yield in DSR-RR [59].The planting dates of the main crop should consider the rainfall and temperature during its growth periods. Delayed planting of the main crop may result in ratoon crops not maturing properly due to low temperatures during the grain filling stage [42]. Additionally, heavy rainfall during the reproductive stage of rice can lead to significant yield losses [47]. Therefore, proper consideration of weather conditions during planting is crucial for successful ratoon rice systems.

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3.4Cutting height of main crop

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The height at which the straw is cut during the harvesting of the main crop determines the number of nodes left on the stubble. Each node, except the first one from the top, has an axillary bud that can potentially produce a regenerated tiller. Regenerated tillers produced at higher cutting heights usually have shorter growth durations compared to those from lower node positions [21][26]. It is essential to adjust the straw cutting height during main crop harvest to avoid cold damage during the panicle development and flowering of the ratoon crop, especially with a high cutting height for late harvesting of the main crop.However, there is a debate on whether high or low cutting heights result in higher grain yields of the ratoon crop. Some studies, like Yazdpour et al. (2012) and Nakano et al. (2020), reported that higher cutting heights (40-50 cm) increased the grain yield of the ratoon crop due to increased panicles per square meter and better grain filling. They attributed this to the greater leaf area index (LAI) and higher nonstructural carbohydrates in the stubble, providing more resources during the growing period[50] [31].

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On the other hand, studies by Banoc et al. (2022) showed that shorter cutting heights (15 cm) resulted in significantly higher ratoon rice grain yields compared to higher cutting heights (45 cm). They observed remarkable growth and development of stems or culms, longer panicles, increased production of filled grains, and extended growth periods, particularly during the reproductive phase. The shorter stubble height led to a delay in the 50% heading of the ratoon crop and a longer time to maturity compared to the higher stubble height [6].Similarly, in a study by Shin et al. (2015), they examined the effects of different stubble heights on the yield of the 'Jinbuol' rice cultivar, the main crop. They harvested the rice at stubble heights of 40, 30, 20, and 10 cm, and the results showed that the highest grain yield of 2,810 kg ha^{-1}, which was about 45% of the main crop yield, was achieved when the stubble height was reduced to 10 cm (as shown in Fig 1 and 2). The findings of the study indicated that increasing the initial stubble height from 10 to 40 cm led to changes in the crop's growth pattern. This alteration was observed in the shifting of the panicle point of origin and a delay in grain ripening. Additionally, the head rice ratio of the ratoon rice increased when the stubble height was reduced by 10 or 20 cm [43].

The contrasting results may be attributed to different varieties and climatic conditions, particularly the availability of thermal energy during the ratoon season's growth period. Overall, finding the optimal straw cutting height for the ratoon crop may depend on various factors and should be tailored to specific rice varieties and environmental conditions.

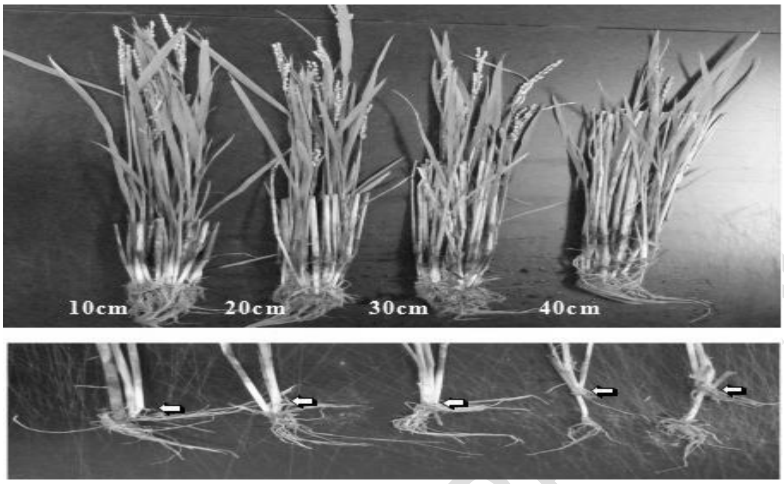

Fig. 1. The image shows the growth phase of the ratoon rice at different stubble heights (upper) and the emergence of new shoots from the main stubble (under). The photo was captured six weeks after the harvest of the main crop [43].

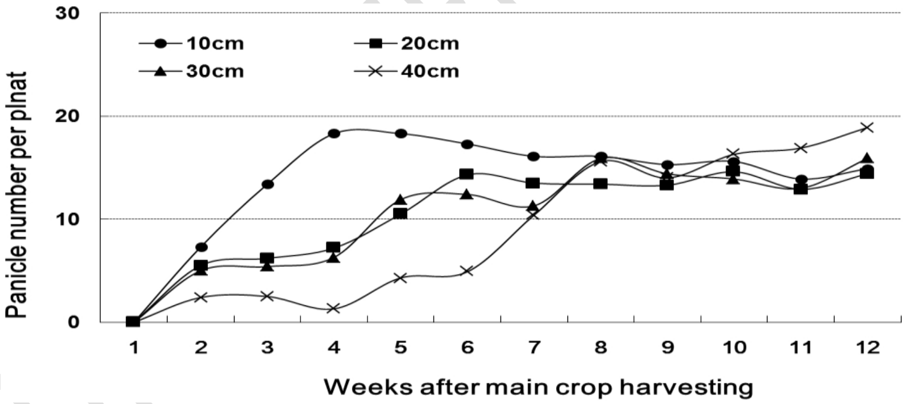

Fig. 2. The heading response of 'Jinbuol' rice cultivar in the ratoon crop varies depending on the stubble heights of the main crop [43]

3.5Water management

Effective water management practices, specifically soil drying, play a vital role in increasing and sustaining the grain yield of ratoon crops. Soil drying during the main crop's maximum tillering stage enhances soil oxygen content and oxidation-reduction potential, promoting root system growth, root activity, root wound flow, and root number. Furthermore, soil drying during the middle-late grain filling stage or at the main crop's harvest reduces rolling damage on ratoon stubbles during machine harvesting. This vigorous root growth and well-preserved ratoon stubble contribute to the successful regeneration of ratoon buds, resulting in improved yield performance of the ratoon crops. Shiraki et al. (2020) observed a significant 69% increase in grain yield in the dry regime compared to the saturated regime during the initial growth period of ratoon crops, potentially attributable to favorable soil oxidation conditions [44].

3.6 Irrigation management

Effective water management practices, specifically soil drying, play a vital role in increasing and sustaining the grain yield of ratoon crops. Soil drying during the main crop's maximum tillering stage enhances soil oxygen content and oxidation-reduction potential, promoting root system growth, root activity, root wound flow and root number. Furthermore, soil drying during the middle-late grain filling stage or at the main crop's harvest reduces rolling damage on ratoon stubbles during machine harvesting.This vigorous root growth and well-preserved ratoon stubble contribute to the successful regeneration of ratoon buds, resulting in improved yield performance of the ratoon crops. Shiraki et al. (2020) observed a significant 69% increase in grain yield in the dry regime compared to the saturated regime during the initial growth period of ratoon crops, potentially attributable to favorable soil oxidation conditions. Effective water management immediately after harvesting the main crop is crucial for achieving high grain yield in the ratoon season [44]. While irrigation on stubbles after the main crop harvest does not affect ratoon crop yield and rice quality [43], flooding irrigation in the ratoon season immediately after the main crop harvest [29] can effectively promote the tillering of ratoon crops. However, it is essential to strictly control the timing and amount of irrigation to avoid heavy and continuous flooding, as excessive water can suppress ratoon crop growth by inhibiting root growth and bud development from basal nodes leading to a 69% reduction in yield compared to shallow flooding practices [5]. Within the growing season, adopting irrigation management practices like alternate wetting and drying (AWD) shows potential to reduce CH_4 emissions by decreasing the total duration of field inundation. AWD involves periodic drying of rice fields between flooding and Runkle et al. (2023) found that it reduced CH_4 emissions by an average of 79.5% compared to delayed, continuous deep flooding (DF) during the main crop season. Across different field-seasons, CH_4 emissions from the main crop ranged from 77.2 to 132.5 kg CH_4-C ha^{-1} under DF and from 7.1 to 40.7 kg CH_4-C ha^{-1} under AWD. In the ratoon crop, emissions ranged from 39.7 to 50.7 kg CH_4-C ha^{-1}, representing up to a 3.6-fold increase from the main crop of the same year [37].

3.7 Nutrient management

The fertilizer management approach for the main crop is quite similar to that of middle-season rice. However, the main difference lies in the nitrogen (N) application rate, which is higher during the vegetative stage when air temperatures are relatively low following the same strategy as used for early-season rice [53]. The application of N has positive effects on various aspects, such as enhancing tillering, increasing the sprouting rate of buds from the lower nodes of the stubble, promoting grain filling and ultimately increasing the grain yield of the ratoon crop. Shin et al. (2015) highlighted the importance of applying fertilizer immediately after the main crop harvest to encourage abundant ratooning, leading to higher grain yield. The ratoon crop's grain yield and straw yield were found to increase with the application of N fertilizer on stubbles after the main crop harvest, while plots with no application showed decreased yields. Among the different N fertilizer doses, top dressing with 30 kg/ha of N fertilizer after main crop cutting resulted in the highest ratoon yield (Fig. 3) [43].

To enhance the regeneration of ratoon buds and increase the productivity of ratoon rice, it is recommended to apply two additional N fertilizations. One should be applied two weeks before the harvesting of the main cropand the other within 3 days after the harvesting of the main crop [9][25]. A slow-release N fertilizer specifically designed for ratoon rice has been developed by CPPC in collaboration with Sinofert Holding Limited, which eliminates the need for the bud-promoting N fertilizer [49]. By using this slow-release N fertilizer, the number of N applications for the entire ratoon rice (main plus ratoon seasons) can be reduced from 5 to 2-3 times without a significant reduction in annual grain yield. Applying N fertilizer 15 days after the heading stage has been found to increase the photosynthetic ability of flag leaves, promote nutrient transportation to the stemsand activate the growth of the ratoon root system, leading to a significant increase in the sprouting of regenerated buds and ultimately increasing the grain yield of ratoon crops.On the other hand, the application of P and K fertilizers to the ratoon crop does not seem to significantly affect ratoon grain yields. Fitri et al. (2018) conducted an experiment with different dosages of phosphate fertilizer and found that it did not have a notable impact on the yield and growth of ratoon rice. However, on study reported that a ratoon crop yielded better with the application of 20 kg ha^{-1} of P and K. Thus, the effects of P and K fertilizers on ratoon rice may vary depending on different factors and conditions [12].

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3.8 Weed management

Weed infestation poses a significant challenge in achieving a successful ratoon crop. However, there is limited research on weed management in ratoon rice. A study by Satapathy et al. conducted over two consecutive years, found that *Cyperusdifformis* was the dominant weed in the main rice crop, while *Ludwigiaadscendens* was dominant in the ratoon rice [39]. Other weeds such as *Echinochloa, Alopecurus, Eclipta, Cyperus, Paspalum*, and *Amaranthus*were also reported in ratoon rice. Crop-weed competition in weedy plots caused a reduction of 28.8% and 37.5% in energy use efficiency and energy productivity of the rice-ratoon rice cropping system, respectively. The yield of both the main crop and the ratoon crop was also significantly reduced by 37.3% and 43.6%, respectively, due to weed infestation in the weedy check. Therefore, effective weed management in ratoon rice is essential to minimize grain yield losses. Satapathy et al. (2022) found that applying bensulfuron-methyl + pretilachlor (60 + 600 g/ha) at 10 days after sowing to the main crop resulted in higher net returns of USD$ 639.2 and 260.1 for the main crop and ratoon crop, respectively. This indicates that appropriate weed management practices can lead to improved economic outcomes for both crops in the rice-ratoon rice cropping system [39].

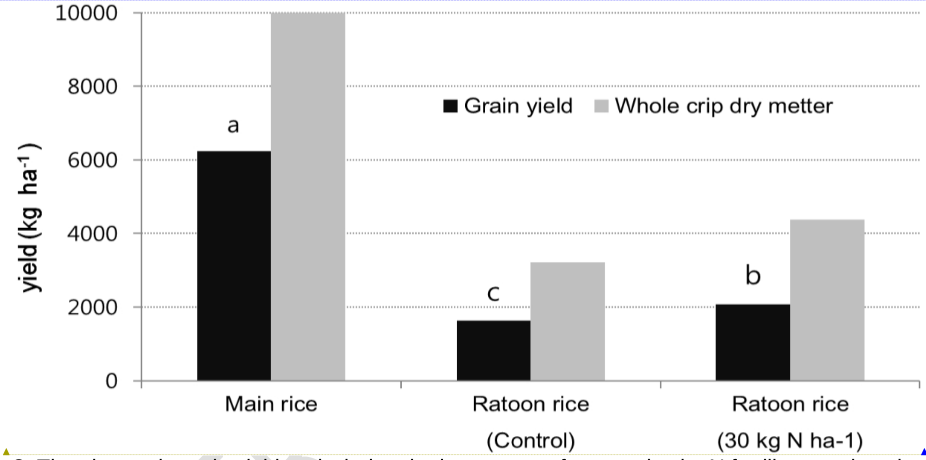

Fig.3. The change in grain yield and whole crip dry matters of ratoon rice by N fertilizer topdressing on stubbles of main crop in 'Jinbuol' rice cultivar [43]

3.9Plant growth regulator

The yield of ratoon rice is generally lower as compared to the main crop. However, better cultivation and management techniques, such as the application of plant growth regulators (PGRs), have the potential to increase the yield of ratoon crops. Cytokinin and gibberellins are two types of PGRs that can stimulate plant growth. These active growth regulators can have significant effects on plant growth even in very small doses.

Some research has been conducted on the use of PGRs, particularly cytokinin and gibberellins (GA) and their effects on plant growth. Fitri et al. (2018) found that the application of gibberellins led to the highest increase in plant growth and yield of ratoon rice. This is because gibberellins can increase cell wall turgor, resulting in cell wall stretching and pushing the cells to grow larger [12]. Utama (2015) also reported that gibberellin application affects plant height by increasing the amount of indigenous gibberellins in the plant, leading to an increase in the number and size of cells, influencing vegetative growth and reducing the risk of dwarf plants [45]. Similarly, Gunalarasi et al. (2022) observed that GA at 5ppm resulted in higher dry matter production, grain yield and straw yield with a higher benefit-to-cost ratio in ratoon rice. On the other hand, BA at 100ppm significantly influenced tiller production, plant height and bud regeneration rate but did not have a substantial impact on grain and straw yield [15].

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4. GRAIN YIELD AND QUALITY

The grain yield of ratoon crops showed significant variation, ranging from 1.1 to 4.9 t ha^{-1} and accounted for 28.6 to 64.3% of the grain yield in the main season [33]. This variability in ratoon season yield can be attributed to differences in climatic conditions, rice varieties and crop management practices across various rice production regions. Notably, the grain yield of ratoon crops in tropical areas tended to be lower compared to subtropical and temperate regions. Wang et al. (2016) previously reported that the high temperatures in tropical areas reduced radiation use efficiency, resulting in lower yields compared to regions with milder temperatures [46].

The quality of rice has become an increasingly important consideration for consumers, particularly with the growing economy and increased purchasing power of a significant portion of the population. It is found that ratooning improved the milling and appearance quality of rice. When compared to the main crop, the ratoon crop exhibited a 5.5% increase in head rice yield and a 10.9% decrease in chalkiness degree. Moreover, the ratoon crop displayed improved nutrient content, cooking properties and taste quality, as indicated by increased amylase content, decreased gelatinization temperature and altered gel consistency of the rice grains, surpassing those of the main crop [2].

5. ECONOMICS OF THE RICE RATIONING

Rice ratooning offers several cost-saving benefits as it reduces the need for labor, water, and seeds during land preparation, sowing and transplanting. Studies have reported a reduction of 28.5% in labor input and a significant decrease of 519% in seed input for the ratoon rice system compared to the double-season rice [24][40]. Additionally, the cost of fertilizers and pesticides in the ratoon system was lowered by 31.5 and 41.1%, respectively, leading to a decrease in total input costs compared to double-season rice.

Although the annual yield of the ratoon rice system is generally lower than that of double-season rice, economic evaluations have shown promising results. Peng et al. (2021) conducted an on-farm survey comparing the economic performance between the main crop (MC) and ratoon crop (RC). They found that while the gross income of RC was reduced by 43.2%, the total production cost was significantly lower due to reduced labor, machinery, pesticide and fertilizer inputs in RC compared to the main crop (Table 1). In fact, the total production cost of RC was found to be 71.0% lower than that of MC. Consequently, RC demonstrated a 49.9% higher net economic return compared to MC, indicating that it was more profitable. These findings were further supported by significantly higher benefit-to-cost ratio, net profit-labor use ratio and eco-efficiency in RC compared to MC. Overall, ratoon rice cultivation proves to be a financially viable and profitable option for farmers[35].

Table 1. Production costs (and percentage of total production cost), total production cost, gross income, and net economic return (US$ ha^{-1}) of main and ratoon crops in 180 farmers[35]

Variable	Main crop	Ratoon crop	Diff (%)
Costs			
Machinery	500.9 (19.4%)	202.7 (27.1%)	-59.5
Diesel	110.7 (4.3%)	40.8 (5.5 %)	-63.1
Seed	235.5 (9.1%)	0.0 (<1%)	-100
Labour	924.1 (35.7%)	167.2 (22.3%)	-81.9
Fertilizers	355.4 (13.7%)	93.0 (12.4%)	-73.8
Pesticides	454.3 (17.6%)	243.6 (32.5%)	-46.4
Electricity	4.9 (<1%)	1.4 (<1%)	-71.4

Total production cost	2855.9	748.7	-71.0
Income			
		4	5
Gross income	3360.0	1909.4	-43.2
Net economic return	774.2	1160.7	49.9

6. FUTURE COURSE OF ACTION

Ratoon rice presents a practical and resource-efficient approach to increase rice production per unit area and address the growing demand for food. However, to fully harness its potential, in-depth research is needed to understand the factors influencing ratooning ability and yield. Ratoon cropping shows promise in specific contexts, such as rainfed hilly areas, where it outperforms a second rice crop or other upland crops. In wet seasons of semi and ~~deep water~~deep-water rice areas, ratooning could be a profitable option due to water scarcity resulting from climate change.

Furthermore, ratooning offers solutions to various challenges, such as labor, fertilizer and energy shortages. By retaining stubbles instead of burning them for a new crop, ratooning mitigates air pollution and proper field management reduces greenhouse gas emissions like CH_4 and N_2O. Developing suitable cultivars for ratooning through traditional and biotechnological methods remains a significant challenge, as does effectively managing pests, which can be more problematic in ratoon crops compared to separate second crops.

To make significant progress, comprehensive studies on ecological consequences and eco-economics are essential. Despite the challenges, ratoon rice should be seen as an opportunity to address emerging ecological and food-related issues. By adopting this climate and resource smart technology, we can enhance rice production sustainably and contribute to food security.

7. CONCLUSION

In conclusion, the ratoon rice system offers a promising solution to the challenges of increasing food production, especially in the face of rapid population growth and climate change. This method has the potential to enhance rice production per unit of land area while conserving resources and being more environmentally friendly. However, there are still challenges to overcome such as lower yields compared to conventional rice cropping. To make ratoon rice farming more widespread, efficient management practices and increased awareness among farmers are essential. The review highlights various agronomic management strategies for successful ratoon rice cultivation under climate change scenarios. These strategies include optimal varietal selection, timely sowing and harvesting of the main crop, proper main crop establishment, appropriate cutting height of the main crop, water and nutrient management, weed control and the use of plant growth regulators. Research indicates that ratoon rice cropping can significantly reduce greenhouse gas emissions and enhance the overall sustainability of rice cultivation. Additionally, economic evaluations show that ratoon rice can be a financially viable and profitable option for farmers due to reduced input costs.

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