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Sucheta Dahiya
Department of Agronomy, CCS Haryana Agricultural University, Hisar, Haryana, India

Correspondence
Sucheta Dahiya
Department of Agronomy, CCS Haryana Agricultural University, Hisar, Haryana, India

Management of irrigation water in direct seeded-rice (*Oryza sativa* L.): A Review

Sucheta Dahiya

Abstract
In the north-western Indo-Gangetic Plains (IGP), puddled transplanted rice is predominantly cultivated. Generally, about 40% of all irrigation water goes to paddy cultivation in the region. To avoid this we need to focus on such practice which can overcome the use of irrigation water. Researchers have developed various establishment methods of rice which could be implement in the field *viz.* direct seeding of rice, transplanting, SRI (System of rice intensification) etc. Direct seeding is the most promising approach for saving both water and labour. Without the compromise of yield direct seeding rice needs less water as compared to continuous submergence methods of rice establishment. Direct seeding with reduced tillage is an efficient resource conservation technology that holds great promise in IGP which can save water up to 25% as compared to other establishment methods. Depending upon the amount and distribution of rains as well as soil moisture of the land, the DSR may be subjected to varying degree of moisture stress at different growth stages. Various stress may be experienced at different growth and vegetative stages of rice may lead to decrease in plant height, panicle number, panicle length, test weight, number of tillers, total dry matter where as in non-puddled conditions hard pan will not form at 15-20 cm soil layer which leads to restrict the root growth. Water saving of 9-57% was recorded by adopting direct seeding rice culture.

Keywords: aerobic rice, IW/CPE ratio, grain yield, growth, water use

Introduction

Irrigated agriculture is by far the biggest user of freshwater, accounting for more than 70% of water withdrawals worldwide (Rosegrant, 1998) [36]. More than 50% of all water used for irrigation is used to irrigate rice (Barker *et al*., 1999) [5]. In Asia, rice is the most important staple, providing 35-80% of total calorie uptake. Increasing food demand is a big challenge to food security and the present as well as future food security largely depend on the irrigated rice production system. This ecosystem, however, is increasingly threatened by water shortage. The reasons are diverse and location-specific, but include deteriorating quality (chemical pollution, salinization), diminishing resources (e.g., falling groundwater tables, silting of reservoirs), and increased competition from other sectors such as urban and industrial users. The water-use efficiency of rice is much lower than that of other crops. On an average, 2500 litres of water is used, ranging from 800 litres to more than 5000 litres to produce 1 kg of rough rice (Bouman, 2009) [8]. A 10% increase in irrigation efficiency can help bring additional 14 million ha area under irrigation. Solely reducing water use in puddle transplanted rice (PTR) resulted in proportional reduction in yield, hence various management practices of rice cultivation have to change simultaneously to enhance water productivity, without reducing the productivity of other factors, primarily land (i.e. yield), labour and fertilizer. Transplanting is the most common method of rice cultivation but owing to increasing water scarcity, scarce labour coupled with higher wages during the peak periods, a shift towards less challenging substitute methods of rice cultivation targeting at higher water and crop productivity, is imperative. To overcome these problems, aerobic rice systems, wherein the crop is established via direct-seeding in non-puddled, non-flooded fields, are among the most promising approaches for saving water and labour (Singh *et al*., 2008) [41]. Irrigation water requirement was also reduced when we use early maturing crop cultivars under DSR (Gill and Dhingra, 2002) [14]. Further, in irrigated direct seeded rice culture, water use efficiency on the farm can be increased by applying only the amount of water needed without any substantial yield reductions. An effort has been made to review in this paper the effect of different method of irrigation scheduling on direct seeded rice culture.

DSR v/s Puddled Transplanted Rice (PTR)

The DSR is a one of the resource conservation technology as it requires less irrigation water with more efficiency, incure low labour and can be highly mechanized (Wang *et al*., 2002) [46]. In DSR, irrigation water saving was to the extent of 35–57 per cent (Sharma *et al*., 2002; Singh *et al*., 2002) [38, 40], 28-33 per cent (Kumar, 2002) [25], 20 per cent (Kaur, 2004) [22], 13 per cent (Mann and Ashraf, 2004) [30], 30–50 per cent with similar yields to flooded PTR (Yadav *et al*., 2011) [47] and 30-50 per cent with yield loss of 20-30 per cent (Bouman *et al*., 2005) [9]. Dawe (2005) [11] reviewed that substantial amount of water savings are possible from DSR. Jat *et al.* (2009) [20] also found reduced water input by 9-24 per cent with DSR (zero till or cultivated) in comparison with PTR. The yield under aerobic conditions was 6.3 t ha-1 in 2002 and 4.2 t ha-1 in 2003, and the irrigation water input was 778 mm in 2002 and 826 mm in 2003. Compared with flooded conditions, the yield was 15 and 39% lower, and the irrigation water use 36 and 41% lower in aerobic plots in 2002 and 2003, respectively (Belder *et al*., 2007). Thus, direct seeding of rice saves irrigation water but varied differently depending upon the rainfall, water and crop management and soil type as also reported by Farooq *et al.* (2006) [13].

Irrigation scheduling and crop productivity

At Ludhiana, Gill and Singh (2008) [15] studied the effect of two irrigation schedules *viz*., 2 and 3-days interval on the yield of direct seeded basmati rice cv. Basmati 370 and Super Basmati. Irrigation at 2-days interval gave significantly more yield (3.69 t ha^{-1}) than 3-days interval. In another study on sandy loam soils in Punjab, increasing irrigation intervals from 2 to 3 days increased the grain yield of direct-seeded rice by 0.2 t ha^{-1} but the effect was non-significant (Mahajan *et al.*, 2006) [28]. Parihar (2004) [32] at Bilaspur (Chhattisgarh) conducted an experiment on rice to find the effect of irrigation scheduling (irrigation at 1, 3, 5 and 7 days after infiltration of applied water) and found that highest grain yield was obtained with irrigation at one day after infiltration of applied water (5.4 t ha^{-1}) which was statistically at par with that obtained with irrigation at three day after infiltration of applied water (5.3 t ha^{-1}). Luikham *et al.* (2004) [27] tested the performance of rice at Coimbatore (Tamil Naidu) on clay loam soil under three different irrigation treatments viz. irrigation of 5 cm on the day of disappearance of water, 1 day after disappearance of water and 3 days after disappearance of water and found that the maximum grain yield (7.11 t ha^{-1}) was obtained with irrigation on the day of disappearance of ponded water which remained at par with that obtained with applying irrigation 1 day after disappearance of ponded water (6.92 t ha^{-1}). Khalifa *et al*. (2005) [23] studied the effect of three irrigation intervals (irrigation on every 4th, 7th and 10th day) in Egypt on rice and found that irrigation at every 4 day recorded the highest grain yield which was statistically at par with grain yield obtained by irrigation at every 7th day. Shekara *et al.* (2010) [39] reported that the irrigation scheduled at IW/CPE ratio of 2.5 produced higher grain yield of 6.21t and 6.58 t ha^{-1} during first and second year, respectively as compared to IW/CPE ratio of 1.0. Maheswari *et al.* (2007) [29] conducted a field experiment in Coimbatore for determining the optimum schedule of irrigation for high DSR yield (*Oryza sativa* L.) and from the experiment he found that irrigation at 1.2 IW/CPE ratio has higher rice yield and crop growth without moisture stress as and when compared to IW/CPE ratio of 0.8 and 1.0. Jadhav *et al.* (2003) [19] in Parbhani, Maharashtra conducted a field experiment to determine the effect of irrigation on the yield of rice cv. Basmati-370. The treatments comprised of irrigation at critical growth stages (I1), 0.8 (I2), 1.2 (I3), and 1.6 (I4) IW/CPE ratio. The treatment I4 registered the highest grain yield (2.26 t ha-1). Jadhav *et al.* (2000) [18] conducted a similar comprehensive study on basmati rice and irrigated the crop at critical growth stages or at IW/CPE ratios of 0.8, 1.2 or 1.6. Yield increased with increasing irrigations, the highest yield with 1.6 IW/CPE ratio (2.53 t ha-1) from 396 mm irrigation water applied. On a marginally sodic silt loam at Modipuram, yield of DSR declined significantly (by 15 per cent) as the threshold for irrigation increased from10 to 20 kPa at 20 cm (Sharma *et al.*, 2002) [38].

Irrigation scheduling and growth and yield attributes

A study at Ludhiana, (Punjab) was conducted to evaluate the effect of two irrigation schedules *viz*., irrigation after 2 and 3-day intervals on yield of direct seeded basmati rice (*Oryza sativa*) cv. Basmati 370 and Super Basmati. It was found that irrigation at 2-day intervals gave significantly more yield (3.69 t ha-1) than 3-day intervals due to significantly higher values of effective tillers and number of grains per panicle (Gill and Singh, 2008) [15]. In the experiment study, Kato and Okami (2010) [21] found lower root biomass in DSR than in puddled transplanted rice due to decrease in root biomass in the surface soil (fewer adventitious roots). Ratio of deep root to the total biomass was higher in dry direct seeded rice. Deeper root and heavy adventitious rooting on surface would be advantageous in improving N and water use efficiency especially during reproductive stage. Biswas and Yamauchi (2007) [6] observed that the root growth of DSR remained inhibited up to 6 DAS. On the other hand, deeper root growth was seen in case of DSR than Puddled rice. The three irrigation regimes (irrigation at 5 cm depth on the DAD, one day after the disappearance and 3 days after DAD of ponded water) were tested by Edwin and Anal (2008) [12] at Coimbatore, Tamil Nadu on rice and found on the basis of the two years result that highest dry matter was produced with irrigation of 5 cm depth on the day of disappearance of ponded water which was statistically at par with irrigation at one day after the disappearance of ponded water. Huang *et al.* (2008) [16] reported from China that in rice the growth duration was longest under dry cultivation (delayed by 13.5 days compared with continuous flooding) and compared with continuous flooding, intermittent irrigation delayed tillering by 5-7 days, reduced the leaf transpiration rate and enhanced the leaf photosynthetic rate. Gill and Singh (2008) [15] was conducted a field study at Ludhiana, Punjab to evaluate the effect of two irrigation schedules viz., irrigation after 2 and 3-days interval on yield of direct seeded basmati rice cv. Basmati 370 and Super Basmati. It was found that irrigation at 2-days interval gave significantly more yield (3.69 t ha-1) than 3-day intervals due to significantly higher values of effective tillers and number of grains per panicle. Rahman *et al.* (2002) [33] reported that plant height, panicle number, panicle length, weight of 100 grain, number of tillers, total dry matter and yield were decreased with stress. Tantawi and Ghanem (2001) [43] reported as stress was imposed to plant it caused reduction in height and yield of plant. In New Delhi, Ramakrishna *et al.* (2007) [34] reported that yield attributing characters of rice *viz.* 1000- grain weight, length of panicle, grains/panicle differs non-significantly among two irrigation treatments viz. irrigation after one day of drainage and three days after drainage of applied water. Khalifa *et al.* (2005) [23] in his experiment which was conducted in Egypt concluded that among three irrigation intervals (irrigation every 4th, 7th and 10th day) and found that irrigation every 4th day recorded the highest values of yield attributes (number of panicles m^2, panicle length, number of filled grains panicle-1, 1000-grain weight) which were statistically at par with values of yield attributes obtained by irrigation at every 7th day. Parihar (2004) [32] conducted field experiment on rice at Bilaspur (Chhattisgarh) to find the effect of irrigation scheduling viz. irrigation at 1(I1), 3 (I3), 5 (I5) and 7 (I7) days after infiltration of applied water and found that number of effective tillers m-2, number of filled grains panicle-1 and thousand grain weight were statistically similar in I1, I3 and I5. Das *et al.* (2000) carried out a field experiment at Jorhat (Assam) on rice for three years using two irrigation schedules *viz.* irrigation with 7 cm of water after 3 and 5 days of infiltration of applied water. The results revealed that out of 3 years, these treatments produced statistically similar number of effective tillers m-2 and 1000 grain weight for two years, whereas, in respect of number of grains panicle-1 these treatments remained statistically at par with each other during all the three years of study. Huang *et al.* (2008) [16] in China studied three irrigation regimes in rice, *i.e.* well-watered (WW), moderate dry-w*et al*ternate irrigation (MDWA); when the soil water potential reached -20 kPa soil was again rewatered) and severe dry-w*et al*ternate irrigation (SDWA); soil was re-watered when the soil water potential reached -40 kPa), the treatments were imposed from 7 days after heading to maturity and the results showed that compared with WW, MD significantly increased, whereas SD significantly reduced the seed setting rate and 1000-grain weight. Lu *et al.* (2001) studied at China the effect on rice (cv. Nipponbare) subjected to four irrigation treatments (continuous flooding and intermittent irrigations I0, I1 and I2 in which plants were irrigated when the soil water potential fell below 0, -10 and -20 kPa, respectively, at soil depth of about 5 cm). The results showed that the reduction in soil water potential to about -10 or -20 kPa did not significantly affected the number of grains and the percentage of ripened grains. In rice, Terashima *et al.* (2003a) [44] found that serious lodging occurred in the field plots which were submerged continuously and less lodging was recorded in the field plots with more frequent and longer drainage treatment because a higher value of pushing resistance was recorded in the field plot drained more frequently and for a longer duration. Terashima *et al.* (2003b) [45] from his experiment found that in DSR due to improvement of anchoring ability of rice roots caused by increased soil hardness and proper drainage increases root lodging tolerance. Growth and yield attributes are negatively correlated with moisture stress.

Irrigation scheduling and water use

Wang *et al.* (2002) [46] and Bouman *et al.* (2005) [9] concluded that potential yield of any crop, it must not be allowed to suffer from water stress at any critical growth stage. But, water should also 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. Aerobic rice systems can reduce water application by 44 per cent relative to conventional transplanted systems, by reducing percolation, seepage and evaporative losses, while maintaining yield at an acceptable level (6 mg ha^{-1}). Singh *et al.* (2005) [42] reported that after germination of direct seeded rice (DSR), irrigation can be delayed for around 7-15 days depending on soil texture. Delayed irrigation facilitates deeper rooting and makes seedlings resistant to drought. Watre requirement and ponding of water requirement is very low in case of DSR, irrigation frequency of 3-7 days after the disappearance of water from the field can be practiced. Under limited water supply and drought situations, irrigation can be delayed up to 10-15 days, but care should be taken that irrigation is crucial once tillering has begun An experiment was conducted by Husain *et al*. (2008) [17] at Kanpur, Uttar Pradesh on sandy loam soil to study the effect of irrigation schedules on yield and water use in rice. The irrigation schedule having three days drainage period yielded higher rice with maximum water use efficiency compared to continuous sub-mergence or sub-mergence at critical stages (tillering, panicle initiation, flowering and milking). The irrigation schedule having four or five days drainage periods was found to be detrimental. Balasubramanian *et al.* (2001) [4] conducted a field experiment at Tamil Nadu Agricultural University, Coimbatore, India, with nine levels of irrigation and found that grain yield was the highest with irrigation of 5-cm depth at 1 day after the disappearance of ponded water in direct seeded rice and transplanted rice. Water use was the maximum with transplanted rice due to extended land preparation and nursery raising. Whereas in field experiments conducted on DSR to study effect of different water management practices on water use, the results revealed that the WUE was resulted optimum when submergence was done continuously at depth of 2.5 cm along the complete cropping period as the irrigation schedule was not significantly different from 5 cm depth (Balasubramanian and Krishnarajan, 2001b) [3]. Nearly 25 per cent of irrigation water was saved when submergence of crop was done with 2.5 cm throughout the crop as and when compared to application of 5 cm depth one day after disappearance of ponded water for transplanted rice. The same treatment also resulted in higher water use efficiency (Balasubramanian and Krishnarajan, 2000) [2]. On the basis of a field study on rice using three irrigation regimes *viz*., continuous water submergence (I1), one day drainage (I2) and three day drainage (I3), conducted for two years at New Delhi, Ramakrishna *et al.* (2007) [34] reported that field water use efficiency was higher in case of I2 which needed 33.3 per cent less water than I1. Parihar (2004) [32] from Bilaspur (Chhattisgarh), reported that rice irrigated at 1, 3, 5 and 7 days after infiltration of applied water required 116.63, 110.87, 109.07 and 97.93 cm of water and resulted in 47.03, 47.89, 45.65 and 47.08 kg/ha/cm of water use efficiency. In Iran, Rezaei *et al.* (2009) [35] concluded on the basis of a trial conducted on rice with 3 different irrigation managements (full irrigation, 5 and 8 day interval irrigation) that increasing interval irrigation decreased water use, but increased water productivity in 5 and 8 day interval irrigation by 40 and 60 per cent, respectively, in comparison to full irrigation, without any yield loss. On clay loam soil in Punjab, India, Yadav *et al.* (2011) [47] conducted field experiment during year 2008 and 2009 to study the irrigation water use and water productivity of dry DSR. Irrigation treatments of 20, 40 and 70 kPa at 18-20 cm soil depth were four irrigation levels based on soil matric tension and ranging from saturation to alternate wetting and drying (AWD) with found that irrigation water productivity was higher in AWD than in daily irrigated treatments. Due to large reductions in irrigation water amount from 40 and 70 kPa irrigation schedules, there was reduction in the grain yield. There was a large effect of both treatments on irrigation water productivity (WPI), which ranged from 0.3 to 1.6 g/kg in 2008 and from 0.2 to 1.4 g/kg in 2009. In both the years, WPI irrigated at 20 kPa was significantly higher than all other treatments. Input water productivity (WPI+R) was much lower than WPI in the respective treatments each year due to the large amount of rainfall each year, which ranged from 0.22 to 0.58 g/kg in 2008 and from 0.22 to 0.63 g/kg in 2009. The four water management practices were applied by Matsuo and Mochizuki (2009) to rice in Japan *viz*. 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 resulted that total water applied was was 2145 mm in CF, 1706 mm in AWD, 804 mm in A15 and 627 mm in A30. Kukal *et al.* (2005) [24] concluded from a trial on rice at Ludhiana that irrigation at 160+20 cm soil matric suction helped in saving 30-35 per cent of irrigation water as compared to that used with the 2-day interval irrigation. Rainfall pattern and time of occurrence are another major deciding factors in irrigation water use and resulting savings (Saharawat *et al*., 2010) [37].

Conclusion

Review of the results presented in the foregoing sections reveal that the effect of different research methods and irrigation scheduling were not uniform at all the agro-ecological situations and years. It can be concluded that comparable yields of DSR can be obtained by adopting proper irrigation management. DSR saves irrigation water but grain yield was affected differently depending upon the timings as well as pattern of rainfall, water and crop management and soil type.

Future line of research

An equal or higher yield is possible in direct seeding provided the harvest index (HI) of an aerobic rice variety for direct seeding is developed. Hence, it is premature to conclude that the direct seeding results in lower productivity than that of conventional practice. Appropriate cultivar of DSR could include traits such as early vigour, optimal grain filling and high HI. Both agronomic management and a suitable cultivar with apposite character are needed to attain utmost potential under DSR.

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