Int.J.Curr.Microbiol.App.Sci (2021) *10*(01): 1993-2004

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 Volume 10 Number 01 (2021)
Journal homepage: http://www.ijcmas.com

Review Article https://doi.org/10.20546/ijcmas.2021.1001.231

Influence of Various Water Saving Techniques on Yield and Water Productivity of Irrigated Rice: A Review

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Keywords

Food security, Rice, Water scarcity, Water saving techniques, Water productivity

Article Info

Accepted:
12 December 2020
Available Online:
10 January 2021

ABSTRACT

Rice (*Oryza sativa* L.) is one among the foremost important staple food crops globally. In Asia, more than two billion people are getting 60-70 per cent of their energy requirement from rice and its derived products. In India, rice occupies an area of 43.79 million ha with an average production of 112.91 million tones and productivity of 2.58 tonnes/ha. Demand for rice is growing every year and it is estimated that in 2025 AD, the requirement would be 140 million tonnes. To accomplish this objective, the profitability of rice must be brought to the level of 3.3 tons/ha (Anjani *et al*., 2014). Food security depends on the power to extend production with decreasing availability of water to grow crops. Rice is one of the greatest water user among cereal crops, consuming about 80% of the total irrigated fresh water resources in Asia. To produce 1 kg of grain, farmers have to supply 3–5 times more water in rice fields than other cereals (Kumar *et al*., 2013). Quickly exhausting water resources threaten the sustainability of the irrigated rice and subsequently the food security and vocation of rice producers and purchasers. In Asia, 17 million hectare (Mha) of flooded rice areas may encounter "physical water scarcity" and 22 Mha may experience "economic water scarcity" by 2025. Key technological interventions which could alter or rectify the utilization of freshwater in agriculture are the need of the hour. In this context, the scientific interventions on water management involving direct seeded rice (DSR), system of rice intensification (SRI), alternate wetting and drying (AWD), furrow irrigated raised bed planting systems (FIRB) and other inclusive technological practices could enforce appropriate irrigation schedules. The potentials for water savings in rice production appear to be very large, however there is need to convince farmers to use less water without compromising land productivity.

Introduction

Rice is the staple food for more than half of the world's population and plays a pivotal role in food security of many countries. More than 90% of the global production and consumption of rice is in Asia (IRRI, 1997). In Asia, more than two billion people are getting 60-70 per cent of their energy requirement from rice and its derived products (Yogeswari and Porpavai, 2018). As for India, the country has witnessed a remarkable progress in rice production since independence. Presently, rice occupies an area of 43.79 million ha with an average production of 112.91 million tones and productivity of 2.58 tonnes/ha in India (Anonymous, 2018). Growth trends in cultivated area, irrigated area, production and productivity of rice in last five decades are given in Table 1.

Based on the current rate of population growth (1.4%) and per capita consumption (215-230 g/day), the projected demand for rice by 2025 would be around 140 million tonnes (Duttarganvi *et al.,* 2016). In order to achieve this target, the productivity of rice has to be brought to the level of 3.3 tonnes/ha (Anjani *et al.,* 2014). The projected demand has to be met in the background of declining land and water resources. Water scarcity will pose a major threat to rice cultivation and efforts are required to ensure more crop from every drop.

Water and Irrigated Rice

Water is one of the essential inputs for crop production as it affects plant development by influencing its vital physiological processes. Fresh water for agriculture is becoming increasingly scarce. In Asia, with relatively more suitable growing conditions for rice, production has declined due to increasing water stress. Rapidly depleting water resources threaten the sustainability of the irrigated rice and hence the food security and livelihood of rice producers and consumers. Groundwater tables have dropped, on average by 0.5–0.7 m/year in the Indian states of Punjab, Haryana, Rajasthan, Maharashtra, Karnataka and Northern Gujarat and by about 1 m/year in Tamil Nadu and hard-rock Southern India. It is expected that around 17 million hectare (Mha) of irrigated rice areas in Asia may experience "physical water scarcity" and 22 Mha may have "economic water scarcity" by 2025 (Tuong and Bouman, 2003).

In India, rice is the staple food of more than 70 % of population and a source of livelihood for about 120-150 million rural households (Nivrutti, 2014)**.** Irrigated rice occupies 50% area and contributes nearly 70% to total rice production of the country with an average yield of 3.1 t/ha. It is estimated that to produce 1 kg of grain, farmers have to supply 3-5 times more water in rice fields than other cereals (Kumar *et al.,* 2013). Average water requirement of irrigated rice has been depicted in Table 2.

There is growing awareness about the need to optimize water use in rice production. At constant level of fresh water availability, per capita supply of water is decreasing progressively with time. Water is going to be most critical input in the future for agriculture, in general and rice cultivation, in particular. Share of water for agriculture is likely to drastically go down from 90% to less than 60% (Kumar *et al.,* 2013). Rice cultivation has traditionally been in water impounded paddies and hence rice has come to be known as water loving crop.

Improper irrigation methods are chief reasons for the high wastage of a scare resource. A large amount of water is lost in seepage and percolation. Fortunately, this aspect of rice cultivation is undergoing radical changes, and technologies are being aggressively developed for more water productive cultivation practices. There is a paradigm shift towards maximizing output/unit of water instead of per unit of land as water is going to be serious constraint in irrigated ecology. For improving productivity of irrigation water in irrigated rice cultivation, the following three approaches are suggested:

1) Enhancing the water supply,
2) Conservation of water and
3) Increasing crop and water productivity.

Increasing water scarcity is becoming real threat to rice cultivation. The challenge is to develop novel technologies and production systems that would allow rice production to be maintained or increased at the face of declining water availability. Several strategies are in vogue to reduce rice water requirements, such as, alternate wetting and drying (AWD), ground-cover systems, system of rice intensification (SRI), Direct seeded rice, aerobic rice, furrow irrigated raised beds, irrigation scheduling, etc. Any approach that would lessen the amount of water use without compromising the rice yield would certainly be a welcome strategy.

Traditional method: Puddled Transplanted rice (TPR)

Transplanted rice is predominantly cultivated in the North-Western Indo-Gangetic Plains (IGP). Transplanting requires at least 25 ha-cm of water for puddling operation, which creates a dense clay layer in the sub-soil to prevent seepage losses. Generally, about 40% of all irrigation water goes to paddy cultivation in the region. In traditional rice cultivation, rice is sprouted in a nursery; sprouted seedlings are then transplanted into standing water. The reported amount of irrigation water required for puddling varies from 100 mm (Sudhir-Yadav *et al.*, 2011) to 544 mm (Bhuiyan *et al.*, 1995). Land preparation for transplanting paddy (puddling) consumes about 20-40 % of the total water required for growing of crop and subsequently poses difficulties in seed bed preparation for succeeding wheat crop in rotation. It also promotes the formation of hard pan which effects rooting depth of next crop. It, therefore, becomes imperative to identify alternative establishment method to puddling especially in those regions where water is becoming scarce, and an upland crop is grown after rice.

Water saving techniques of cultivating paddy

Various strategies and options to make rice production more water-efficient with integrative use of crop improvement and management tools have been discussed below. Effect of different water saving techniques on grain yield and water productivity of paddy with respect to methods of crop establishment and irrigation regimes have been presented in Table 3, 4 and 5.

Alternate wetting and drying (AWD)

AWD has been commonly used as a water-saving practice in many parts of the world for more than a decade. In this system, the soil is allowed to dry for a few days within irrigation events depending on plant developmental stages. Savings in irrigation water in the AWD treatments were 53–87 mm (13–16%) compared with the continuously submerged regime. Water productivity was significantly higher in the AWD regime than in the continuously submerged regime (Belder *et al.*, 2004).Yield penalty was commonly observed under AWD compared with continuously flood-irrigated (CF) rice (Bouman and Tuong, 2001). However, the water consumption is still high in AWD since the soils need to be submerged at least during the irrigation period.

Direct seeded rice (DSR)

In direct seeded rice (DSR) cultivation, raising of nursery for transplantation is excluded. DSR gives the farmer flexibility to take up direct sowing of paddy in case of water shortage or delayed monsoon. Direct sowing can be practiced for cultivating both coarse rice and basmati rice wherever feasible in the North-West IGP region. In DSR, crop established after applying pre sowing irrigation, first irrigation can be applied 7-10 days after sowing depending on the soil type. During active tillering phase i.e. 30-45 days after sowing (DAS) and reproductive phase (panicle emergence to grain filling stage) optimum moisture (irrigation at 2-3 days interval) is required to be maintained to harvest optimum yields from DSR crop. In a 6-year study conducted in Modipuram on sandy-loam soil, it was observed that dry DSR can be irrigated safely at the appearance of soil hairline cracks (Gathala *et al.*, 2011). The direct seeded rice (DSR) on raised beds decreased water use by 12-60 per cent, and increased yield by 10 per cent as compared to puddle transplanted rice, in trials at both experimental stations and on-farm (Gupta *et al.*, 2002).

Aerobic rice

Aerobic rice is a new way of production system in which specially developed, input-response rice varieties with aerobic adaptation are grown in well-drained, non-puddled, and non-saturated soils without ponded water. It is a fundamental approach to reduce water inputs in rice is growing like an irrigated upland crop, such as wheat or maize. Main driving force behind aerobic rice is the economic water use. Kadiyala *et al.*, (2012) reported that the total amount of water applied (including rainfall) in the aerobic plots was 967 and 645 mm compared to 1546 and 1181 mm in flooded rice system, during 2009 and 2010, respectively. This resulted in 37 to 45% water savings with the aerobic method. Jinsy *et al.*, (2015) found that compared to conventional flooded rice, the average water productivity of aerobic rice (0.68 kg/m^3) was 60.7 per cent higher. Reddy *et al.*, (2010) reported that water productivity was higher under aerobic (0.20 to 0.60 kg/m^3 of water) than that under transplanted (0.14 to 0.43 kg/m^3 of water) condition.

Nevertheless, decline in yield was observed when aerobic rice when continuously grown and the decline was greater in the dry than in the wet season (Peng *et al.*, 2006). In crux, aerobic rice is an attractive option to the traditional rice production system. Yield penalty and yield stability of aerobic rice have to be considered before promoting this water-saving technology.

Ground cover rice production

In this method, the soil surface is covered by material, such as plastic film, paper, or plant mulch to check evaporation losses. Huang *et al.*, (1999) reported that amount of water saved with plastic film mulching can be as high as 60– 85% of the need in the traditional paddy systems with no adverse effects on grain yield. Some researcher have recorded up to 60% reduction in water requirements of rice crop; however, grain yields were up to 10% lower than the traditional lowland rice. This was associated to micronutrient deficiency and difficulties in nitrogen fertilizer management contributed to significant yield reductions under such conditions (Borrell *et al.*, 1997).

Furrow irrigated raised beds

Transplanting of rice on beds omits puddling and hence avoids the detrimental effects of puddling. In this case rice is grown on raised beds and irrigation is applied in furrows between the beds. Naresh *et al.*, (2014) revealed that among different crop establishment techniques, wide raised beds saved about 15%–24% water and grain yield decrease of about 8%. Sandhu *et al.*, (2012) revealed that transplanting of rice seedlings on slopes of freshly constructed beds resulted in 15% saving of irrigation water as compared to puddled plots (conventional method used by farmers) without any significant reduction in grain yield of rice. Singh *et al.,* (2001) evaluated the yield and water use of rice established by transplanting, wet and dry seeding with subsequent aerobic soil conditions on flatland and on raised beds. Compared with transplanted rice, dry-seeded rice on flatland and on raised beds reduced total water input during crop growth by 35–42% when the soil was kept near saturation and by 47% and 51% when the soil dried out to 20 and 40 kPa moisture tension in the root zone, respectively. Gathala *et al.,* (2013) reported that irrigation water productivity (IWP) was significantly higher in beds to the tune of 13.9% and 13.16% than flat puddled planting.

System of rice intensification

SRI that evolved in the 1980s and 1990s in Madagascar permits resource limited farmers to realize paddy yields of up to 15 t/ha even on infertile soils, with greatly reduced rates of irrigation and without external additional inputs (Stoop *et al.,* 2002). The main features of this system are transplanting young seedlings singly in a square pattern with wide spacing, using organic fertilizers and hand weeding, and keeping the paddy soil moist during the vegetative growth phase. Significant phenotypic changes occur in plant structure and function and in yield and yield components under SRI cultivation. SRI increased yields substantially (50–100% or more), while requiring only about half as much water as conventional (Uphoff *et al.,* 2010), whilst not needing the purchase of additional external inputs.

Moser and Barett (2003) conducted a survey of farmers in Madagascar to investigate farmer implementation of AWD as part of SRI and showed that farmers have adapted AWD practices to fit the soil type, availability of water and labor. They suggested that by combining AWD with SRI, farmers can increase grain yields while reducing irrigation water demand. In another study, Thiyagarajan *et al.,* (2003) reported savings in irrigation water of 56% and 50% using conventional and young seedlings, respectively, without a significant effect on grain yield under SRI system. Krupnik *et al.,* (2012) explain that substantial water savings and increases in water productivity can be obtained with SRI, although significant yield increases compared to recommended management practices should not be expected. Further work should be conducted to investigate the mechanisms underlying these results, and to compare SRI‘s yield and water productivity performance to other water-saving rice management systems.

Irrigation scheduling

Crop must not be allowed to suffer from water stress at any critical growth stage and water should be utilized efficiently for getting higher yield per unit of water applied. There is possibility of reducing water requirement of rice without affecting the grain yield in comparison to the continuous sub-mergence and this can be achieved by scheduling irrigation as per crop water requirement. Criterion of scheduling irrigation is based either on soil water regime or climatological approaches. Various techniques for scheduling irrigation include soil moisture tension, IW/CPE ratio, feel and appearance method, cumulative pan evaporation, etc. Sudhir-Yadav *et al.,* (2011) found that irrigation water productivity was higher in alternate wetting drying (AWD) than in daily irrigated treatments due to large reductions in irrigation water amount from 40 and 70 kPa irrigation schedules. Matsuo and Mochizuki

(2009) revealed that continuously flooded paddy (CF), alternate wetting and drying system (AWD) in paddy field and aerobic rice systems in which irrigation water was applied when soil moisture tension at 15 cm depth reached -15 kPa and -30 kPa and reported that total water applied was 2145 mm in continuous flooding, 1706 mm in AWD, 804 mm in aerobic rice. Water requirement varies with the crop and crop growth and development status, soil water status, as well as environmental conditions. Closely monitoring soil water status, crop growth conditions and their spatial and temporal patterns can aid in irrigation scheduling and precise water management.

Table.1 Scenario of cultivated area, area under irrigation, production and productivity of rice crop in India over past five decades (Anonymous, 2018)

Year	Area (million-hectare)	Area under irrigation (%)	Production (million-tonne)	Productivity (kg/ha)
1974-75	37.89	38.81	39.58	1045
1984-85	41.16	43.72	58.34	1417
1994-95	42.81	49.87	81.81	1911
2004-05	41.91	55.23	83.13	1984
2014-15	44.11	60.09	105.48	2391

Table.2 Water requirement of irrigated rice (Kumar *et al*., 2013)

S.No.	Farm operations and processes	Water requirement (mm)
1	Land preparation	150 – 200
2	Evapo-transpiration	500 – 1200
3	Seepage and percolation	200 – 700
4	Mid season drainage	50 – 100
5	Total	900 – 2250

Table.3 Effect of different crop establishment methods on grain yield of paddy

Establishment method	Grain yield (t/ha)	Location	Source
System of Rice intensification	6.10	ICAR-IIRR, Hyderabad	Duttarganvi, *et al.* (2016)
Direct Seeded Rice	4.60	IGKV, Chattisgarh	Hemlata *et al.* (2018)
Normal transplanted rice	4.00	ICAR-IIRR, Hyderabad	Duttarganvi *et al.* (2016)
Wet Seeded Rice	3.50	IGKV, Chattisgarh	Hemlata *et al.* (2018)
Furrow irrigated raised bed	3.04	ANGRAU, Hyderabad	Balamani *et al.* (2012)

Table.4 Effect of different irrigation methods on grain yield of paddy

Irrigation method	Grain yield (t/ha)	Location	Source
Drip irrigation	5.30	IGKV, Chattisgarh	Hemlata *et al.* (2018)
Alternate wetting and drying	5.10	ICAR-IIRR, Hyderabad	Duttarganvi, *et al.* (2016)
IW/CPE ratio 1.2	4.91	TNAU, Coimbatore	Maheshwari, *et al.* (2007)
Flooding	4.60	ICAR-IIRR, Hyderabad	Duttarganvi, *et al.* (2016)
Sprinkler irrigation	3.70	IGKV, Chattisgarh	Hemlata *et al.* (2018)

Table.5 Effect of different systems of rice cultivation on grain yield and water productivity of rice (Geethalakshmi *et al.*, 2011)

System of rice cultivation	Grain Yield (kg/ha)	Water productivity (kg/m^3)
Transplanted rice	6262	0.37
System of rice intensification	6682	0.47
Alternate wetting drying	5796	0.42
Direct wet seeded rice	5500	0.35
Aerobic rice	3933	0.42

Other water efficient management strategies of paddy cultivation

Pressurized irrigation systems (sprinkler, surface, and subsurface drip) have the potential to increase irrigation water use efficiency by providing water to match crop requirements, reducing runoff and deep drainage losses, and generally keeping the soil drier, reducing soil evaporation and increasing the capacity to capture rainfall. There are few reports of the evaluation of these technologies in rice–wheat systems. Kumar *et al.*, (2013) observed that the substantial water saving 41 to 94 mm/ha in 2010 and 86 to 144 mm//ha in year 2011 was recorded with all the micro irrigation systems.

The highest water productivity was recorded with sprinkler irrigation system than remaining irrigation techniques during both the study years. No yield penalty was recorded under micro irrigation systems. The performance of drip and sprinkler irrigation on yield contributing charter and yield was found at par with flood irrigation.

Irrigation water use was reduced by about 200 mm in rice with subsurface drip commencing 2 weeks prior to panicle initiation compared with flooded rice culture. Yields with drip also decreased, although there was no increase in irrigation water productivity (Beecher *et al.*, 2006).

Substantial irrigation water savings can be achieved by delaying transplantation from mid-May to mid-June (Narang and Gulati, 1995). Direct seeding could help overcome the problem of labor availability, although the optimum sowing date may need to be earlier than the optimum transplanting date, which could increase the crop water requirement. Although delayed rice planting can save

water, it can also delay planting of wheat beyond the optimal time, causing yield loss of 1–1.5% per day due to higher temperatures at grain filling (Ortiz-Monasterio *et al.*, 1994).
Soil type has a large influence on irrigation water requirement due to much higher percolation losses on coarser textured soils. The extent of laser leveling in South Asia and China is currently extremely small, compared with 50–80% of the rice land in Australian rice-based systems (Lacy and Wilkins, 2003).

Land leveling can reduce evaporation and percolation losses by enabling faster irrigation times and by eliminating depressions. Rice yields in rainfed lowland laser-leveled fields were 24% higher than in without laser-leveled fields in Cambodia, and yield increased with the uniformity of leveling.

As different growing techniques may be used to grow rice with less water, it is important to find out the best one. Hydrogel may prove as a practically convenient and economically feasible option to achieve the goal of agricultural productivity under conditions of water scarcity. Kalhapure *et al.,* (2016) reported that the low application rate (i.e. 2.5–5.0 kg/ha) of hydrogel is effective for almost all the crops in relation to soil type and climate of India.

The improvement in growth and yield attributing characters and yield of different field, ornamental and vegetable crops has been reported with the application of hydrogel. It is well documented that the addition of gel-polymers has the potential to improve plant vegetative growth by retaining more moisture contents (Choudhary *et al.*, 1995). Rehman *et al.,* (2011) reported that sowing of rice on beds with hydrogel amendment was found the most effective; it not only improved the performance of aerobic rice but also enhanced growth and yield of aerobic rice more than other sowing techniques. Hence application of hydrogel will be a fruitful option for increasing agricultural production with sustainability in water-stressed environment. Furthermore, much work is done on hydrogel in different crops but little is known with regard to the thirstiest rice.

In conclusion water is one of the essential inputs for crop production. For realizing potential yield of any crop, it must not be allowed to suffer from water stress at any of the critical growth stages. However water is becoming increasingly scarce globally therefore, irrigation water saving strategies in rice production is becoming increasingly important to identify effective and sustainable crop production and management practices.

Various scientific interventions on water management involving direct seeded rice (DSR), system of rice intensification (SRI), alternate wetting and drying (AWD), furrow irrigated raised bed planting systems (FIRB) and other inclusive technological practices could enforce appropriate irrigation schedules. Adoption of these techniques can substantially reduce water input at the field level while increasing water productivity at the same time.

However, with water saving, decrease in land productivity may be observed when compared with continuously flooded rice. Amongst all the water saving techniques SRI proves to be one of the most promising options to save water and increase water productivity without decreasing land productivity.

The promising approaches are to improve water management to bridge the yield gap, by use of advanced strategies and technologies that are developed location specific. In addition, technology transfer and adoption in conjunction with manpower development are necessary elements supplement to the success, and has to be carried on by the local governments. The location specific and socio-economic circumstances of rice ecology determine the degree of freedom for effective intervention in the water resource system and management scheme. With the flexibility and reliability, such an integrated water management approach should be the appropriate answer to rice water management that would provide a change to really improve irrigation efficiency and water productivity now and the future. The potentials for water savings in rice production appear to be very large, however there is need to convince farmers to use less water without compromising land productivity. None the less, improved water management in rice production systems is likely to be an important item on the menu for a sustainable food future.

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How to cite this article:

Aaina Sharma, Akhil Bharti, Anuradha Saha, Jyoti Sharma, Rakshit Bhagat and Shubham Jamwal. 2021. Influence of Various Water Saving Techniques on Yield and Water Productivity of Irrigated Rice: A Review. *Int.J.Curr.Microbiol.App.Sci.* 10(01): 1993-2004.
doi: https://doi.org/10.20546/ijcmas.2021.1001.231