Review Article

Rice Ratooning: A Revolutionary Approach for Resource-Efficient and Sustainable Practice for Promising Future of Rice

Abstract

Ratoon rice, a unique method of cultivating a second crop from primary harvested stubble, is gaining recognition for its potential to revolutionize rice productionsustainability and resource efficiency. This comprehensive study aimed to assess the effectiveness of ratoon rice cropping systems compared to traditional methods, focusing on grain yield, quality, economics, and overall sustainability. To achieve better yields in ratoon crops, it is crucial to adopt suitable management practices for both the main crop and the ratoon crop. These practices encompass land preparation,use of suitable cultivars, water management, precise fertilizer application, appropriate cutting stubble height, and effective control of insects and diseases. Results unveiled that with proper management, ratoon rice yields were on par with approximately 60% of the main crop while utilizing only 50% of the labor and resources. The ratoon rice system demonstrated multiple benefits, including farmer profitability, improved crop quality, and reduced greenhouse gas emissions. Despite its promising potential, the widespread adoption of ratoon rice faced limitations such asinconsistent and lower ratoon crop yields, and the lack of suitable cultivars and specialized rice mechanical harvesters. Addressing these challenges, critical agronomic practiceswere identified, encompassing nutrient and water management, stubble cutting height, variety selection, and integrated technologies for disease and insect control. Ratoon rice iscrucial for promoting widespread adoption and securing ratoon rice as a viable solution for the future of rice cultivation.

Keywords: Agronomic practices, Crop yield, Economic benefits, Ratoon rice, Resource efficiency,Sustainability, Quality.

1. Introduction

Rice (*Oryza sativa* L.) stands as a crucial source of nutrition worldwide, second only to wheat, with an estimated 165.25 million hectares devoted to rice cultivation and a total production of 502.9 million metric tonnes [1]. As one of the most vital staple crops, rice accounts for approximately 21% of the world's caloric intake [2]. Recent decades have witnessed a surge in the adoption of intensive agricultural practices, such as inorganic fertilizers, herbicides, mechanization, and improved cultivars, contributing to significant yield growth. However, this intensification has also led to rising production costs and adverse environmental effects, necessitating the exploration of solutions that can enhance production while minimizing environmental impacts and ensuring farmer profitability [3].Considering the challenges faced by conventional rice cropping systems, exploring alternate planting techniques becomes imperative. In the realm of multiple rice cropping systems, the predominant approach has been double-season rice, widely practiced in Asia. This system, along with other multiple cropping methods like triple-season rice and ratoon rice, has demonstrated the potential to boost overall rice production per land area, significantly contributing to theglobal rice supply [4]. Ratoon rice cultivationinvolves harvesting a second crop, known as the ratoon crop, from the stem nodes on the rice stubbles left after harvesting the main crophas emerged as a viable alternative to traditional double-season ricehas garnered significant attention in recent times. This unique approach offers the advantage of obtaining two harvests from a single planting, thereby reducing production costs and increasing resource use efficiency compared to conventional double-season rice cropping systems.Various studies have shown that ratoon rice can significantly contribute to enhancing the sustainability and profitability of rice cropping systems. It has been observed that ratoon rice exhibits high economic returns, decreased agricultural inputs, reduced resource consumption, and lower environmental impact [5-6].Studies indicate that ratoon rice yields approximately 40–50% of those obtained from the primary crop while demanding reduced labor and water resources, ranging between 50 and 70% [7-8]. Ratoon rice cropping offers significant advantages over traditional double-cropping systems, leading to a reduction of 29% in labor and 52% in seed inputs [9-10].As ratoon cropping requires no nursery supplies or land preparation and has a shorter growth duration (40-90 days) compared to the leading rice crop (85-175 days). This results in 50-60% less labor and reduced crop maintenance costs [11].However, challenges such as manpower constraints, limited automation, and suboptimal production efficiency have led to a decline in the area planted with double-season rice in recent years. Ratoon rice (RR) is emerging as a game-changer in rice production, meeting the global demand while addressing environmental concerns [12] by allowing more frequent harvests on existing land without intensive activities, RR proves to be an eco-friendly solution for the future [13]. Rapidly gaining popularity, RR has seen an average yield increase of 26.1% to 71.43%, making it a lucrative option for farmers [14-15]. From an environmental perspective, RR requires lower water and pesticide inputs compared to traditional rice cycles. To ensure a secure and sustainable rice production, strategies to improve the viability and profitability of various rice cropping systems are urgently needed. RR cultivation has been proven to improve farmer revenue, enhance agricultural productivity, reduce labor and input requirements, and sustain crop production [16].In recent years, the planting area of ratoon rice has rapidly expanded, making it a significant cropping system not only in China but also in other countries like the United States, Japan, Brazil, India, the Philippines, and Thailand [17-19]. Ratoon riceis a promising cultivation system practiced on a commercial scale in the United States [18]. Rice ratoon technology presents an ideal solution for a viable and economic choice, especially in the mid-altitude valley ecosystem of the North-eastern Himalayan region in India [8].Researchers have also made significant advancements in understanding the factors influencing ratoon rice performance, including crop management practices, stubble height, and the adoption of new hybrid cultivars and high-yielding technologies [20-21].Previous studies have primarily focused on optimizing agronomic management practices to achieve high ratoon crop yields. Key techniques include variety selection [22], timing of sowing/planting [23], timing of main crop harvest [24], cutting height of the main crop [18], and efficient fertilizer and water management [25-26].This review article aims to comprehensively assess the benefits and challenges associated with ratoon rice cultivation, examining its impact on agronomic aspects and resource efficiency. Furthermore, we will explore the recent advancements and strategies to improve the sustainability and productivity of ratoon rice systems.

2. Climatic conditions of ratoon rice

The success of ratoon rice production hinges upon key factors such as temperature, solar radiation, and humidity, which influence the grain yield and flowering of the ratoon crop.The Influence of daily mean temperature and sunshine durationemerges as the key climatic factors impacting the grain yield of ratoon rice[27]. It thrives in regions with an average annual temperature exceeding 18□,adaily mean temperature above 23□ for the first 30 days post-harvest ensures successful flowering of the ratoon crop.Optimal climatic conditions for ratoon rice success with the initiation of axillary bud benefits from an optimum temperature of 25°C-28°C and relative humidity of 83% [28]. Higher daily mean temperature, solar radiation, and sunshine duration after the heading of the ratoon crop positively impact ratoon crop yield [29].Appropriate planting time is crucial for effective water management, as well as to optimize the impact of temperature and solar radiation on the growth of main crops and ratoon crops.For rice seed germination, the minimum, optimum, and maximum temperatures are 8–10°C, 30–32°C, and 42°C, respectively [30]. The ideal temperature for rice seed germination is 20–35°C, 25–31°C for tillering, 25–28°C for panicle differentiation, and 20–25°C for grain ripening [31].If temperatures are too low during the late stages of the main crop growth, it can lead to increased grain sterility and hinder the proper development of ratoon crops. Hence, careful consideration of planting time and seeding methods is vital for ensuring optimal conditions and maximizing crop productivity (**Table 1**).As the grain ripens, the optimum temperature decreases to 20°C to 25°C.It is crucial to avoid exposing rice plants to low temperatures during the late main crop growth stage, as it can increase grain sterility and hinder ratoon development. Utilizing rice cultivars with short growth duration, along with dry bed-raised seedlings, early sowing, and timely transplanting, contributes to success in specific regions [29]. Early planting and precise timing lead to increased dry matter accumulation, enhanced grain yield, and improved quality, fostering a flourishing ratoon rice harvest. Understanding climatic influences and employing innovative agricultural techniques are essential for improved ratoon rice yield and sustainable crop production.

Table 1. Different strategies of crop season for maximizing the yield

Strategy	Way to enhance ratoon rice	References
Planting Date	Early sowing and transplanting maximize dry matter accumulation	[32]
	Avoid chilling damage to ensure ratoon crop maturity with precise timing	[33-34]
	Early planting increases grain filling percentage and grain yield	[5, 35-36]
Seeding Methods	Pot seeding enhances seedling plasticity and minimizes transplanting shock	[37-38]
	Dry seeding improves root systems and stress resistance	[39-41]
Planting and Harvesting Dates	Early planting optimizes thermal and radiation resource utilization	[32]
	Delays in main crop planting led to delayed ripening stage and reduced ratoon yield	[43]

Thermal Energy	Ratoon rice suits regions with insufficient thermal energy for double-season rice	[44-45]

3. Understanding the varietal characteristics for enhancing ratoon rice production

The selection of rice varieties with crucial traits is a vital task, as it directly influences grain yields in both the main and ratoon seasons. Specifically, prioritizing rice cultivars with strong ratooning ability is essential as this trait plays a critical role in achieving high grain yield. The selection of rice cultivars with high ratooning ability is the linchpin for successful and sustainable ratoon rice production (**Table 2**). This comprehensive exploration of rice variety traits and their influence on ratooning ability offers valuable insights for farmers and breeders seeking to optimize ratoon rice production. The selection of appropriate rice cultivars with strong ratooning ability, suitable growth duration, and specific morphological and physiological traits can significantly contribute to sustainable crop productivity.

Table 2. Key varietal characteristics for Successful ratoon rice production

Rice Varietal Traits	Improved Ratooning Ability	References
High-yield ratoon rice varieties	Suitable growth duration (within 135 days), good ratooning ability	[46]
	Strong lodging and high-temperature resistance, high leaf area duration, low rice shattering	
Rice cultivars for high ratoon yield	High leaf area index (LAI), low grain-leaf ratio, high dry weight per stem-sheath at maturity stage of the main crop	[47]
Rice cultivars with strong ratooning ability	Strong tillering ability, more panicles per unit land area, few spikelets per panicle	[48-50]
	High ratio of leaf area to grains at full heading in the main season	
Hybrid rice for higher grain yield in main and ratoon seasons	Higher carbohydrate content in the stubble, more vigorous root system at the harvesting of the main crop	[48, 51-52]

Ratoon rice cultivation holds the promise of significantly augmenting grain yield and stability by understanding the critical relationships between ratooning ability and various crop indices, coupled with the selection of high-performance cultivars, farmers can unleash the true potential of ratoon rice.Practical strategies like postponed N fertilizer application and alternate wetting and drying irrigation enhance root activity and improve yields in ratoon rice cultivation(**Table 3**). Apart from ratooning ability, other significant characteristics profoundly impact the success of ratoon rice production. Moreover, different agronomic practices and cultivation techniques can be utilized in the forefront for enhancing rice ratoon productivity.

Table 3. Indicators for the high regeneration ability for rice ratoon production

Characteristics	Improved specific attributes	References

Practical strategies for elevated crop performance	N fertilizer application in the main crop benefits root activity and delayed leaf senescence	[53]
	Alternate wetting and drying irrigation improve root morphological and physiological traits	[54]
Effective cultivation techniques	Short to medium duration rice varieties, early seeding and transplanting, early main crop harvest, and high stubble maintenance	[21]
	Evaluation of plant senescence characteristics during grain filling stage and lodging resistance of main crop is crucial for variety selection	[53, 55]

4. Growing Ratoon Rice Varieties: Cultivating Success across countries

Ratoon rice varieties are gaining recognition and momentum in multiple countries due to their potential to boostcropping intensity and rice productivity. The primary objective of rice farmers is to achieve higher yields in the main crop prior to ratoon crop. To accomplish this, they use high-yielding cultivars that also possess good ratooning ability. Several studies [56-58] have reported variations in ratooning capabilities among different rice genotypes (**Table 4**). Interestingly, principal crop early maturing genotypes showed an average 68% higher grain yield compared to the early maturing genotypes of ratoon crops. The lower yield of the ratoon crop was primarily attributed to the number of grains per panicle or panicle size.

Table 4. Factors contributing to the improved productivity of ratoon crop

Characteristics	**Different studies on enhancing the yield**
Total yield	Rice cultivars with high total yields in both main and ratoon seasons are preferable. Selection of cultivars with 160-190 spikelets per panicle can result in high total yields [27, 59].
Spikelets per Panicle	An important indicator for selecting high-yield rice cultivars. Cultivars with fewer spikelets per panicle exhibit strong ratooning ability, while those with more spikelets have higher yield potential in the main crop. Optimal spikelets per panicle for both seasons fall within the range of 160-190 [27, 59].
Axillary bud regeneration	Cultivars with strong axillary bud regeneration capability are preferred for ratooning [35, 5]

Ratoon cultivation is gaining attention as a viable strategy to enhance rice yields not only in the Philippines and Pakistan but also in India [60]. Likewise, promising research outcomes in Bangladesh have shown the potential of ratooning practices to improve rice production [61]. However, to address challenges related to yield variability and stability, it remains crucial to focus on developing improved ratoon varieties [62]. By doing so, sustained and efficient rice production can be achieved, contributing to food security and economic growth across the region.

5. Nitrogen Fertilizer Management for Enhanced Ratoon Yield

Nitrogen (N) fertilizer management is a critical factor influencing the growth and yield of ratoon rice crops. To achieve higher grain yield in the ratoon season, the application of N fertilizer is strategically timed and tailored based on the stubble height and growth duration of the ratoon crop. The ratoon cropbiomass production is significantly influenced by N fertilizer management practices, impacting plant canopy light interception, radiation use efficiency, and N utilization [63].The bud-promoting N fertilizer serves a dual role in ratoon rice production, prolonging leaf senescence during main crop grain filling and boosting leaf N content and photosynthetic rate [64].Precise N fertilizer management is key to unlocking the ratooning ability and grain yield of the ratoon crop (**Table 5**). Various studies have investigated the impact of N fertilizer application on ratoon rice attributes, and the findings offer valuable insights for optimizing N management practices.

Table5.Effect of nitrogen application rate on ratoon crop

N Fertilizer Application	Enhancement in Ratoon Rice Attributes	References
Bud-promoting N fertilizer application	Increased leaf N content, photosynthetic rate, and transport of photosynthetic products to grains	[64-65]
Application of 100 kg N ha^{-1} at 15 days after heading of the main crop	Increased ratoon crop yield by 12.7% – 55.4%,	[63, 66]
Bud-promoting N rate increased from 0 to 103.5 kg N ha^{-1}	Ratoon crop yield increased from 3.78 to 4.36 t ha^{-1}	[67]
Bud-promoting N with application rate of 170 and 125 N kg ha^{-1}	Enhanced grain yield of the ratoon crop compared with control	[68]
Early application of bud-promoting N fertilizer	Improved grain yield, especially in heavy-panicle type cultivars	[65]
Tiller-promoting N applied 1–2 days after harvesting the main crop	Promoted growth of regenerated tillers, improved head rice yield, and reduced chalkiness in ratoon crop rice	[69]

It is evident from the studies that proper N fertilizer management significantly enhances the ratoon crop's growth and yield. The timing, rate, and combination of bud-promoting and tiller-promoting nitrogen play a crucial role in promoting bud initiation, tiller growth, and panicle development, ultimately contributing to higher grain yield in ratoon rice production. We explore the crucial role of N fertilizer application in stimulating bud initiation, tiller growth, and panicle development for both low-stubble and high-stubble ratoon rice systems. The timing of fertilizer application should be carefully considered, with early application at the full-heading stage being recommended for enhanced ratooning bud survival.

6. Optimizing Water Management for Better Ratoon Crop Yield

Water management is crucial for boosting ratoon crop yield in ratoon rice system. Moderately draining paddy fields during the main crop growing season is an effective and widely recommended strategy [70]. Water management strategy for a ratoon crop differs from that of a normal transplanted crop (**Table6**).Critical stages, such as grain filling during the main crop, are essential for promoting the initiation and growth of axillary buds. Decreasing soil moisture content at the maturity of the main crop is beneficial as it improves soil hardness, reducing rolling damage to stubbles caused during harvesting of main crop[71].

Table 6. Comprehensive study of different water management practices with recommendations

Aspect	Key Findings and Recommendations
Effect of soil moisture	Proper water management during the late growth stages of the main rice crop can delay plant senescence, improve root activity, and promote the growth and development of ratooning buds [72]. Adequate drainage during the main crop season significantly improves root activity and enhances ratoon rice yield by up to 15% compared to shallow water irrigation [73]. However, soil moisture below 21% negatively affects ratooning bud growth and causes yield loss.
Alternative wetting and drying (AWD)	Hybrid rice cultivars under AWD conditions produce higher grain yields (5.8%-11.3%) in the main crop season and (11.9%-14.3%) in the ratoon season compared to continuous flooding conditions [74]. Implementing ridge furrow patterns and proper drainage techniques during the main crop season in Southeast China significantly improves root activity, resulting in a higher ratoon rice yield [27, 75-76].
Comparison of water management techniques	Ratoon rice yields generally due to better water management practices, allowing for adequate drainage during the main rice crop season [27]. Properly drained paddy fields during the main crop season improves root activity and creates suitable soil conditions for mechanical harvesting of the main rice crop, ultimately leading to higher ratoon rice yields.

However, mechanical harvesting of the main cropcan result in damage negatively impacts bud initiation and regenerated tiller growth, leading to reduced grain yield in the ratoon crop.By understanding and implementing proper water management techniques for both the main and ratoon seasons, farmers with proper water management strategies can significantly enhance the overall productivity and success of ratoon rice production.

7. Optimal Harvesting Time for Main Crop in Ratoon Rice Farming

The timing of harvesting of the main crop plays a crucial role in improving overall grain yield and ensuring successful heading of the ratoon crop and varies based on the planting region.Early harvesting of the main crop should be avoided as it can lead to yield loss due to poor grain filling. On the other hand, delaying the harvest may expose the ratoon crop to cold stress during the heading stage, adversely affecting its growth and development.For mechanized ratoon rice farming, the optimal harvesting time of the main crop is when around 95% of the grains have reached the yellow-ripe stage and thereby ensures minimal yield loss and prevents significant delays in the heading of the ratoon crop when compared to manually harvested ratoon rice. Harvesting the main crop when axillary buds emerge from the leaf sheath has been found to mitigate the negative effects of high temperature and drought conditions on the growth and development of axillary buds, leads to higher yield of the ratoon crop [27, 45, 51]. Harvesting the main crop too early may result in immature grains and reduce the grain yield in the main season. Conversely, if the main crop is harvested too late, the leaves of the regenerated tillers may be damaged, affecting the grain yield of the ratoon crop.Based on previous studies, it is recommended to harvest the main crop when approximately 90–95% of the grains have matured and acquired a yellow color [77]. Therefore, choosing the optimal harvesting time for the main crop is essential for maximizing grain yield and ensuring successful ratooning. By adopting the right timing, farmers can enhance the productivity and efficiency of ratoon rice farming, contributing to food security and sustainable agricultural practices.

8. Ratoon Rice Farming: Yield, Quality, Economics, and Sustainability

Ratoon rice yields vary from 1.1 to 4.9 t ha^{-1}, representing 28.6% to 64.3% of main season output as temperature, selection of varieties, and management techniques influence yield fluctuations [62, 78]. We knew proper variety selection and effective management can achieve 3-6 t ha^{-1}in subtropical and temperate climates [23, 44, 79] and even best practices lead to yield as high as 9.7 t ha^{-1}[80]. In temperate regions, varieties resilient to low temperatures and shorter development periods are necessary [44]. Factors like planting date, establishment method, stubble cutting height, fertiliser use, and water management also affect ratoon rice yield.

Exemplify superior grain quality with superior milling, aesthetic attributes, and nutritional properties compared to the main crop. It demonstrates increased amylose content, lowered gelatinization temperature, and better gel consistency [81]. Lower temperatures during ratoon rice growth contribute to enhanced grain maturity, appearance, cooking quality, and flavor [82]. Ratoon rice efficientlytransportscarbohydrates and nitrogen resulted in beneficial compounds like phenolic compounds, lipids, and lysine. However, high temperatures during grain filling can adversely affect ratoon rice quality, leading to spikelet infertility, decreased grain weight, increased chalkiness, and reduced amylose content [83-85]. Despite some challenges, ratoon rice remains an attractive option due to its overall superior grain quality attributes.

Ratoon system offers economic benefits with reduced labor, water, seed, pesticide, and fertilizer costs [9-10]. Despite lower yearly output, it yields higher net profit than double-season rice. Ratoon rice is 125.4% more profitable than single-season rice [8]. It also proves energy-efficient for bioethanol production compared to single rice cropping as reduced greenhouse gas emissions make it an eco-friendly choice [14]. It serves as a valuable adaptation strategy for flood-prone areas [86]. Overall, ratoon rice is an economically viable, eco-friendly, and resource-efficient cropping system, enhancing rice production sustainability [87].Ratoon farming holds promise for increasing grain yield, enhancing grain quality, and realizing economic gains, all while fostering environmental sustainability.Further research and implementation of effective management practices are essential to optimize ratoon rice farming and ensure its contribution to a sustainable future.

9. Maximizing Ratoon Rice Yield: Agronomic Management Techniques

Exploring the best agronomic management techniques to enhance ratoon rice grain yield. Selecting varieties with high regeneration capacity and yield potential, incorporating direct-seeded rice, and optimizing nitrogen and water management are key factors. Mechanized harvesting, proper stubble cutting height, and effective pest and disease control also play vital roles in maximizing ratoon rice productivity (**Table 7**). Integrating these practices will contribute to sustainable rice production and improved crop yields.

Table 7: Agronomic Management practices for ratoon rice

Management technique	Findings and Recommendations	References
Variety selection	Hybrid rice cultivars have ahigher regeneration rateand dry weight per stem after themain crop harvest.	[52]
	Novel plant type varieties show superior vegetative growth and harvest season output.	[88]
Methods of Establishment	Direct-seeded ratoon rice offers sustainable alternative to transplanted ratoon rice.	[44]
	Ensure proper crop establishment and choose varieties with high lodging and cold tolerance for direct-seeding.	[89]
Nitrogen fertilizer management	Apply lower N rates for main crop, followed by additional N application of bud-promoting fertilizers is recommended around 15 days after heading in the main season to facilitate ratoon bud regeneration.	[24]
	Adjust N rate for bud-promoting fertilizers to optimize ratoon crop grain production.	[26]
	Administer tiller-promoting fertilizers 2 to 5 days after main crop harvest to increase ratoon crop grain production.	[90]
OptimisingWater management	Soil drying at maximum tillering and middle-late grain filling stages improves ratoon crop growth.	[33]
	Controlled flooding after main crop harvest encourages tillering in ratoon crops.	[25]
Main season crop harvest& stubble height	Mechanized harvesting minimizes yield losses and damage, improving ratoon rice productivity.	[91]
	Adjust stubble cutting height based on ratooning characteristics and climate conditions of the region	[18]
Control of pests and diseases	Implement separate management strategies for ratoon crops and use pest-resistant cultivars.	[16]
	Consider eco-friendly, non-chemical approaches to reduce environmental contamination and resistance development.	[92]

Conclusion

Ratoon rice emerges as a promising and sustainable cropping system, offering economic, environmental, and resource-efficient benefits for rice production. Ratooning is widely practiced in various rice-growing regionsexcept Europe, and typically yields 40 to 60% of the main crop, depending on cultivars and management practices. The economic benefits stem from reduced land preparation and planting efforts, shorter crop cycles, and better utilization of the growing season. By implementing essential agronomic practices such as varietal selection, nutrient and water management, stubble cutting height, harvesting methods, and the application of plant growth regulators, the grain yield of the ratoon crop can be significantly enhanced.To fully unlock the potential of ratoon rice, a strong emphasis on ratoon rice breeding programs is crucial. It is a cost-effective practice with the potential to significantly increase rice production and overall farming profitability.With continuous advancements inratoon rice holds the promise of becoming a sustainable alternative for sustaining cropping intensity and ensuring food security with reduced labor and agronomic inputs. By fostering research and promoting adoption, ratoon rice can play a vital role in enhancing global rice production and addressing the challenges of the future.

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REFERENCES

[1] FAOSTAT, 2022. FAO Statistical Databases. www.fao.org, Food and Agriculture Organization (FAO) of the United Nations, Rome.

[2] Awika JM. Major cereal grains production and use around the world. In: Awika, J.M., Piironen, V., Bean, S. (Eds.), Advances in Cereal Science: Implications to Food Processing and Health Promotion. American Chemical Society. 2011;1–13.

[3] Garnett T, Appleby MC, Balmford A, Bateman IJ, Benton TG, Bloomer P, Burlingame B, Dawkins M, Dolan L, Fraser D, Herrero M. Sustainable intensification in agriculture: premises and policies. Science. 2013;341, 33–34.

[4] Ray DK, Foley JA. Increasing global crop harvest frequency: recent trends and future directions. Environ. Res. Lett. 2013;8, 044041.

[5] Wang SM, Zhang CH, Hu P, Hu L, Wang CZ, Yang L. Experimental research on key technology of ratooning rice based on yield first season rice plus ratooning rice. Jiangsu Agric. Sci. 2021b;49, 89–97.

[6] Fu J, Ji C, Liu H, Wang W, Zhang G, GaoY, Zhou Y, Abdeen MA. Research progress and prospect of mechanized harvesting technology in the first season of ratoon rice. Agriculture. 2022;12, 620.

[7] Krishanamurthy K. Rice ratooning as an alternative to double cropping in tropical Asia. In: Rice Ratooning. International Rice Research Institute, Los Ban˜os, Laguna, Philippines, 1988;3–17.

[8] MundaGC, Das A, Patel DP. Evaluation of transplanted and ratoon crop for double cropping of rice (*Oryza sativa* L.) under organic input management in mid altitude sub-tropical Meghalaya. Current Science. 2009; 96(12):1622-27.

[9] Liang YG, Zhang QF, Zhou J, Li Y, Tan CL, Huang H. Effects of different cultivation patterns on rice quality and economic efficiency. Acta Agric. Boreali-Sin. 2016;31, 265–269.

[10] Sen LTH, BondJ. Agricultural adaptation to flood in lowland rice production areas of central Vietnam: understanding the ‘regenerated rice’ ratoon system. Clim. Dev. 2017;9, 274–285.

[11] ChauhanJS, Vergara BS, Lopez FSS. Rice Ratooning. International Rice Research Institute. Manila. 1985.

[12] MacleanJL, Dawe DC, HettelGP. Rice almanac: Source book for the most important economic activity on earth. Int. Rice Res. Inst. 2002.

[13] BooneL, Roldán-Ruiz I, Muylle H, Dewulf J.Environmental sustainability of conventional and organic farming: Accounting for ecosystem services in life cycle assessment. Sci.Total Env. 2019;695, p.133841.

[14] Firouzi S, Nikkhah A, Aminpanah H. Resource use efficiency of rice production upon single cropping and ratooning agro-systems in terms of bioethanol feedstock production. Energy. 2018a;150, 694–701.

[15] Yuan, S., Cassman, K.G., Huang, J.L., Peng, S.B., Grassini, P., 2019. Can ratoon cropping improve resource use efficiencies and profitability of rice in central China? Field Crops Res. 234, 66–72. https://doi.org/10.1016/j.fcr.2019.02.004.

[16] Santos, A.B., Fageria, N.K., Prabhu, A.S., 2003. Rice ratooning management practices for higher yields. Commun. Soil Sci. Plant Anal. 34, 881–918.

[17] Golam, F., Rosna, T., Zakaria, P., 2014. Rice ratoon crop: a sustainable rice production system for tropical hill agriculture. Sustainability 6, 5785–5800. Guangdong Bureau of Statistics, 2022. http://stats.gd.gov.cn/gdtjnj/.

[18] Harrel DL, Bond JA, Blanche S. Evaluation of main-crop stubble height on ratoon rice growth and development. Field Crops Research, 2009; 114 (3): 396-403.

doi:10.1016/j.fcr.2009.09.011

[19] NakanoH, Tanaka R, Nakagomi K, Hakata M. Grain yield response to stubble leaf blade clipping in rice ratooning in southwestern Japan. Agron. J. 2021;113, 4013–4402.

[20] HuR, Zhu Q, ZhangLX, Lu CM, Wu WG, Yuan XM, Jiang Y.Effects of stubble height on growth duration and grain yield of early indica rice cultivars under ratoon rice system. Anhui Agricultural Sciences Bulletin, 2019;25, 51-52.

[21] Zhang Q, Liu X, Yu G, Zhao H, Feng D, Gu M, Zhu T, Kuang X, Li B. Progress and challenges of rice ratooning technology in the south of Henan Province, China. Crop and Environment, 2023;2 (1) 75-80. https://doi.org/10.1016/j.crope.2023.04.002

[22] Tu J, Cao Z, Chen J, Peng S, Huang J, Cheng J, Fang X, Qian T, Zhang Q. Comparative experiment results and evaluation of 16 varieties as ratooning rice. Hubei Agric. Sci. 2017;56, 4475–4478.

[23] Dou F, Tarpley L, Chen K, Wright AL, Mohammed AR. Planting date and variety effects on rice main and ratoon crop production in South Texas. Commun. Soil Sci. Plant Anal. 2016;47, 2414–2420. https://doi.org/10.1080/00103624.2016.1243705.

[24] Nakano H, Morita S. Effects of time of first harvest, total amount of nitrogen, and nitrogen application method on total dry matter yield in twice harvesting of rice. Field Crop Res, 2008;105, 40–47

[25] Mengel DB, Wilson EF. Water management and nitrogen fertilization of ratoon crop rice. Agron. J.1981;73: 1008-1010

[26] BondJA, Bollich PK. Ratoon rice response to nitrogen fertilizer. Crop Management, 2006;5, 1–5.

[27] Xu FX, Xiong H. High-yielding Theory and Regulation Approach of Ratooning Rice with Medium Hybrid Rice. China Agricultural Science and Technology Press, Beijing, 2016;1-220.

[28] Xiong H, Fang W. Ecological study on germination and yield formation of axillary buds in ratoon rice. Acta Ecol. Sin. 1994;2, 161-167.

[29] Jiang P, Zhang L, Chen C, Zhou X, Liu M, Xiong H, Guo X, Zhu Y, Xu F. Progress and challenges of rice ratooning technology in Sichuan Province, China. Crop and Environment. 2023;2 (3),111-120.

[30] TakahashiN. Physiology of seed germination and dormancy. In Science of the Rice Plant: Physiology; MatsueT, Kumazawa K, Ishii K, Ishihara K, Hirata H. Eds.; Food and Agriculture Policy Research Center: Tokyo, 1995;2, 35–45.

[31] YoshidaS. Fundamental of rice crop science. International Rice Research Institute, 1981;222-223

[32] Li B, YangF, Qin Q, Zhong XY, Li QP, Zeng YL, Lu H, Chen Y, Wang L, Tao YF, Li J, Feng BL, Ren WJ, Deng F. Effects of sowing dates on eating quality of different indica hybrid rice in the sub-suitable region of ratoon rice. Sci. Agric. Sin. 2022;55, 36–50.

[33] LinWX, Chen HF, Zhang ZX, Xu QH, Tu NM, Fang CX, Ren WJ. Research and prospect on physio-ecological properties of ratoon rice yield formation and its key cultivation technology. Chin. J. Eco-Agric. 2015;23,14–23.

[34] Liu XC, Feng DQ, Yu GL, Zhao HY, Qiao L, Li YT, Fan XJ, Liu MC, ZhangQJ. Effects of different sowing dates on growth and yield of ratooning rice in the south of Henan Province. Shandong Agric. Sci. 2015;47, 59–63.

[35] Wang F, Huang JL, Peng SB.Research and development of mechanized riceratooning technology in China. China Rice. 2021a;27, 1–6.

[36] HuangCZ, Lei SF, Yan MJ, Hu JT, Lv ZW, Liu ZX, Wu Y, Huang MX. Optimum seeding period and sowing amount of medium rice þ ratooning rice. Hunan Agric. Sci. 2018;1, 21–24.

[37] LyuTF, Shen J, Ma J, Ma P, Yang ZY, Dai Z, Zheng CG, Li M. Hybrid rice yield response to potted-seedling machine transplanting and slow-release nitrogen fertilizer application combined with urea topdressing. Crop J. 2021;9, 915–923.

[38] Zhang HC, Zhu CC, Huo ZY, Xu K, Jiang XH, Chen HC, Gao SQ, Li DJ, Zhao CM, Dai QG, Wei HY, Guo BW. Advantages of yield formation and main characteristics of physiological and ecological in rice with nutrition bowl mechanical transplanting. Trans. Chin. Soc. Agric. Eng. 2013;29, 50–59.

[39] Burger JC, Chapman MA, BurkeJM. Molecular insights into the evolution of crop plants. Am. J. Bot. 2008;95, 113–122.

[40] Chen HF, Liang YY, Lin WX, Zheng LD, Liang KJ. Quality and physio biochemical characteristics of the first rice crop seedlings under different raising seedling patterns for early rice and its ratoonal crop (I)—studies on super high-yield ecophysiology and its regulation technology in hybridize rice. Chin. Agric. Sci. Bull. 2007;23, 247–250.

[41] Zhang SW, Li YZ, Zheng W, Ye C, Xiao XJ, Huang TB, Wu Y, Lv WS, Xiao FL, ChenM, Lai SS, Xiao GB. Variety screening of high-quality ratoon rice for the triple-cropping of

rapeseed-rice-ratoon rice in the north-central Jiangxi and the effects of climatic factors on its grain quality. Hybrid Rice. 2018;33, 56–63.

[43] Liu S. Effect of nitrogen application on ratooning yield and rice quality. Thesis. Huazhong Agricultural University, Wuhan, China. 2016 (in Chinese with English abstract).

[44] Dong HL, Chen Q, Wang WQ, Peng SB, Huang JL, Cui KH, Nie LX. The growth and yield of a wet seeded rice-ratoon rice system in central China. Field Crops Res, 2017;208, 55-59

[45] Xu FX, Zhang L, Zhou XB, Guo XY, Zhu YC, LiuM, Xiong H, Jiang P. The ratoon rice system with high yield and high efficiency in China: Progress, trend of theory and technology. Field Crops Res. 2021b;272,108282

[46] Xi M, Wu WG, Wang JG, Wang HW, Chen G, Xu YZ. Study on formation of grain yield differences in ratooning rice cultivation. Acta Agric. Boreali-Sin. 2017;32, 104–110. https://doi.org/10.7668/hbnxb.2017.01.017.

[47] YiZ, Tu N, Chen P. Source-sink characteristics of main crop and ratooning rice of several new hybrid rice combinations. Chin. J. Rice Sci. 2005;19, 243–248.

[48] Ren T, Jiang Z, Wang P, Li J, Zhang X, Lu Y, Liu X. Correlation of ratooning ability with its main crop agronomic traits in midseason hybrid rice. Acta Agron. Sin. 2006;32, 613–617.

[49] Xu F, Hong S, Xiong H. Relation between N applying for bud development and ratooning ability and its mechanism in Hybrid rice. Acta Agron. Sin. 1997;23, 311–317.

[50] Xu FX, Xiong H. Relationship between ratio of grain to leaf area and ratooning ability in middle season hybrid rice. Chin. J. Rice Sci. 2000;14, 249-252.

[51] Xu F, Xiong H, Zhang L, Zhu, Y, Jiang P, Guo X, Liu M. Progress in research of yield formation of ratooning rice and its high-yielding key regulation technologies. Sci. Agric. Sin. 2015;48, 1702–1717.

[52] Chen Q, He AB, Wang WQ, Peng SB, Huang JL, Cui KH, Nie LX. Comparisons of regeneration rate and yields performance between inbred and hybrid ricecultivars in a direct seeding rice-ratoon rice system in central China. Field Crops Res. 2018;223, 164-170.

[53] Huang JW, Wu JY, Chen HF, Zhang ZX, Fang CX, Shao CH, Lin WW, Weng PY, Lin WX. Nitrogen fertilizer management for main crop rice and its carrying-over effect on rhizosphere function and yield of ratoon rice. Chin. J. Rice Sci. 2021a; 35, 383–395.

[54] ChenY, Li K, Li T, Li S, Li G, Zhang W, Zhang H, Gu J, Liu L, Yang J. Effects of alternate wetting and moderate soil drying irrigation on root traits, grain yield and soil properties in rice. Chin. J. Rice Sci. 2022;36, 269–277.

[55] Huang SH, Lin XY, Lei ZP, Ding ZS, Zhao M. Physiological characters of carbon, nitrogen, and hormones in ratooning rice cultivars with strong regeneration ability. Acta Agron. Sin. 2021b;47, 2278–2289.

[56] BalasubramanianB, Morachan YB, Kaliappa R. Studies on ratooning in rice. Growth attributes and yield. Madras Agric. J., 1970;57(11), 565-570.

[57] KarunakaranK, Jalajakumari MB, Sreedevi P. Ratoon performance of some short duration rice culture. Int. Rice Res. Newsl. 1983;8, 461.

[58] Nayak RL, DasM, Mandal SS. Ratoon rice can yield well. Int. Rice Newsl. 1983;8, 5.

[59] XuFX, Yuan C, Wang XC, Han D, Liao S, Chen Y, Zhou XB, Jiang QS,Zhang L, Jiang P. Differences in the two-crop yield and main-crop rice qualities among different hybrid mid-season rice varieties in the ratooning rice region of southern Sichuan, China. Chin. J. Eco-Agric. 2020;28, 990-998.

[60] Gomez SM, Sarao MS, Balisnomo ER, Canlas JB, Villegas NV. Response of direct-seeded rice (Oryza sativa L.) to ratooning and foliar fertilization under varied seeding rates. Philippine Journal of Crop Science, 2018;43(3), 77-85.

[61] Rahman MA, Hasanuzzaman M, Naher N, RanaMS. Ratoon crop performance of hybrid rice and its parental lines under system of rice intensification in the Eastern Ganges floodplain. Journal of the Bangladesh Agricultural University, 2017;15(1), 1-6.

[62] Sinaga PH, Trikoesoemaningtyas DS, Aswidinnoor H. Screening of rice genotypes and evaluation of their ratooning ability in tidal swamp area. Asian J. Agric. Res. 2014;8, 218-233.

[63] WangYC, Zheng C, Xiao S, Sun YT, Huang JL, Peng SB. Agronomic responses of ratoon rice to nitrogen management in central China. Field Crops Res. 2019;241,107569.

[64] XuF, Zhang L, Zhou X, Guo X, Zhu Y, Liu M, XiongH, Jiang P. The ratoon rice system with high yield and high efficiency in China: progress, trend of theory and technology. Field Crops Res. 2021a;272, 108282.

[65] Xu F, Xiong H, Hong S, Tu S. Effects of nitrogen application for bud development on the ratooning ability of hybrid mid-season rice and its relationship with grain number per panicle of the main crop. J. Southwest Agric. Univ. 2000a;22, 310–311.

[66] Xi M, Xu XJ, Wu WG, Wang JG, Chen ZG, Sun XY, Xu YZ. Effects of buds promoting fertilizer on yield and grain quality of ratoon rice. China Rice 2018;24, 93–96. https://doi.org/10.3969/j.issn.1006-8082.2018.03.020 (in Chinese with English abstract).

[67] Chen J, Chen C, Tian Y, Zhang X, Dong W, Zhang B, Zhang J, Zheng C, Deng A, Song Z, Peng C. Differences in the impacts of nighttime warming on crop growth of rice-based cropping systems under field conditions. Eur. J. Agron. 2017;82, 80–92.

[68] Xia GL, Ouyang JP, Liu KL, Li YZ, Zhou LJ, Yu PL, Hu HW.Effects of bud fertilizer and stubble types on grain yield and regeneration capacity of ratoon rice in northeast of Jiangxi Province. China Rice 2016;22, 27–30.

[69] Yang D, Peng S, Zheng C, Xiang H, Huang J, Cui K, Wang F. Effects of nitrogen fertilization for bud initiation and tiller growth on yield and quality of rice ratoon crop in central China. Field Crops Research, 2021; 272, p.108286.

[70] Hu X, Ma M, Huang Z, Wu Z, Su B, Wen Z, Fu Y, Pan J, Liu Y, Hu R, Li M. Progress and challenges of rice ratooning technology in Guangdong Province, China. Crop and Environment, 2023;2(1), 17-23.

[71] NegalurRB, Yadahalli GS, Chittapur BM, Guruprasad GS, Narappa G. Ratoon rice: a climate and resource smart technology. Int. J. Curr. Microbiol. Appl. Sci. 2017;6, 1638–1653.

[72] Wu WB, Huang YQ, Wang GX, Liu SL, Li FM. Photosynthesis and respiration of main crop of ratoon rice for the late growth duration under different soil moisture. J. Agric. Southwest Univ. 1995;6, 489–494 (in Chinese with English abstract).

[73] Xiong H, Chinawong S. Relationship between soil water content and rice yield of main crop and ratoon crop. Chin. J. Ecol. 1995;14, 5–9 (in Chinese with English abstract).

[74] Wang ZH. Effects of Half-period Dry Management of Middle Hybrid Rice on the Growth and Development of Its Ratooning Rice. Dissertation. Huazhong Agricultural University, Wuhan. 2009;126p.

[75] TongXH.High-yielding cultivation techniques for hybrid rice combination 704 D297 Youming86 as ratoon rice. Fujian Sci. Technol. Rice Wheat, 2011;29, 35-36.

[76] Fan KZ. High yielding cultivation techniques of "Tianyou 3301" as ratoon rice. Fujian Sci. Technol. Rice Wheat, 2012;30, 30-32.

[77] Yao X, Tang YQ, Wen M, Zhang XW, Li JY. Research progress and developing strategies of ratoon rice in southwest ecotope. J. Southern Agric. 2013;44, 1059–1064.

[78] Olivier K, Cherif M, Kone B, Emmanuel D, Firmin KK. Growth, yields and ratooning performance of lowland rice Nerica l14 as affected by different fertilizers. Ind. J. Sci. Res. Tech. 2014;2, 18–24.

[79] Oad FC, CruzPS, Memon N, Oad NL, Hassan ZU. Rice ratooning management. Pak. J. Appl. Sci., 2002;2(1): 29-35.

[80] Li J, Zhang H, Tang Y. Research and application of ratooning rice in China. ChinaAgr. 2009;5, 23–27

[81] Alizadeh MR, Habibi F. A comparative study on the quality of the main and ratoon rice crops. J. Food Qual. 2016;39(6):669-674.

[82] Funaba M, Ishibashi Y, Hossain MA, Iwanami K, Iwaya-Inoue M. Influence of low/high temperature on water status in developing and maturing rice grain. Plant Prod. Sci. 2006;9, 347–354.

[83] Cooper N, Siebenmorgen T, Counce P. Effects of nighttime temperature duringkernel development on rice physicochemical properties. Cereal Chem. 2008;85, 276–282.

[84] KadamNN, Xiao G, Melgar RJ, Bahuguna RN, Quinones C, Tamilselvan A, Prasad PVV, JagadishKS. Agronomic and physiological responses to high temperature, drought, and elevated CO2 interactions in cereals. Adv. in agron. 2014;127, pp.111-156.

[85] PengS.Reflection on China's rice production strategies during the transition period. Sci. Sin. Vitae 2014;44, 845–850.

[86] Manzanilla DO, Paris TR, Vergar, GV, Ismail AM, Pandey S, Labios RV, Tatlonghari GT, Acda RD, Chi TTN, Duoangsila K,Siliphouthone I. Submergence risks and farmers' preferences: implications for breeding Sub1 rice in Southeast Asia. Agricultural Systems, 2011;104(4), pp.335-347.

[87] Hussain S, Peng S, Fahad S, Khaliq A, Huang J, Cui K. Rice management interventions to mitigate greenhouse gas emissions: a review. Environ. Sci. Pollut. Res. 2015;22, 3342–3360.

[88] Susilawati S, Purwoko BS, Aswidinnoor H, Santosa E. Performance of varieties and lines of Indonesian new plant type of rice in a ratoon system. J. Agron. Indonesia 2010;38, 177–184.

[89] Hyun DY, Oh MW, Choi YM, Lee S, Lee MC, Oh S. Morphological and molecular evaluation for germinability in rice varieties under low-temperature and anaerobic conditions. J. Crop Sci. Biotech. 2017;20, 21–27.

[90] Turner FT, McIlrath WO. N fertilizer management for maximum ratoon crop yields. In: Ratooning Rice. International Rice Research Institute, Los Ban˜ os, Laguna, Philippines, pp. 1988;187–195.

[91] Cai H, Chen Q. Rice research in China in the early 21st century. Chin. Rice Res. Newsl. 2000;8, 14–16.

[92] Heap I. International Survey of Herbicide Resistant Weeds. 2012.www.weedscience.org.