Review Article

Optimizing Water Utilization Effectiveness in Rice Agriculture: An All-Inclusive Examination of Cutting-Edge Irrigation Technology

Rizwana Mehmood [1*], Rabia Mustafa [2], Tania Ijaz [3]

1. Agronomy Department, PMAS Arid Agriculture University Rawalpindi, Pakistan; rizwanamehmod5423@gmail.com
2. Institute of Food and Nutrition Science, Pir Mehr Ali Shah Arid Agriculture University Rawalpindi, Pakistan; rabiamustafa08@gmail.com
3. Institute of Food and Nutrition Science, Pir Mehr Ali Shah Arid Agriculture University Rawalpindi, Pakistan; Tania.ijaz@gmail.com

* Correspondence: rizwanamehmod5423@gmail.com

Abstract: Rice is an extremely thirsty crop that is primarily grown using ineffective irrigation techniques, which results in low water use efficiency and other environmental issues. The sustainability of rice cultivation and food security are further threatened by the impending water crisis and the export of virtual water through rice trading. To increase the effectiveness of water utilization in rice cultivation, there are various different techniques. These include of drip-irrigated rice, aerobic rice, direct-seeded rice (DSR), saturated soil culture (SSC), alternate wetting and drying (AWD), drip-irrigated rice, a rice intensification system (SRI), and smart irrigation using sensors and the Internet of Things (IoT). Every approach, though, has benefits and drawbacks of its own. For instance, the high production costs associated with specialised machinery and tools make automated irrigation systems based on the Internet of Things and drip irrigation impractical for impoverished farmers. Similar to aerobic rice, drip-irrigated rice, and the SRI, these labor-intensive practices are inappropriate for places where labour is scarce. DSR, on the other hand, works well in places where labour is sparse as long as weeds are controlled with herbicides. This article reviews and assesses the applicability of several water-saving rice production techniques based on labour, energy, climate, soil type, and greenhouse gas emissions, as well as the opportunities and difficulties they present. The paper also looks at how cultural techniques that improve water use efficiency in rice cultivation, like nutrition management, weed control, and seed treatment, are applied.

Keywords: cutting edge irrigation technology, agriculture, effectiveness, water utilization

1. INTRODUCTION

For more than half of the world's population, rice is a staple diet, and growing it takes a lot of water [1]. But there is now concern over the worsening water situation in nations that farm rice. In nations that cultivate rice, there is a serious water issue as a result of the rise in demand for rice cultivation and the decrease in available water supplies. The Food and Agriculture Organisation (FAO) estimates that 34-53% of the irrigation water used worldwide is used for rice production [2]. Water scarcity is a major problem in nations like China and India where rice production is a major agricultural activity. India's water supply has been decreasing, and by 2030, estimates indicate that the country's water consumption will be 50% greater than its supply [3]. Similarly, forty percent of China's water use is related to rice cultivation. More than one-third of the world's irrigated land is in China, a country that also struggles with water constraint. China has significantly less water available per person than the rest of the world, and future predictions indicate that the country's water shortage will get worse [4]. The food security of nations that farm rice is seriously threatened by the worsening water issue [4]. In many developing nations, rice is a key crop for ensuring food security. A decline in rice production might have an impact on food security due to water scarcity [2]. The production of rice is impacted by water scarcity, which can also raise costs and make it unaffordable for the underprivileged. Reduced agricultural production and soil degradation can result from the depletion of water resources used for rice farming. Overuse of water resources can also result in waterlogging and increased salinization, which lowers agricultural production even more [2]. It is also anticipated that climate change will have a major effect on the amount of water available for rice farming. The availability of water for irrigation is expected to change due to changes in temperature and precipitation patterns, which could lead to both water shortages and flooding. It is anticipated that as global temperatures rise, the hydrological cycle will become more intense, leading to longer dry periods in some regions and more intense rainfall events in others [5]. Elevated temperatures are anticipated to escalate evaporation rates and soil water loss, perhaps resulting in decreased soil moisture content and an increased frequency of droughts. Given that rice crops need enough moisture in the soil to grow and yield large amounts, this could have an impact on their production and growth. Climate change is predicted to intensify and increase the frequency of extreme weather events such storms, cyclones, and floods in addition to altering precipitation patterns [6]. These occurrences may harm rice fields and related infrastructure, like irrigation systems, which may further limit the amount of water available for rice farming. In many areas, the current problems with water scarcity will be made worse by climate change, thus adaptation measures will be required to guarantee rice production that is sustainable going forward [5]. This could result in more frequent and severe droughts in areas where rainfall is already insufficient, making it more difficult for communities to acquire the water they require for drinking, agriculture, and other purposes. The rate of evaporation increases with warmth, which can result in lower soil moisture content and less water available for crops. This is especially crucial for the development of rice, one of the crops that uses the most water worldwide. In areas where water is already limited, rising temperatures are predicted to raise the amount of water needed for rice farming, increasing the demand for irrigation water [2]. Similarly, because they raise competition for fresh water, contribute to water pollution and degradation, and result in changes in land use that lower the availability of surface water, industrialization and urbanisation can have a substantial impact on the availability of freshwater for rice farming [7]. Due to over-extraction of surface and groundwater and a reduction in the amount of water available for irrigation in rice-growing regions, this increased demand may put strain on freshwater resources. Due to the flow of wastewater and other pollutants into water bodies, urbanisation and industrialization can also cause pollution and degradation of the aquatic environment. The quality of freshwater resources may be impacted by this contamination, making them less suitable for rice farming [8]. Although there has been over 20 years of research on new irrigation management systems to improve water usage efficiency in rice farming, there are still certain knowledge gaps that require filling. One of these gaps is the absence of a thorough analysis of how different cutting-edge irrigation management techniques affect rice farming's water use efficiency. It is crucial to thoroughly examine how these technologies affect rice yield and quality in addition to water use efficiency. The cost-effectiveness gap is another important one to fill. It's important to assess the cost-effectiveness of innovative irrigation management systems, even though they can help conserve irrigation water and increase water use efficiency. The return on investment and prospective long-term cost reductions should be included in this analysis. Furthermore, the efficiency of water use in rice cultivation is affected by the distinct meteorological conditions and soil features found in various places. As a result, using the available research data, it is vital to select appropriate and efficient irrigation techniques among the variety of cutting-edge irrigation management systems currently in use. Lastly, farmer adoption is a critical factor in the success of innovative irrigation management technology. To encourage farmer adoption, suitable policies must be developed. This research thoroughly examined the effects of novel irrigation methods on water consumption efficiency, cost-effectiveness, rice production and quality, appropriateness of the soil and climate, and policies to encourage their adoption in light of these shortcomings.

2. LITERATURE REVIEW

In the future, feeding a growing population and providing for their water needs will become more difficult. Achieving global food security requires sustainable use of agricultural water resources [9]. Three strategies can be used to alleviate the food scarcity brought on by water scarcity: (i) recycling wastewater to increase water availability; (ii) improving water productivity through improved yields or better use of water, or both; and (iii) addressing regional water scarcity by importing food through virtual water trade [10]. The primary goals of all three strategies are to increase agricultural water use efficiency through integrated methodologies, maximise the use of rainwater that is available, and make effective use of the limited irrigation water. India has to increase agricultural water efficiency in order to meet the country's rising food demand. Several techniques and technologies can be used to accomplish this, such as: (i) modernising and streamlining irrigation and drainage systems; (ii) creating and lining field channels and waterways; (iii) levelling and shaping land; (iv) building field drains; (v) utilising surface and groundwater jointly; (vi) putting into practice and regulating suitable cropping patterns; (vii) introducing and enforcing rotational water distribution systems (warabandi's); (viii) creating plans for supplying inputs such as credit, seeds, fertilizers, and pesticides, and (ix) strengthening current extension, training, and demonstration programs in farmers' fields to conserve freshwater and increase irrigation efficiency. India's freshwater resources are under increasing strain, especially in the major rice-producing states. Reducing the demand for freshwater requires increasing agricultural water productivity, or producing more goods or income per drop. The traditional method of growing rice is continuously flooded (CF) conditions, which are very productive but need a lot of water and have detrimental effects on the environment, including deteriorating soil health, increasing methane emissions, and increasing the buildup of dangerous materials like mercury and arsenic [11,12]. Therefore, the goal of agricultural research and development should be to find ways to replace the traditional system and minimise the amount of water needed for rice growing [13]. Many water-saving methods have been tested and distributed to farmers in an effort to increase rice yield. These methods include the following: (i) irrigation using the alternate wetting and drying (AWD) method; (ii) the aerobic rice system; (iii) the system of rice intensification (SRI); (iv) saturated soil culture (SSC); (v) direct seeded rice (DSR); and (vi) drip-irrigated DSR. Rice is grown on raised beds in the raised-bed method, which uses less water and improves soil aeration because the raised beds are well-drained and do not flood frequently. In order to save water, the ground cover rice production technique uses AWD at a shallow water depth. It is also possible to use non-flooded mulching cultivation and transplanting on non-puddled soil to save water usage without sacrificing crop yield. Semi-dry farming and intermittent dry intervals are deliberate dry spells that are used to lower rice production water consumption and increase plant water efficiency. These alternative techniques are well-known for using less water, enhancing soil health, emitting less greenhouse gases, and preventing the buildup of dangerous components in rice grains. The agriculture industry in India may be able to lessen its water scarcity problem if these strategies are put into practice. The International Rice Research Institute (IRRI) created AWD irrigation, which is a technically sound, practically water-saving, commercially feasible, and environmentally friendly method [14]. After undergoing rigorous testing, AWD is currently being used in numerous Asian nations, including as Bangladesh, Vietnam, the Philippines, and India. With AWD irrigation, the field experiences alternating cycles of flooding and drying, or unsaturation, which conserves irrigation water, enhances water-use efficiency, lowers greenhouse gas emissions, and uses less labour, fertiliser, and pesticide. Irrigation is applied when the soil reaches a particular lower moisture level. The fields are converted from a continuously moist rice field to one with sporadic dry spells during the crop-growing season. The field is allowed to dry out for two to three weeks following transplanting (or three to four weeks after sowing) until the water table reaches a depth of 10 to 15 cm below the soil's surface [13]. Depending on the soil, this could take one to seven days if there is no precipitation. Irrigation water should be applied until the field has three to five centimetres of standing water after the threshold is reached [15]. Up to 37% less water can be used with the AWD irrigation technique without compromising output. Comparing AWD rice systems to continuously flooded rice systems, 23% less water is used [16]. AWD systems have the ability to reduce total arsenic (As) and mercury (Hg) content in rice grains by 50%, reduce greenhouse gas (GHG) emissions by 45–90%, increase water efficiency, and maintain or even increase grain output, all while saving water [17]. It has been discovered that using AWD for sporadic irrigation during rice agriculture will reduce insect pests by 92% and illnesses by 100% [11]. Furthermore, the research conducted by Duttarganvi et al. (2016) shown that the application of AWD in combination with cono-weeding produced noticeably greater yields in comparison to alternative irrigation and weed control techniques. This is because an aerated growing environment and profuse root growth are encouraged [18]. In addition, compared to traditional rice production systems, the AWD approach has produced a 22% decrease in the frequency of watering [19]. Deep drainage, seepage, runoff, and evapotranspiration have all decreased significantly in AWD, which is primarily responsible for the decrease in irrigation water input [20]. The AWD method's lack of flooding reduces water loss through seepage and percolation, albeit the speed at which these processes occur is mostly influenced by the hydrological characteristics of the soil. Under dry direct-seeded rice (DDSR), the use of AWD decreased water production by 44–50% and the overall water input by 27–29% [11]. According to a different study by Sujono et al. (2011), when compared to shallow intermittent irrigation, the use of AWD in rice boosted grain production by 22.9%, decreased irrigation water input by 13.1%, and enhanced water productivity by 41.6% [21]. Similar to this, Ceesay et al. (2006) found that AWD resulted in 60% less water usage than continuous submergence [22]. One of the main reasons for the decreased water input with this technique is the lack of standing water in the field under AWD [23]. Carrijo et al. (2017) determined that severe AWD in rice saved 33.4% of water input with a 22.6% yield drop based on a meta-analysis of 56 experiments, while mild AWD saved 25.7% of water input with higher rice productivity [24]. Grain productivity rises when AWD encourages root growth because it makes it easier for roots to absorb nutrients and water from deeper soil layers [25]. With a non-significant difference in grain output, AWD plots used 57% less irrigation water than CF plots, suggesting that AWD could significantly improve agricultural water usage efficiency in Nepal [26]. The application of AWD has been shown to alter plant hormone signalling, which in turn increases grain filling rate, lowers the percentage of unfilled grain, and improves water use efficiency in addition to lowering water usage and raising yields [27,28,29, 30]. According to research, compared to continuous fertiliser (CF) irrigation, the use of intermittent irrigation with three- and seven-day intervals can save 55% and 74% of water, respectively. It was discovered that the irrigation water productivity throughout the seven-day intervals was 0.48 kg grain/m3 and the total water productivity was 0.35 kg grain/m3 [31]. It has been demonstrated that maintaining a six-centimeter standing water depth every seven days will stimulate plant growth and increase yields. It is essential for the growth and development of the rice crop to maintain the ideal amounts of soil moisture without creating stress. While adopting AWD has shown to be beneficial in improving water use efficiency, reducing water inputs, and raising or maintaining yields, it's crucial to remember that in certain situations, especially with light-textured sandy soils, applying severe AWD may result in yield loss in exchange for increased water savings and WUE. Furthermore, it was discovered that in cases of severe AWD, the influence of soil features on the efficacy of AWD was more evident [24]. Crops must be consistently irrigated both throughout and after the onset of the reproductive phase in order to prevent yield decreases in AWD. It has been demonstrated that the AWD can dramatically cut water consumption while maintaining or even increasing yields when compared to CF [32]. In consequence, compared to continuous submergence, rice's water productivity rose due to the 34% decrease in water input in AWD [33]. According to Tan et al. (2013), there was no discernible drop in yields while using the AWD technique, and compared to CF irrigation, using AWD increased water productivity by 17%. In comparison to CF irrigation, the AWD irrigation system reduced greenhouse gas emissions by 27%, according to Islam et al. (2022). AWD emitted less methane (CH4) (1.67 kg ha−1 day−1) than did CF (2.33 kg ha−1 day−1) [34]. In contrast to CF, the deployment of AWD irrigation management with a pressure head of 30 kPa significantly increased rice yield and nitrogen usage efficiency while lowering the requirement for irrigation applications by 27.3%, according to a study by Djaman et al. (2018). It was discovered that soils with a pH of less than 7 and a minimum of 1% soil carbon concentration exhibited the highest efficacy of AWD [35]. AWD has not been widely used because of its potential for lower yields, even though it reduces water input and produces a respectable yield in many places of the world [24, 36]. Under other circumstances, the adoption of AWD led to a decrease in rice productivity [24, 26, 37, 38]. A major obstacle to the broad implementation of AWD is the large differences in grain yield that exist between soils, climates, seasons, years, cultivars, and management approaches [16, 39]. Humphreys et al. (2012) discovered that AWD caused just a minor decrease in yield [40]. In a similar vein, 5.4% less yield was found under AWD by Carrijo et al. (2017). Grain yields, however, are not considerably impacted by modest AWD, such as preserving a soil water potential (SWP) of 20 kPa or greater or making sure the field water level does not go below 15 cm from the soil surface [24]. Although the AWD technique can save irrigation water, it is unlikely that Nepal will implement it broadly because there are no direct incentives to do so from the current water administration structure [26]. It should be emphasised that because AWD produces modest water savings and rapid water drainage, it might not be the best method for growing rice in sandy soils. Similarly, since the water table in these soils never falls below the roots at their lowest point, AWD may not be required in soils with thick clay and shallow water tables [41]. When switching from the traditional flooding system to water-saving rice production technologies, the rice grain quality may vary [45]. Table 2 shows the impact of AWD on rice grain quality. Because CF accumulates dangerous heavy elements like arsenic and mercury, it has been demonstrated to have a deleterious effect on grain quality [46, 47]. However, it has been discovered that using AWD irrigation improves grain quality by raising grain yield, milling recovery, and protein content. Reduced protein content, however, can be the outcome of excessive AWD [48]. AWD increased the amount of amino acids and phenolic acids while lowering the amount of lipids and alkaloids in milled rice, according to Song et al. (2021) [49]. In comparison to CF, rice plants cultivated under AWD exhibited lower leaf trans-zeatin concentrations of 36% and higher levels of leaf abscisic acid and foliar isopentenyladenine (37%), respectively [50]. AWD irrigation decreased the amount of opaque kernels (62%), abortive kernels (51%), and chalkiness (42%), when compared to aerobic irrigation management. Furthermore, compared to CF irrigation, AWD irrigation reduced the kernel amylose levels by 15%, amylopectin by 6%, and mercury uptake by 21% [51]. Under AWD water management, brown rice's nutritional quality was enhanced as evidenced by a notable drop in grain arsenic relative to CF and a rise in grain antioxidants, flavonoids, γ-oryzanol, total tocopherols, iron, and zinc [52]. An inventive method for cultivating rice on unsaturated, well-drained soils without ponding water is aerobic rice cultivation [56]. When compared to conventional irrigated rice cultivation, this method produces an impressive yield of 4 to 6 tonnes per hectare with a water consumption rate of only 50 to 70%. It does this by utilising specialised aerobic rice cultivars that are responsive to inputs and optimised water management techniques. This approach is strongly advised in locations where there is a severe labour shortage or high water expenses, as well as in areas where salaries are rapidly increasing. Table 3 displays the WUE and water productivity of rice grown in an aerobic system. Weed infestation is the biggest obstacle to aerobic rice's widespread use. There are several low-dose, highly effective herbicides on the market that can be used to manage weeds in the aerobic rice system. There is also a longer application window for these herbicides. According to Shahane et al. (2019), compared to traditional transplanted rice, the aerobic rice system conserved 37.4% and 50.8% of irrigation water in the first and second years of the trial, respectively [57]. Because there is no nursery rearing, no field puddling, and no upkeep of arable soil, the aerobic system uses less water than both the SRI and puddled transplanted rice. However, compared to puddled transplanted rice, the aerobic rice method resulted in a considerable yield penalty. Aerobic rice is known to minimise greenhouse gas emissions and minimise the potential for global warming in addition to saving water [58]. When rice was grown using an aerobic system instead of a normal flooded one, 79.8% less CH4 was released on average, but 14.4% more nitrous oxide (N2O) was released than with transplanted paddy [59, 60]. Furthermore, compared to transplanted rice, Kato et al. (2009) discovered that aerobic rice systems had water productivity that was 1.4 to 3.7 times higher [61]. Despite a 36–39% drop in paddy production as a result of increased panicle sterility, the use of aerobic irrigation with DDSR boosted water productivity by 22–30% and water savings by 49–55% [11]. According to a study by Shahane et al. (2019), aerobic rice conserved 50.8% of the water utilised in transplanted rice when compared to the system of rice intensification (SRI), transplanted rice, and aerobic rice [57]. Ramulu et al. (2020) observed similar outcomes when they discovered that aerobic rice on sandy loam soil conserved 50% of the irrigation water in comparison to transplanted rice [62]. The system of rice intensification (SRI) has been promoted as a collection of agronomic management techniques for rice cultivation that boosts productivity while consuming less water for more than ten years. While collaborating with small-scale farmers in Madagascar in 1983, Henri de Laulanié created the SRI [64, 65]. The technology has quickly expanded to several nations that cultivate rice. Transplanting young (13–15 days old) and single seedlings, wider and square planting, intermittent water management (irrigation after the development of hair-like cracks), using a cono-weeder or mechanical weeder for better weed control and soil aeration, and promoting the use of organic nutrients and inorganic fertilisers are some of the unique practices that make up this method. It has been shown that employing the SRI method in paddy farming considerably boosts land productivity while requiring less water. By eliminating evaporation and heavy percolation losses, the SRI method of paddy farming conserved up to 50% of irrigation water as compared to the traditional method. In contrast to irregular rainfed land, the SRI is the recommended technique for rice growing on flat, irrigated ground [66]. Although this method somewhat increases the initial need for human effort, it is particularly ideal for places where water is scarce. Regarding water use, the main distinction between SRI and non-SRI irrigation methods is that the former employ a dry-wetting irrigation system, whereas the latter employs the more conventional inundation method. Secondly, the SRI method does not require deep or frequent puddling, which saves a substantial amount of water. Third, unlike the usual approach, irrigation is applied sparingly during transplanting. Fourth, all that's needed to effectively run a motorised or hand-drawn cono-weeder in a paddy field is a light misting of the ground. Because of the large distance used while transplanting, extended root development occurs. The SRI's strong root system makes it easier for it to absorb water and nutrients from a lot of soil, which increases output. Compared to the traditional way of rice production, the SRI approach can increase rice grain yield while requiring a significantly lower water input [66]. In comparison to conventional transplanted rice, Shahane et al. (2019) observed that the SRI approach conserved 21.9% and 27.4% of irrigation water during the first and second year of the experiment, respectively, without reducing yield [57]. The SRI approach conserved thirty-one and thirty-seven percent of irrigation water during the Kharif and Rabi seasons, respectively, in comparison to regular transplanting [67]. The SRI saved water since it applied irrigation water at a lower depth than conventional transplanted rice did during the early development phase. In comparison to traditional transplanted rice (67.0 kg rice equivalent yield/ha/cm) and the alternative wetting and drying method of irrigation, the SRI method of stand formation conserved irrigation water and produced a higher WUE (70.8 kg rice equivalent yield/ha/cm) [68]. Utilising the SRI technique rather than the standard inundation approach allows farmers to conserve around 40% of irrigation water, increase land yield by approximately 46%, and lower cultivation costs by 23% [69]. When compared to conventional agricultural methods, Toungos (2018) reports that the SRI technique of rice cultivation reduced irrigation water usage by 40% in Indonesia, 67% in the Philippines, and 25% in Sri Lanka [70]. When compared to standard transplanting, the SRI approach used 31% and 37% less water for irrigation during the Kharif and Rabi seasons [71]. The results showed that the SRI approach produced greater irrigation water productivity (IWP) and economic water productivity (EWP) of 6.62 kg and ₹ 108, respectively, compared to 2.70 kg and ₹ 45, respectively, produced by the non-SRI method. When comparing the SRI approach to the non-SRI method, it was discovered that the IWP was 145% greater [69]. The SRI method's increased IWP and EWP can be attributed to the fact that farmers who use it often save more water and yield more rice. Cono-weeders are recommended by proponents of SRI for weeding and soil aeration; nevertheless, impoverished farmers find the equipment prohibitively expensive and find it difficult to operate in field circumstances [72]. It was discovered that groundwater-irrigated areas saved more water (about 45 percent) while employing the SRI technique than canal-irrigated areas (about 33 percent) [69]. This variation can be attributed to the fact that since groundwater irrigation ensured water availability, farmers were able to strictly follow a dry-wetting irrigation technique. This resulted in a significant water savings for the farmers cultivating SRI paddy. But in the canal-irrigated area, it was impractical since farmers are not responsible for managing the water, thus they tend to over-irrigate crops when there is an abundance of water available [69]. By incorporating weeds into the soil and encouraging the use of organic nutrient sources (green manure, green leaf manure, farmyard manure, compost), the SRI approach increases the soil's ability to hold water and nutrients. The SRI agriculture method produces fewer greenhouse gas emissions than the standard flooded paddy method, with an average emission of 26.8% less CH4 and 3.8% more N2O [59]. Due to low literacy and a lack of understanding about required irrigation measures, the majority of farmers who used the SRI approach did not follow all recommended practices. Consequently, farmers have not fully embraced the SRI technique [69]. Partial application of SRI principles, i.e., adopting particular SRI methods, could benefit farmers to some extent but may not be able to create synergies between all of the principles, depending on local agronomic or institutional opportunities and limits [66]. As the depth of the irrigation water in the field increases, so does the percolation rate [73]. In contrast to other technologies that require a water depth of 5 cm, SSC maintains a water depth above the soil of less than 3 cm. The SSC's water percolation loss is lessened by the shallower water. Table 4 shows the impact of SSC on rice yield and WUE. According to Tuong and Bhuiyan (1999), SSC can maintain or boost output in rice-based systems while lowering water losses and water consumption. Under extreme water stress, however, plants decreased their evapotranspiration, which in turn caused a reduction in photosynthesis, which in turn produced a fall in height, tiller number, and chlorophyll [74]. The amount of panicles per hill was greatly decreased by water stress during the tillering stage [75]. Maintaining a saturated level of soil moisture prevents moisture stress and has no effect on biomass accumulation, tiller development, or root growth. With a non-significant yield reduction of 6%, SSC can reduce water input from the constantly flooded state by an average of 40% [76]. Evaporation and yield determine how efficient the use of water is. The WUE will rise with every agronomic management technique that raises grain yield. To attain higher yield potential, it is imperative to employ other improved agronomic management practices in addition to these smart irrigation technology and improved irrigation systems. To improve WUE, agronomic management techniques include the ideal planting period, sufficient plant population establishment, prompt weed control, balanced and ideal fertilisation, appropriate insect and disease control, and harvesting are crucial. To improve soil water-holding capacity and WUE of rice-based cropping systems, a variety of agronomic techniques can be used, such as crop rotation, water conservation through minimum- or no-tillage, the use of plastic film or straw mulching, regulated deficit irrigation, fertigation, anti-transpirants, and soil amendments [14]. To increase water use efficiency, it is highly recommended to implement sprinkler irrigation, modernise canal irrigation systems, use low-pressure pipe conveyance, laser-controlled land levelling technology, harvest and store rainwater for irrigation and groundwater recharge, and improve surface irrigation by shortening or narrowing borders or furrows [77].

3. CONCLUSION

Millions of people are fed by the paddy, a staple crop that has historically relied on the extremely water-intensive inundation irrigation method. Nonetheless, in the face of increased water scarcity, farmers continue to struggle to produce crops profitably in order to fulfill the world's expanding food demands. Rice-growing nations must adopt innovative techniques and technology that allow farms to use limited irrigation water sustainably in order to meet this issue. Numerous water-efficient rice production technologies, including drip-irrigated rice, aerobic rice, SSC, DSR, and the SRI, have been devised in answer to this difficulty. By using these technologies, paddy production can become more profitable and productive while using less water. Adoption of these methods, however, varies by area and is dependent on factors like soil type, resource availability, competence, and climate compatibility. Cost-effective solutions that can be used in fields include DSR, the SRI, and AWD; they must to be encouraged for quick and widespread adoption. Farmers have been slow to adopt these better irrigation techniques, despite their proven efficacy. Extension agents at the grassroots level should instruct farmers on new irrigation technologies like smart irrigation that uses sensors and the Internet of Things, as they are not well-versed in these areas and don't know how to manage weeds mechanically or with herbicides. It is necessary to develop and implement targeted programmes with alluring incentives in order to encourage the use of these technologies in regions with severe water constraint. All parties involved, including farmers, extension agents, and the government sector, must work together to encourage and facilitate the widespread adoption of these technologies in order to accomplish this. Big projects, though, ought to originate from the government.

REFERENCES

[1] Vijayakumar, S.; Kumar, D.; Ramesh, K.; Jinger, D.; Rajpoot, S.K. Effect of Potassium fertilization on water productivity, irrigation water use efficiency, and grain quality under direct seeded rice-wheat cropping system. J. Plant Nutr. 2022, 45, 2023–2038.

[2] Surendran, U.; Raja, P.; Jayakumar, M.; Subramoniam, S.R. Use of efficient water saving techniques for production of rice in India under climate change scenario: A critical review. J. Clean. Prod. 2021, 309, 127272.

[3] Gulati, A.; Sharma, B.; Banerjee, P.; Mohan, G. Getting More from Less: Story of India's Shrinking Water Resources; NABARD and ICRIER Report; Indian Council for Research on International Economic Relations: New Delhi, India, 2019; p. 170.

[4] Udimal, T.B.; Jincai, Z.; Ayamba, E.C.; Owusu, S.M. China's water situation; the supply of water and the pattern of its usage. Int. J. Sustain. Built Environ. 2017, 6, 491–500.

[5] Vijayakumar, S.; Nayak, A.K.; Ramaraj, A.P.; Swain, C.K.; Geethalakshmi, V.; Pazhanivelan, S.; Tripathi, R.; Sudarmanian, N.S. Rainfall and temperature projections and their impact assessment using CMIP5 models under different RCP scenarios for the eastern coastal region of India. Curr. Sci. 2021, 121, 222.

[6] Mirza, M.M.Q. Climate change and extreme weather events: Can developing countries adapt? Clim. Policy 2003, 3, 233–248.

[7] Teng, Y.; Yang, J.; Zuo, R.; Wang, J. Impact of urbanization and industrialization upon surface water quality: A pilot study of Panzhihua mining town. J. Earth Sci. 2011, 22, 658–668.

[8] Sarker, B.; Keya, K.N.; Mahir, F.I.; Nahiun, K.M.; Shahida, S.; Khan, R.A. Surface and ground water pollution: Causes and effects of urbanization and industrialization in South Asia. Sci. Rev. 2021, 7, 32–41.

[9] Du, T.; Kang, S.; Zhang, J.; Davies, W.J. Deficit irrigation and sustainable water-resource strategies in agriculture for China's food security. J. Exp. Bot. 2015, 66, 2253–2269.

[10] Fereres, E.; Orgaz, F.; Gonzalez-Dugo, V. Reflections on food security under water scarcity. J. Exp. Bot. 2011, 62, 4079–4086.

[11] Ishfaq, M.; Akbar, N.; Anjum, S.A.; Anwar-Ijl-Haq, M. Growth, yield and water productivity of dry direct seeded rice and transplanted aromatic rice under different irrigation management regimes. J. Integr. Agric. 2020, 19, 2656–2673.

[12] Kumar, A.; Nayak, A.K.; Hanjagi, P.S.; Kumari, K.; Vijayakumar, S.; Mohanty, S.; Tripathi, R.; Panneerselvam, P. Submergence stress in rice: Adaptive mechanisms, coping strategies and future research needs. Environ. Exp. Bot. 2021, 104448.

[13] Nelson, A.; Wassmann, R.; Sander, B.O.; Palao, L.K. Climate-Determined Suitability of the Water Saving Technology "Alternate Wetting and Drying" in Rice Systems: A Scalable Methodology demonstrated for a Province in the Philippines. PLoS ONE 2015, 10, e0145268.

[14] Nayak, A.K.; Chatterjee, D.; Tripathi, R.; Shahid, M.; Vijayakumar, S.; Satapathy, B.S.; Kumar, A.; Mohanty, S.; Bhattacharyya, P.; Mishra, P.; et al. Climate Smart Agricultural Technologies for Rice Production System in Odisha; ICAR-National Rice Research Institute: Cuttack, India, 2020; pp. 1–336. ISBN 81-88409-14-6.

[15] Bouman, B.A.M.; Lampayan, R.M. Rice Fact Sheet—Alternate Wetting Drying (AWD); International Rice Research Institute: Los Baños, Philippines, 2009.

[16] Bouman, B.; Tuong, T. Field water management to save water and increase its productivity in irrigated lowland rice. Agric. Water Manag. 2001, 49, 11–30.

[17] Das, S.; Chou, M.L.; Jean, J.S.; Liu, C.C.; Yang, H.J. Water management impacts on arsenic behavior and rhizosphere bacterial communities and activities in a rice agro-ecosystem. Sci. Total Environ. 2016, 542, 642–652.

[18] Duttarganvi, S.; Kumar, R.M.; Desai, B.K.; Pujari, B.T.; Tirupataiah, K.; Koppalkar, B.G.; Umesh, M.R.; Naik, M.K.; Reddy, K.Y. Influence of establishment methods, irrigation water levels and weed management practices on growth and yield of rice (Oryza sativa). Indian J. Agron. 2016, 61, 174–178.

[19] Hasan, K.; Abdullah, A.H.M.D.; Bhattacharjee, D.; Afrad, S.I. Impact of alternate wetting and drying technique on rice production in the drought prone areas of Bangladesh. Indian Res. J. Ext. Educ. 2016, 16, 39–48.

[20] Yadav, S.; Humphreys, E.; Kukal, S.S.; Gill, G.; Rangarajan, R. Effect of water management on dry seeded and puddled transplanted rice, Part 2, Water balance and water productivity. Field Crops Res. 2011, 120, 123–132.

[21] Sujono, J.; Matsuo, N.; Hiramatsu, K.; Mochizuki, T. Improving the water productivity of paddy rice (Oryza sativa L.) cultivation through water saving irrigation treatments. Agric. Sci. 2011, 2, 511.

[22] Ceesay, M.; Reid, W.S.; Fernandes, E.C.; Uphoff, N.T. The Effects of Repeated Soil Wetting and Drying on Lowland Rice Yield with System of Rice Intensification (SRI) Methods. Int. J. Agric. Sustain. 2006, 4, 5–14.

[23]Martin-Vertedor, A.I.; Dodd, I.C. Root-to-shoot signalling when soil moisture is heterogeneous: Increasing the proportion of root biomass in drying soil inhibits leaf growth and increases leaf ABA concentration. Plant Cell Environ. 2011, 34, 1164–1175.

[24]Carrijo, D.R.; Lundy, M.E.; Linquist, B.A. Rice yields and water use under alternate wetting and drying irrigation: A meta-analysis. Field Crop Res. 2017, 203, 173–180.

[25]Yang, J.; Huang, D.; Duan, H.; Tan, G.; Zhang, J. Alternate wetting and moderate soil drying increases grain yield and reduces cadmium accumulation in rice grains. J. Sci. Food Agric. 2009, 89, 1728–1736.

[26]Howell, K.R.; Shrestha, P.; Dodd, I.C. Alternate wetting and drying irrigation-maintained rice yields despite half the irrigation volume, but is currently unlikely to be adopted by smallholder lowland rice farmers in Nepal. Food Energy Secur. 2015, 4, 144–157.

[27]Tabbal, D.F.; Bouman, B.A.M.; Bhuiyan, S.I.; Sibayan, E.B.; Sattar, M.A. On-farm strategies for reducing water input in irrigated rice; case studies in the Philippines. Agric. Water Manag. 2002, 56, 93–112.

[28]Zhang, H.; Chen, T.; Wang, Z.; Yang, J.; Zhang, J. Involvement of cytokinins in the grain filling of rice under alternate wetting and drying irrigation. J. Exp. Bot. 2010, 61, 3719–3733.

[29]Davies, W.J.; Zhang, J.; Yang, J.; Dodd, I.C. Novel crop science to improve yield and resource use efficiency in water-limited agriculture. J. Agric. Sci. 2011, 149, 123–131.

[30]Zhang, H.; Li, H.; Yuan, L.; Wang, Z.; Yang, J.; Zhang, J. Post-anthesis alternate wetting and moderate soil drying enhances activities of key enzymes in sucrose- to starch conversion in inferior spikelets of rice. J. Exp. Bot. 2012, 63, 215–227.

[31]Pascual, V.J.; Wang, Y.M. Impact of water management on rice varieties yield and water productivity under the system of rice intensification in Southern Taiwan. Water 2016, 9, 3.

[32]Mishra, A.; Salokhe, V.M. The effects of planting pattern and water regime on root morphology, physiology and grain yield of rice. J. Agron. Crop Sci. 2010, 196, 368–378.

[33]Dahmardeh, K.; Rad, M.R.N.; Hadizadeh, M. Effects of Potassium Rates and Irrigation Regimes on Yield of Forage Sorghum in Arid Regions. Int. J. Agron. Agric. Res. 2015, 6, 207–212.

[34]Islam, S.M.; Gaihre, Y.K.; Islam, M.R.; Ahmed, M.N.; Akter, M.; Singh, U.; Sander, B.O. Mitigating greenhouse gas emissions from irrigated rice cultivation through improved fertilizer and water management. J. Environ. Manag. 2022, 307, 114520.

[35]Djaman, K.; Mel, V.C.; Diop, L.; Sow, A.; El-Namaky, R.; Manneh, B.; Saito, K.; Futakuchi, K.; Irmak, S. Effects of alternate wetting and drying irrigation regime and nitrogen fertilizer on yield and nitrogen use efficiency of irrigated rice in the Sahel. Water 2018, 10, 711.

[36]Senthilkumar, K.; Bindraban, P.S.; de Boer, W.; De Ridder, N.; Thiyagarajan, T.M.; Giller, K.E. Characterising rice-based farming systems to identify opportunities for adopting water efficient cultivation methods in Tamil Nadu, India. Agric. Water Manag. 2009, 96, 1851–1860.

[37]Chu, G.T.; Chen, S.; Chen, C.; Xu, D.W.; Zhang, X. The effect of alternate wetting and severe drying irrigation on grain yield and water use efficiency of Indica-japonica hybrid rice (Oryza sativa L.). Food Energy Secur. 2018, 7, e00133.

[38]Rungrat, T.; Poothab, C. Short-term water deficit stress induces anthocyanin accumulation and changes in grain yield and yield components in coloured rice grain. Agric. Nat. Resour. 2019, 53, 292–297.

[39]Price, A.H.; Norton, G.J.; Salt, D.E.; Ebenhoeh, O.; Meharg, A.A.; Meharg, C.; Islam, M.R.; Sarma, R.N.; Dasgupta, T.; Ismail, A.M.; et al. Alternate wetting and drying irrigation for rice in Bangladesh: Is it sustainable and has plant breeding something to offer? Food Energy Secur. 2013, 2, 120–129.

[40]Humphreys, E.; Li, T.; Gill, G.; Kukal, S.S. Evaluation of tradeoffs in land and water productivity of dry seeded rice as affected by irrigation schedule. Field Crops Res. 2012, 128, 180–190.

[41]Belder, P.; Bouman, B.A.M.; Cabangon, R.; Guoan, L.; Quilang, E.J.P.; Yuanhua, L.; Spiertz, J.H.J.; Tuong, T.P. Effect of water-saving irrigation on rice yield and water use in typical lowland conditions in Asia. Agric. Water Manag. 2004, 65, 193–210.

[42]Yang, J.C.; Liu, K.; Wang, Z.Q.; Du, Y.; Zhang, J.H. Water-saving and high-yielding irrigation for lowland rice by controlling limiting values of soil water potential. J. Integr. Plant Biol. 2007, 49, 1445–1454.

[43]Yang, J.; Zhou, Q.; Zhang, J. Moderate wetting and drying increases rice yield and reduces water use, grain arsenic level, and methane emission. Crop. J. 2017, 5, 151–158.

[44]Jabran, K.; Ullah, E.; Hussain, M.; Farooq, M.; Haider, N.; Chuhan, B.S. Water saving, water productivity and yield outputs of fine-grain rice cultivars under conventional and water-saving rice production systems. Exp. Agric. 2015, 51, 567–581.

[45]Sarwar, N.; Ali, H.; Irfan, M.; Akhter, M.T.; Ali, M.T. Boron nutrition under intermittent flooding and drying condition seems sustainable nutrient management technique in rice. Cercet. Agron. Mold. 2016, 1, 17–27.

[46]Carrijo, D.R.; Li, C.; Parikh, S.J.; Linquist, B.A. Irrigation management for arsenic mitigation in rice grain: Timing and severity of a single soil drying. Sci. Total Environ. 2019, 649, 300–307.

[47]Rothenberg, S.E.; Anders, M.; Ajami, N.J.; Petrosino, J.F.; Balogh, E. Water management impacts rice methylmercury and the soil microbiome. Sci. Total Environ. 2016, 572, 608–617.

[48]Darzi-Naftchalia, A.; Ritzemab, H.; Karandishc, F.; Mokhtassi-Bidgolid, A.; GhasemiNasre, M. Alternate wetting and drying for different subsurface drainage systems to improve paddy yield and water productivity in Iran. Agric. Water Manag. 2017, 193, 221–231.

[49]Song, T.; Das, D.; Zhu, F.; Chen, X.; Chen, M.; Yang, F.; Zhang, J. Effect of Alternate Wetting and Drying irrigation on the nutritional qualities of milled rice. Front. Plant Sci. 2021, 12, 721160.

[50]Norton, G.J.; Arvajesh, M.R.; Travis, A.J.; Decon, C.M. Impact of alternate wetting and drying on rice physiology, grain production, and grain quality. Field Crops Res. 2017, 205, 1–13.

[51]Ishfaq, M.; Akbar, N.; Zulfiqar, U.; Ali, N.; Ahmad, M.; Anjum, S.A.; Farooq, M. Influence of water management techniques on milling recovery, grain quality and mercury uptake in different rice production systems. Agric. Water Manag. 2021, 243, 106500.

[52]Orasen, G.; De Nisi, P.; Lucchini, G.; Abruzzese, A.; Pesenti, M.; Maghrebi, M.; Kumar, A.; Nocito, F.F.; Baldoni, E.; Morgutti, S. Continuous flooding or alternate wetting and drying differently affect the accumulation of health-promoting phytochemicals and minerals in rice brown grain. Agronomy 2019, 9, 628.

[53]Zhang, H.; Zhang, S.; Zhang, J.; Yang, J.; Wang, Z. Post anthesis moderate wetting drying improves both quality and quantity of rice yield. Agron. J. 2008, 100, 726–734.

[54]Sandhu, N.; Subedi, S.R.; Yadaw, R.B.; Chaudhary, B.; Prasai, H.; Iftekharuddaula, K.; Thanak, T.; Thun, V.; Battan, K.R.; Ram, M.; et al. Root traits enhancing rice grain yield under alternate wetting and drying condition. Front. Plant Sci. 2017, 8, 1879–1891.

[55]Itoh, M.; Sudo, S.; Mori, S.; Saito, H.; Yoshida, T.; Shiratori, Y.; Suga, S.; Yoshikawa, N.; Suzue, Y.; Mizukami, H.; et al. Mitigation of methane emissions from paddy fields by prolonging midseason drainage. Agric. Ecosyst. Environ. 2011, 141, 359–372.

[56]Vijayakumar, S.; Jinger, D.; Parthiban, P.; Lokesh, S. Aerobic rice cultivation for enhanced water use efficiency. Indian Farm. 2018, 68, 3–6.

[57]Shahane, A.A.; Shivay, Y.S.; Prasanna, R.; Kumar, D. Improving water and nutrient use efficiency in rice by changing crop establishment methods, application of microbial inoculations, and Zn fertilization. Glob. Chall. 2019, 3, 1800005.

[58]Wang, W.Q.; Peng, S.B.; Liu, H.Y.; Tao, Y.; Huang, J.L.; Cu, K.H.; Nie, L.X. The possibility of replacing puddled transplanted flooded rice with dry seeded rice in central China: A review. Field Crops Res. 2017, 214, 310–320.

[59]Ramesh, T.; Rathika, S. Evaluation of rice cultivation systems for greenhouse gases emission and productivity. Int. J. Ecol. Environ. Sci. 2020, 2, 49–54.

[60]Grassi, C.; Bouman, B.A.; Castañeda, A.R.; Manzelli, M.; Vecchio, V. Aerobic rice: Crop performance and water use efficiency. J. Agric. Environ. Int. Dev. 2009, 103, 259–270.

[61]Kato, Y.; Okami, M.; Katsura, K. Yield potential and water use efficiency of aerobic rice (Oryza sativa L.) in Japan. Field Crops Res. 2009, 113, 328–334.

[62]Ramulu, V.; Devender Reddy, M.; Umadevi, M. Evaluation of water saving rice production systems. J. Pharmacogn. Phytochem. 2020, 9, 658–660.

[63]Thejaswi Kumar, J.; Lokesha, H.; Samjhauta, T. Resource Use Efficiency Among Aerobic and Conventional Rice Farms in Eastern Dry Zone of Karnataka: A Comparative Analysis. Econ. Aff. 2021, 66, 439–446.

[64]Stoop, W.A.; Uphoff, N.; Kassam, A. A review of agricultural research issues raised by the system of rice intensification (SRI) from Madagascar: Opportunities for improving farming systems for resource-poor farmers. Agric. Syst. 2002, 71, 249–274.

[65]Uphoff, N. Opportunities for raising yields by changing management practices: The system of rice intensification in Madagascar. In Agroecological Innovations: Increasing Food Production with Participatory Development; Oxford University Press: Oxford, UK, 2014; pp. 145–161.

[66]Glover, D. The system of rice intensification: Time for an empirical turn. NJAS-Wagening. J. Life Sci. 2011, 57, 217–224.

[67]Kumar, V.; Singh, A.K.; Jat, S.L.; Parihar, C.M.; Pooniya, V.; Sharma, S.; Singh, B. Influence of site-specific nutrient management on growth and yield of maize (Zea mays) under conservation tillage. Indian J. Agron. 2014, 59, 657–660.

[68]Mohanty, A.; Mishra, K.N.; Garnayak, L.M.; Patra, A.K. Impact of system of rice intensification (SRI) on the water holding capacity (WHC) of soil and water use efficiency (WUE) in a tropical rainfed agro-ecosystem of Odisha. J. Pharmacogn. Phytochem. 2019, 8, 1576–1580.

[69]Narayanamoorthy, A.; Jothi, P. Water saving and productivity benefits of SRI: A study of tank, canal and groundwater irrigated settings in South India. Water Policy 2019, 21, 162–177.

[70]Toungos, M.D. System of rice intensification: A review. Int. J. Innov. Agric. Sci. 2018, 6, 27–38.

[71]Kumar, M.R.; Somasekhar, N.; Surekha, K.; Padmavathi, C.H.; LV, S.R.; Latha, P.C.; Sreedevi, B.; Ravichandran, S.; Ramprasad, A.S.; Muthuraman, P.; et al. SRI-A method for sustainable intensification of rice production with enhanced water productivity. Agrotechnology 2013, S11, 9.

[72]Deb, D. Is the system of rice intensification (SRI) consonant with agroecology? Agroecol. Sustain. Food Syst. 2020, 44, 1338–1369.

[73]Chang, Y.C.; Kan, C.E.; Lin, G.F.; Chiu, C.L.; Lee, Y.C. Potential benefits of increased application of water to paddy fields in Taiwan. Hydrol. Process. 2001, 15, 1515–1524.

[74]Tuong, T.P.; Bhuiyan, S.I. Increasing water-use efficiency in rice production: Farm-Level perspectives. Agric. Water Manag. 1999, 40, 117–122.

[75]Pirdashti, H.; Sarvestani, Z.T.; Bahmanyar, M.A. Comparison of physiological responses among four contrast rice cultivars under drought stress conditions. World Acad. Sci. Eng. Technol. 2009, 25, 52–53.

[76]Kima, A.S.; Chung, W.G.; Wang, Y.M. Improving irrigated lowland rice water use efficiency under saturated soil culture for adoption in tropical climate conditions. Water 2014, 6, 2830–2846.