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Management interventions to enhance water productivity in dry-seeded rice (*Oryza Sativa* L.)

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Abstract

Rice (*Oryza sativa* L.) is grown in alluvial irrigated tract of north-west India due to high productivity and profitability. Rice is the major source of calories for half the world'spopulation as well as in our country (Roy and Bisht, 2012).However, large amount of water input in rice culture has led to over-exploitation of groundwater as indicated by alarming fall in water table. Average fall in water table in Punjab and Haryana state has been more than 0.75 m year-1 in the last decade (Minhas et al. and Humphreys et al. 2010). Thus, there is a need to explore alternate techniques that can sustain rice production and are resource conservative. On the face of global water scarcity and escalating labour rates, when the future of rice production is under threat, direct seeded rice offers an attractive alternative. In this regard, dry-seeded rice (DSR) is one option that can help in saving water, energy, labor and time. Management interventions that reduce irrigation water and increase water productivity (WP) are required in dry-seeded rice. Irrigation scheduling, tillage and short duration cultivars are some of the interventions in this regard. Irrigation scheduling aimed at eliminating over or under irrigation and ensures optimum yields with high water productivity. Tillage affects crop growth by altering soil edaphic environment. Rice plants are unable to utilize soil water in the deeper layers because of shallow root system. Deep tillage has emerged as a better option to improve deep root growth (advantageous for water extraction during drought in upland rice) of rice cultivars. Based on the existing evidence, present paper reviews the management interventions to enhance water productivity in dry-seeded rice.

Highlights

- Deep tillage enhanced productivity of dry seeded rice in irrigated subtropical environments.
- Tillage gains on productivity is greater in in-frequent irrigation regimes than frequent irrigation regimes.
- Short duration cultivars in rice saves more water than medium or long duration cutivars.

Keywords: Dry-seeded rice, water productivity, irrigation scheduling, tillage, short duration cultivars,

Rice (*Oryza sativa* L.) is an important cereal food for more than half of the global population. About 55 per cent of the rice area is irrigated that accounts for 75 percent of the rice production in the world (Bouman 2001). Rice is a major user of freshwater accounting for approximately 50 per cent of the total diverted fresh water in Asia. Irrigated lowland rice is the most important agricultural ecosystem in Asia, and the food security of most of its population depends on it. The irrigated rice-wheat (R-W) cropping system of north-west India is fundamental to India's food security (Timsina and Connor 2001). Productivity and profitability of rice is high under alluvial irrigated tract of north-west India and groundwater is the primary source for irrigation. Flood-irrigated rice utilizes two or three times more water than other cereal crops such as maize and wheat. The water productivity (WP) of rice in terms of evapo-transpiration (ET) is not different from other C_3 cereals such as wheat

(Table 1). However, large amount of water input in rice culture is due to water requirements for puddling and losses associated with continuous flooding such as seepage and deep percolation losses to ground water. Seepage and percolation losses vary from 25 to 85 per centage of total water input depending on soil type and water table 25-50 per cent in heavy soils with shallow water tables and 50-85 per cent in coarse-textured soil with deep water table depth. DSR reduces the need for nursery preparations and transplanting.thereby reducing the production cost (Singh *et al*. 2012).

Table 1: Amount of water evapo-transpired (liters) to produce one kilogram of major cereals

Crop	Photo-synthesis type	Maximum	Minimum	Average
Rice	C_3	1667	625	917
Wheat	C_3	1667	588	917
Maize	C_4	909	317	556

Source: Zwart and Bastiannssen (2004).

Unproductive losses of water in traditional rice cultivation resulted in alarming fall in water table that threatens sustainability of rice production. This fall has resulted in increased energy requirement and cost of pumping groundwater, increased tube well installation cost and deteriorated the ground water quality (AICRP 2009, Kamra *et al*. 2002). Thus, there is a need to explore alternate techniques that can sustain rice production and are resource conservative.

On the face of global water scarcity and escalating labour rates, when the future of rice production is under threat, direct-seeded rice offers an attractive alternative (Farooq *et al*. 2011). Direct sowing of rice refers to the process of establishing a rice crop from seeds sown in the field rather than transplanting seedlings from the nursery. At present, 23 per cent of rice is direct-seeded globally (Rao *et al*. 2007). Direct-seeded rice is a resource conservation technology as it uses less water with high efficiency, incurs low labour expenses and is conducive to mechanization (Bhuiyan *et al*. 1995). Low wages and adequate water favors transplanting, whereas high wages and low water availability suit direct-seeded rice (Pandey and Velasco 2005). Direct-seeded rice can be categorized as (1) Wet, in which sprouted rice seeds are broadcast or sown in lines on pudddled soil (2) Dry, in which dry rice seeds are broadcast on unpuddled soil and (3) Water seeding, in which seeds are broadcast in standing water condition. Dry seeding of rice with subsequent aerobic soil conditions avoids water application for puddling and maintenance of submerged soil conditions, and thus reduces the overall water demand (Bouman 2001, Sharma *et al*. 2002). Dry-seeded rice (DSR) provides an opportunity for earlier crop establishment to make better use of early season rainfall and to increase crop intensification in some rice based system (Tuong 2000).

Table 2: Classification of direct-seeded rice system

Direct-seeding method	Abbre-viations	Seedbed conditions	Seed environ-ments	Depth of seeding
Direct seeding in dry bed	Dry-DSR	Unpuddled	Aerobic	0-5 cm
Direct seeding in wet bed	Wet-DSR	Puddlled	Anaerobic	Various
Direct seeding in standing water	Direct-WS	Standing water condition	Anaerobic	5-10 cm in standing water

As soil water dynamics in dry-seeded rice is different from that of puddle transplanted rice, this is likely to affect water and nutrient uptake, and ensuing growth and crop yields. In semi-arid subtropical climatic conditions, dry-seeded rice is expected to respond (like maize) to changes in soil physical environment caused by deep tillage resulting in improved crop productivity. Deep tillage has emerged as a better option to improve deep root growth (advantageous for water extraction during drought in upland rice) of rice cultivars. Tillage under intensive cropping system has the additional challenges of ensuring high water use, nutrient use and energy use efficiencies through deeper and denser crop rooting (Gajri *et al*. 2002). In addition, duration of the cultivar is likely to influence irrigation and tillage responses of dry-seeded rice. Longer duration of the crop leads to higher number of irrigations and hence lower irrigation water use efficiency.

Management interventions to enhance water productivity in dry-seeded rice

Irrigation effect

Water is one of the essential inputs for crop production as it affects plant development by influencing its vital physiological processes. For realizing potential yield of any crop, it must not be allowed to suffer from water stress at any of the critical growth stages. Water stress, especially at reproductive stages, may substantially reduce the yield (O'Toole 1982). On the other hand, water should also be utilized efficiently for getting higher yield per unit of water applied. Thus, proper scheduling of irrigation should be aimed at eliminating over- or under- irrigation and ensuring optimum yields with high water productivity. Water management has a significant influence on rice growth, grain production and water productivity. There is a possibility of reducing water requirement of rice without affecting grain yield in comparison to continuous submergence. Intermittent irrigation appears to be as effective as continuous submergence. Several studies reported a positive effect of intermittent aerobic conditions on flooded rice growth (Lin *et al*. 2005) indicating that continuous flooding may not be the best method of irrigating rice (Horie *et al*. 2005). Rice is significantly more sensitive to water deficit than other grain crops (Angus *et al*. 1983, Tanguiling *et al*. 1987, Inthapan and Fukai 1988). Flood-irrigated rice utilizes two or three times more water than other cereal crops such as wheat and maize. The dry-seeded rice (DSR) is a resource conservation technology as it requires less irrigation water, incurs low labor and is suitable for mechanization (Bhuiyan *et al*. 1995). In tropical monsoon Asia, direct-seeded rice is often a rainy season crop. Seeds are broadcast at the beginning of the monsoon season and germinate when rainfall is adequate to moisten the soil (Lantican *et al*. 1999). Aerobic rice is characterized by sowing of dry seed with the onset of monsoon rains and subsequently irrigating the crop using tank, canal or ground water. Aerobic rice offers scope to advance crop establishment and to increase the effective use of early season rainfall (Tuong 1999). Humphreys *et al*. (2010) reported that information on irrigation and water management in dry-seeded rice is scarce. Bouman (2001) reported that the potential water savings at the field level when rice can be grown as an upland crop are large, especially on soils with high seepage and percolation rates. Bhuiyan *et al*. (1995) and Tuong (1999) suggested that direct-seeding (wet and dry seeding) could be an option to shorten the land preparation period. Thus, minimizing land preparation duration can potentially reduce the water input for rice cultivation (Tuong 1999). Dawe (2005) reviewed that substantial amount of water savings are possible from direct-seeded rice. Castaneda *et al*. (2003) reported a saving of 73 per cent water in land preparation in aerobic rice system. Bouman et al. (2005) studied that on average, aerobic fields used 190 mm less water in land preparation, and had 250-300 mm less seepage and percolation, 80 mm less evaporation, and 25 mm less transpiration than flooded fields. Jalota *et al*. (2006) observed that reducing evapo-transpiration (ET) through deficit irrigation and identification of the most sensitive crop growth stage to water stress has been reported as one of the way to enhance crop water productivity (CWP).

The rice–wheat productivity is plateauing and total factor productivity is declining because of a fatigued natural resource base and therefore, sustainability of this cropping system is at risk (Saharawat *et al*. 2010). Traditional rice-wheat system is the most input-intensive process and therefore more efficient alternatives are urgently needed. As part of our comprehensive programme, we have been addressing these issues through designing and testing various alternative options (Jat *et al*. 2009). Shekara *et al*. (2010) studied the response of aerobic rice to different irrigation regimes based on irrigation water (IW) to cumulative pan evaporation (CPE) ratios of 2.5, 2.0, 1.5 and 1.0 at Mandya, Karnataka during dry season of 2005 and 2006. It was found that irrigation scheduled at IW/CPE ratio of 2.5 recorded higher grain yield (6.2 and 6.6 t ha^{-1} during 2005 and 2006) and required more water (154.8 cm) leading to lower water productivity (41.3 Kg ha^{-1} cm-^{1}) whereas irrigation scheduled at IW/CPE ratio of 1.0 required less water (91.84 cm) with higher water productivity (52.1 Kg ha^{-1} cm^{-1}). Ramamoorthy *et al*. (1996) studied the response of upland direct-seeded rice to different soil moisture regimes at National Pulse Research Centre, Pudukkottai (Tamilnadu) for 3 seasons during 1992 and 1993. Total water requirement was more under high moisture regimes (2.00 IW/CPE) and the water productivity was highest under medium moisture regimes (1.50 IW/CPE) than other regimes and saving of 13 per cent irrigation water than high moisture regimes. There was little adverse effect of moisture stress on growth of rice in low regimes or rainfed compared with medium and high moisture regimes. Sudhir-Yadav *et al*. (2011) observed the response of dry direct-seeded rice to different irrigation levels at Ludhiana during 2008 and 2009 on a clay loam soil. The treatments consisted of four irrigation levels based on soil water tension ranging from saturation to alternate wetting and drying (AWD) with irrigation treatments of 20, 40 and 70 KPa at 18-20 cm soil depth. The experiment results revealed that the irrigation water use efficiency was higher in alternate wetting and drying (AWD) than daily irrigated treatments. It was also found that irrigation scheduling at 20 KPa soil water tension results in 33-53 per cent saving of irrigation water in dry direct-seeded rice than transplanted rice. The yield component of DSR and PTR were similar when irrigation was scheduled daily and at 20 KPa soil moisture tension. At Asian Institute of Technology in Thailand, Thabonithy and Murali (1994) reported that dry seed broadcasted on unpuddled soil was the best rice cultivation method on heavy clay soils to save water and labor cost.

In China, the water use for aerobic rice production was 55-56 per cent lower than the flooded rice with 1.6-1.9 times higher water use efficiency. Bouman *et al*. (2005) carried out experiments at Philippines and reported that water inputs in aerobic rice system were 30-50 per cent less than in flooded system with yields 20-30 per cent lower, with a maximum of about 5.5 t ha^{-1} and evaporation losses were reduced on the order of 50-75 per cent which results in higher water productivitywith aerobic rice than flooded rice. Yang *et al.* (2005) found similar results for aerobic rice on water use efficiency and yield in China. Fujii (1995) from Malaysia reported less water expense under dry direct-seeded rice as compared to puddled transplanted rice, due to shortening of irrigation period. Bouman (2001) claimed the potential water savings at the field level in upland rice due to less evaporation since there is no permanent ponded water layer, and the amount of water used for puddling is eliminated altogether. Gill *et al*. (2006b) observed the response of rice to different seeding techniques at Ludhiana during rainy season of 2002 and 2003. It was found that the water productivity in wet direct-seeded rice in 2002 was 35 Kg ha^{-1} cm^{-1} and in 2003 was 76 Kg ha^{-1} cm^{-1} compared with that of transplanting rice being 31 Kg ha^{-1} cm^{-1} and 57 Kg ha^{-1} cm^{-1} clearly indicating better water productivity under direct-seeded rice. Experiments from Northwest India using direct-seeded rice into non-puddled soils found 35-57 per cent water savings (Sharma *et al*. 2002, Singh *et al*. 2002). In these trials, soils were kept near saturation or field capacity unlike the flooded conditions used in puddled-transplanted systems. Sudhir-Yadav *et al*. (2010) carried out experiment at Ludhiana during 2008 and reported that water productivity in dry-seeded rice (DSR) was highest (71 Kg ha^{-1} cm^{-1}) with irrigation at 20 KPa followed by puddled transplanted riced (PTR) irrigated at 20 KPa (50 Kg ha^{-1} cm^{-1}) and least in daily irrigated PTR (28 Kg ha^{-1} cm^{-1}). Kato *et al*. (2009) in Japan found that dry direct-seeded rice, when irrigated with a sprinkler system, produced equal or higher yield than transplanted or direct-seeded rice under a flooded system with total water savings ranging from 21 to 74 per cent. Mann *et al*. (2004) reported 25 per cent saving of water with an average of 1410 mm irrigation water used by direct seeding of rice over conventionally transplanted crop that used 1850 mm of irrigation water in Pakistan, Punjab. Kumar (2002) carried out an experiment on loamy sand soil of Ludhiana, Punjab and the experiment result revealed that 28-33 per cent saving of irrigation water in direct-seeded rice as compared to transplanted crop. Kaur (2004) also recorded about 20 per cent less water expense under direct-seeded rice than its transplanting in sandy loam soil at Ludhiana.

Singh *et al*. (2002) carried out an experiment on a sandy loam soil at New Delhi to quantify the effects of different soil moisture tension (ranging from saturation to 40 KPa) on water productivity of dry-seeded rice under raised bed conditions. The experiment results revealed that irrigation water use efficiency was higher at 20 KPa soil moisture tension (37 Kg ha^{-1} cm^{-1}) than saturation and 40 KPa soil moisture tension. Borell (1991) at Queensland in Australia reported that rice grown on 1.5 m wide raised beds with water maintained in the furrow between bed used 33 per cent less water than the flooded treatments as evaporation from saturated soil surface was significantly less than that from free water surface throughout crop growth. Balasubramanian and Krishnarajan (2000) conducted experiment to evaluate the effect of different ponding depths on water productivity and yield of direct-seeded rice. It was reported that in direct-seeded rice continuous submergence with 2.5 cm water depths throughout the crop period gave good yield and saved nearly 25 per cent of irrigation water as compared to application of 5 cm depth of irrigation. Narayansamy *et al*. (1993) from Tamilnadu reported that direct-seeded rice used 275-283 mm less water than transplanted rice in clay loam soils. According to Xiaoguang *et al*. (2005) the water productivity of aerobic rice was higher or at a par with that of low land rice cultivars under flooded conditions, reaching value of 60-80 Kg ha^{-1} cm^{-1}. Bhushan *et al*. (2007) compared direct-seeded rice and puddled transplanted rice on a silty loam at Modipuram and the direct-seeded rice was sown on the same day as the nursery for puddled transplanted rice. They used the same irrigation scheduling rules for both establishment methods, daily irrigation for the first 2 weeks after transplanting or sowing, followed by irrigation when hairline cracks appeared and it was found that 20 per cent reduction in irrigation water with direct-seeded rice compared with puddled transplanted rice in both the poorly and well-distributed rainfall years. Sharma *et al*. (2005) also reported similar yields (more than 6.5 t ha^{-1}) for direct-seeded rice and transplanted rice on a sandy loam soil at Modipuram with similar irrigation management. Jat *et al*. (2009) also found reduced water input (irrigation plus rainfall) by 9-24 per cent with direct-seeded rice in comparison with puddled transplanted rice. Tabbal *et al*. (2002) reported that direct-seeded rice required 19 per cent less water than puddled transplanted rice during the crop growth period and increased water use efficiency by 25-48 per cent with continuous standing water conditions. Cabangon *et al*. (2002) compared the water input and water productivity of transplanted and direct-seeded (dry and wet seeded) rice production system and reported that dry-seeded rice had significantly less irrigation water and higher water use efficiency as compared to wet seeded and transplanted rice production system.

Ali *et al*. (2006) observed that during both wet and dry seasons, direct-seeded rice yielded the same as transplanted rice, and dry seeding had a higher benefit: cost ratio. Gupta *et al*. (2003) reported 10 per cent higher yield in direct-seeded rice than transplanted rice. Nayak and Lenka (1989) reported that direct-seeded rice produced 4.3 per cent higher grain yield and 7.1 per cent more straw yield than transplanted rice. The increase in yield was due to more effective tillers m^{-2}in direct-seeded rice. Sudhir-Yadav *et al*. (2011) reported that yields of both direct-seeded rice and transplanted rice declined when the soil was allowed to dry to higher tensions than 20 KPa and yield of direct-seeded rice declined more rapidly as tension increased to 40 KPa and 70 KPa. The water use efficiency of aerobic rice is typically double that of traditional rice culture grown under optimum conditions in the same climate (Bouman *et al*. 2006, Feng *et al*. 2007, Yang *et al*. 2005). Sharma *et al*. (2005) reported that unpuddled and transplanted method of establishment of rice gave statistically similar yields due to almost same crop stand under unpuddled and transplanted condition. Singh *et al*. (2008) observed that the best varieties only produced around 4.5 t ha^{-1} when dry seeded and irrigated at a soil water tension of 20 KPa, with about a 10 per cent yield decline when the irrigation threshold tension was increased to 40 KPa and reported that irrigation at soil water tensions of 20 and 40 KPa reduced input water by 23 and 32 per cent, respectively, in comparison with irrigation to keep the soil close to saturation. At Aduthurai, Tamil Nadu similar grain yields were recorded in direct seeded and transplanted rice (Muthukrishnan 1997). Goel and Verma (2000) reported that mean grain yield of direct and transplanted rice were of same magnitude (5.31t ha^{-1}) at Karnal, Haryana. The yield attributing characters such as panicles m^{-2} were significantly more in direct-seeded rice whereas panicle length and 1000 grain weight were at par with transplanted rice. For instance substantially higher paddy yield was recorded in direct-seeded rice (3 t ha^{-1}) than transplanted rice (2 t ha^{-1}), which was attributed to the increase panicle number, higher 1000 kernel weight and lower sterility percentage (Dingkuhn *et al*. 1991, Sarkar *et al*. 2003). Kumar and Ladha (2011) reviewed and found that the yield of direct-seeded rice (dry) in India were significantly lower (9.2-28.5 per cent) than flooded rice. Sharma *et al*. (2002) observed that yield of DSR declined significantly by 15 per cent as the threshold for irrigation increased from 10 to 20 KPa on sodic silt loam soil at Modipuram. Yambo and Ingram (1988) reported that a yield reduction due to water stress from 25-45 per cent for 5-10 days of water deficit and 88 per cent for 15 days of water stress. Thus rice yields were affected more by duration of drought. Choudhury *et al*. (2007) carried out an experiment at New Delhi during rainy season of 2002 and 2003 on aerobic rice cultivated on raised bed under different soil moisture regimes (field capacity, 20 and 40 KPa tension). The yield was considerably less on raised bed, varying from 12 to 24 per cent at field capacity to 40 to 46 per cent in beds irrigated at 40 KPa soil water tension compared with the direct seeded flat land at 20 cm row spacing.

Dry matter accumulation is an important character which expresses the photosynthetic efficiency of plants and influences the yield of a crop. In rice, water uptake, dry matter production in shoot, and root length were largely suppressed under severe water stress compared with mild stress. Crop canopy decreases with increased soil moisture stress. The reduction in leaf area results in reduced light interception, which reduced total crop photosynthesis and hence total biomass production. Kumar (2002) from PAU reported that direct-seeded rice produced significantly more dry matter than that the transplanted rice (TPR) at all growth stages and at maturity which was due to more plant population per unit area compared to TPR. The increase in dry matter was 56.5, 32.3, 18.2 and 15.9 per cent over TPR at 50, 75 and 100 days after sowing and maturity, respectively. Shekara *et al*. (2010) reported that irrigation scheduled at IW/CPE ratio of 2.5 recorded significantly higher plant height, dry matter accumulation, and more number of productive tillers, filled spikelet's and 1000 grain weight. Similar results were reported by Thomas *et al*. (2003). This might be due to the fact that increased frequency of irrigation led to effective uptake of water and nutrients. Sudhir-Yadav et al. (2011) observed that crop performance in terms of tiller density, leaf area index and growth rate was better in direct-seeded rice than transplanted rice with daily and 20 KPa irrigation scheduling. However, crop performance was poorer in direct-seeded rice than transplanted rice at higher (40 and 70 KPa) irrigation thresholds. Venkateswaralu (1977) reported that the direct-seeded rice gave significantly more productive tiller m^{-2} (256) than the transplanted rice (204) possibly due to greater plant population rather than more tillers per plant. The direct-seeded rice in moistened soil produced taller plants, more dry matter, lower chlorophyll contents and specific leaf weights and more panicles and sterile spikelets than transplanted rice (Sarkar *et al*. 2003). Yield attributes were affected by water stress treatments beyond 20 KPa. Sudhir-Yadav *et al*. (2011) observed that the rates of biomass, leaf area and tiller production in DSR showed much greater sensitivity to the higher water stress treatments (40 and 70 KPa) than PTR. After maximum tillering, greater tiller mortality and reduced crop growth rate in direct-seeded rice may have been the result of higher intraspecific competition for light, water and nutrients due to the higher plant density, especially in the alternate wetting and drying treatments (Dingkuhn *et al*. 1990). Yamboo and Ingram (1988) reported a yield reduction due to water stress from 25-45 per cent for 5-10 days of water deficit and 88 per cent for 15 days of water stress. Thus, rice yields were affected more by the duration of drought. Miyagawa *et al*. (1998) reported that yield of direct sown rice and transplanted rice did not differ significantly in irrigated condition due to profuse vegetative growth and a large number of spikelets per panicle in North East Thailand. Dingkuhn *et al*. (1990) recorded more dry matter accumulation in direct-seeded rice as compared to transplanted rice and the grain yield of direct-seeded rice and transplanted rice were similar when irrigation was scheduled daily and at 20 KPa soil moisture tensions. Direct-seeded rice was found advantageous in securing more value of yield attributes, viz., number of panicles m^{-2}, number of filled grains $panicle^{-1}$ and test weight (Budhar *et al*. 1990).

Alexander and Martin (1995) also reported non-significant difference between transplanted rice and direct-seeded rice with respect to plant height. The plant height also did not differ significantly among the direct seeding treatments at any stage of crop except when the crop was only 30 days old. The plant height at 30 and 60 days after sowing/transplanting was significantly higher in transplanted rice as compared to direct-seeded rice. Plant height at 90 days after sowing/transplanting till harvest of transplanted and direct-seeded rice did not differ significantly. Results of most of the field experiments and on-farm trials showed that upon proper management, comparable yield from direct-seeded rice could be secured as that of transplanted crop and this might be the reason as to why majority of the rice growing countries are striving hard to make a shift from transplanted to direct-seeded rice (De Datta and Nantasomaran 1990, Ramaswamy *et al*. 1994, Peng *et al*. 1996). Rice systems that increase production using less water are urgently needed, especially in Northwest India where ground water is over exploited. There is also an urgent need to develop efficient irrigation schedules for the selected alternative tillage and rice establishment methods such as dry-direct seeded rice.

Tillage effect

Tillage affects crop growth by altering soil edaphic environment (Gajri *et al*. 2002). Bouman (2001) suggested that rice could be grown aerobically under irrigated conditions just like upland crops, such as maize and wheat. The lower water-capturing capacity of rice than that of maize under severe stress was characterized by a lower response to the enhancement of the morphological growth of the roots in deeper soil layers and the limited ability of water extraction per unit length of root, especially in the deeper layers. Rice plants are unable to utilize soil water in the deeper layers because of shallower root system (Angus *et al*. 1983, Inthapan and Fukai 1988, Kondo *et al*. 2000). Deep tillage has emerged as a better option to improve deep root growth of rice cultivars. Deep root development is advantageous for water extraction during drought in upland rice (Puckridge and O'Toole 1981, Yoshida and Hasegawa 1982, Lilley and Fukai 1994). Deep tillage has been suggested to improve crop production through enhancing water and nutrient uptake under drought conditions. Kato *et al*. (2006) observed that under field condition, high mechanical impedance in the hard pan layer prevents rice roots from penetrating into deeper soil layers. Not only water itself, but increased mechanical impedance from soil as drought progresses, greatly affects deep root development in rice grown under drought conditions in the field (Cairns *et al*. 2004). Bennie and Botha (1986) reported that deep tillage break up high density soil layers, improve water infiltration and movement in the soil, enhance root growth and development and increase crop production. Deep tillage can break a hardpan with as much as 3 MPa of mechanical impedance, which often develops just below ploughing depth in upland rice fields (Price *et al*. 2002).

Kato *et al*. (2007) studied the response of upland rice to different agronomic practices (deep tillage and conventional tillage) at Nishitokyo, Japan during summer season (April-October) of 2001-02 and 2002-03. The experiment results revealed that the penetrometer resistance at around 30 cm depth in deep tillage was much lower than conventional tillage during the vegetative stage and after harvest. Penetrometer resistance in conventional tillage at 30-40 cm depth ranged from 1.8-2.3 MPa. It was also observed that under water deficit condition in 2003, the deep root length and deep root weigh was higher in deep tillage as compared to conventional tillage. The hard pan formed due to normal puddling at 15-20 cm soil layer restricted the growth of root below 15 cm soil layers (Kaddah 1976, Van Ouwerker and Raats1986).

Thangaraj *et al*. (1990) also observed that root growth decreased with increasing soil mechanical impedance. Bazaya *et al*. (2009) reported the response of direct-seeded rice to different planting methods (Rotavator seeding, Zero till seeding and Conventional seeding) at Varanasi, India during the *kharif* seasons of 2002 and 2003 and observed that higher bulk density (penetration resistance) and lower infiltration rate in zero till seeding as compared to rotavator and conventional seeding.

Kato *et al*. (2007) reported that deep tillage greatly enhanced grain yield and yield attributing parameters under water deficit condition and observed that the grain yield in deep tillage was 20 per cent higher than in conventional tillage. Total dry matter at maturity was significantly increased by deep tillage with higher panicle number, fertility and harvest index. It was also found that higher panicle numbers in deep tillage (251 m^{-2}) as compared to conventional tillage (224 m^{-2}). Some findings suggest that direct-seeded rice achieves higher tiller density, leaf area, and vegetative biomass (Dingkuhn *et al*. 1990, Schnier *et al*. 1990). Ranjit and Suwanketnikom (2005) conducted an experiment at Khumaltar, Nepal during the summer season of 2002 and observed that the grain and straw yield in conventional tillage was 5.6 and 7.4 t ha^{-1} as compared to 5.2 and 6.4 t ha^{-1} in minimum tillage. However, conventional and minimum tillage did not affect the yield attributes. Bazaya *et al*. (2009) also reported that highest grain and straw yield (3.8, 5.5 t ha^{-1}) was in conventional seeding as compared to ratavator seeding (3.6, 5.2 t ha^{-1}) and zero till seeding (3.1, 4.6 t ha^{-1}) with higher harvest index.

There are visible differences in rooting pattern of direct-seeded and transplanted rice plants. Akhtar and Quereshi (1999) reported a depthwise increase in root distribution from 12 to 20 cm and a yield benefit of 30 per cent with adoption of deep tillage prior to transplanted rice. Kundu *et al*. (1996) observed that primary tillage treatments significantly influenced root mass distribution of rice in different soil layers. The soil layers at 0-13, 13-26 and 26-39 cm contained 89, 9 and 2 per cent respectively of total root mass under the 15 cm deep tillage, but 78.6, 15.6 and 5.8 per cent, respectively of the total root mass under the 40 cm deep tillage. Naklang *et al*. (1996) observed that direct-seeded rice had more root biomass than transplanted rice. Chen and Liu (2002) reported that a four-fold rise in water export when pre-existings plough soles are breeched with deep tillage.

Yoshida *et al*. (1981) reported a significant positive correlation between root growth and total biomass production of rice. Kato *et al*. (2007) observed that in deep tillage, soil water content at 89 days after sowing at 40 and 60 cm depths was lower than that in conventional tillage. Bouman et al. (2004) measured soil moisture tension for aerobic field in three consecutive seasons. In the dry season (DS) for all the 3 years, the tension at 15 cm stayed mostly below 30 KPa as imposed by the irrigation treatment. At deeper depth, the soil was wetter than at shallower depth, probably because less water was extracted by the rice root and more capillary rise occurred from the shallow groundwater table. Biswas and Yamauchi (2007) observed that the root growth of DSR remained inhibited up to 6 DAS. However, the root growth is expected to be deeper in case of DSR than PTR. Vigorous growth of superficial roots has been linked with the better performance of high yielding low land adapted cultivars (Morita and Yamazaki 1993). Therefore, in addition to deeper roots, vigorous adventitious surface rooting would be beneficial to improving water uptake efficiencies, especially during reproductive growth stages.

Cultivar effect

Aerobic rice is higher yielding than traditional upland varieties and combine input responsiveness with improved lodging resistance and harvest index (Atlin *et al*. 2006). Achieving high yields under irrigated but aerobic soil conditions requires new varieties of "aerobic rice" that combine the drought-resistant characteristics of upland varieties with the high-yielding characteristics of lowland varieties (Lafitte *et al*. 2002). Alternatively, high-yielding lowland rice varieties grown under aerobic soil conditions, but with supplemental irrigation have been shown to save water, but at a severe yield penalty (Blackwell *et al*. 1985, Westcott and Vines 1986, McCauley 1990).

In China, breeders have produced aerobic rice varieties with an estimated yield potential of 6-7 t ha^{-1} in irrigated lowlands where water is scarce and in favorable rainfed uplands (Wang Huaqi *et al*. 2002). Yields obtained with aerobic rice varieties vary from 4.5 to 6.5 t ha^{-1}, which is about the double of that obtained with traditional upland rainfed varieties and 20-30 per cent lesser than that obtained with lowland varieties grown under flooded conditions (Farooq *et al*. 2009). Genetic improvement for large and deep root system is considered to be an important strategy for improving the water capture and yield stability of upland rice varieties (Mambani *et al*. 1983, Yoshida and Hasegawa 1982). Aerobic rice system uses rice varieties capable of responding well to reduce water inputs in non-puddled and non-saturated soils (Atlin *et al*. 2006, Peng *et al*. 2006). Therefore, identification of physiological traits contributing to superior yield performance of crop plants under aerobic condition will be useful in developing rice varieties suitable for aerobic cultivation. Aerobic rice varieties should have low tillering, thicker and deep penetrating roots, and bigger culms with thick walls, erect stems and leaves that allow light penetration to lower canopy and can be adapted to denser planting (Kim *et al*. 1995, Won *et al*. 1996). Bouman *et al*. (2005) demonstrated that the capacity to retain spikelet fertility and hence the harvest index is one of the successes of aerobic adaptation of these newly developed aerobic rice varieties. Root characteristics such as, density, length, and thickness and greater root penetration are important for aerobic rice varieties (Fukai and Cooper 1995, Nguyen *et al*. 1997). Watanabe (1997) reported that early emergence of a vigorous crop stand provides better root anchorage and improves nutrient absorptive capacity. Early heading rice varieties with better drought tolerance are better suited for dry-seeded rice, such as IR36 (105 days duration) good drought tolerance variety (Gines *et al*. 1978). Dingkuhn *et al*. (1991) reported that increased plant density and avoiding transplanting shock by using DSR resulted in more biomass than in TPR. Lodging has been observed more often in DSR than TPR rice fields in recent years. In this regard, intermediate plant heights, large stem diameters, thick stem walls and high lignin contents are lodging resistant characteristics (Mackill *et al*. 1996).

Deep roots are a key trait for improving drought resistance in rice in upland environments because they contribute to water uptake from deeper soil layers during drought (Araki and Iijima 2005, Lilley and Fukai 1994, Yoshida and Hasegawa 1982). Azhiri-Sigari *et al*. (2000) carried out pot experiment and characterized deep root system development using three root traits: root to shoot ratio, deep root ratio (ratio of deep root mass below 30 cm depth to total root mass), and specific root length (root length per unit root weight). Root length density in deeper layers has been identified as a factor that determines the drought tolerance of rice genotype (Yoshida and Hasegawa 1982). Kato *et al*. (2006) studied the root system of six rice cultivars) in upland field conditions under different water regimes (irrigated and intermittent drought conditions during panicle development) at Nishitokyo, Japan in two years 2004 and 2005. It was found that deep root length and deep root ratio was highest in IRAT109 followed by Yumeno-hatamochi in both years. Jaggi (1987) at Raipur in M.P. studied the root densities of different varieties; Poorwa, MW 10, Usha, Safri 17 and Mahasuri in depthwise soil layers and found that Safri had a maximum root density at 0-10 cm depth and that MW10 and Poorwa had the lowest.

Brar and Bhullar (2014) conducted a field experiment on research farm, Punjab Agricultural University during *Kharif* 2008 to observe the interactive effect of sowing dates, cultivars and weed control practices and found that rice seeded directly on day of nursery sowing produced similar grain yield to transplanted crop. Short and medium duration varieties recommended for transplanted culture are equally good for dry seeding also. Sequential application of pre and post emergence herbicides is desirable for achieving effective weed control in dry seeded rice.

Early vigour is important in direct seeded rice systems (Balasubramanian and Hill 2002, Cairns *et al*. 2009). Zhao *et al*. (2006) reported that rapid early growth increases stand establishment which is important components for high yields in dry-seeded rice. Earlier workers reported that direct-seeded rice had an early maturity by week (Peng *et al.* 1996, Santhi *et al*. 1998). Mahajan *et al*. (2009) observed that irrigation water productivity decreased with the duration of cultivars. Long duration of the crop leads to higher number of irrigations and hence lower irrigation water use efficiency. Reducing varietal duration reduces irrigation water use through decreasing both evapo-transpiration and deep drainage. Gill and Dhingra (2002) revealed that direct sowing of basmati rice may save at least 20 per cent irrigation water mainly due to its 10-15 days earlier maturity than transplanted rice. Earlier flowering in direct-seeded rice leads to shorter crop duration (Farooq *et al*. 2006, Santhi *et al*. 1998). Jalota *et al*. (2009) reported that in short duration variety irrigation water applied was 125 mm less than that in long duration variety. Gill *et al*. (2006a) studied four rice cultivar (PR111, PR115, PR116 and IR64) under direct sown conditions at Ludhiana and found that short duration and early maturity variety (PR115) was suitable in terms of paddy yield and yield attributing parameters as compared with other tested cultivars. At IRRI, Manila, Dingkuhn *et al*. (1991) reported that direct seeding gave more grain yield than transplanted rice, using short duration variety IR-58, but equal or lower yield was observed with medium or long duration varieties. Yoshida (1983) reported the highest paddy grain yield (9-11 t ha^{-1}) with short to medium duration cultivars (115-125 days) such as IR-58 or IR-64 as compared to that obtained from long duration variety (IR-29723-143-3-2). Another study conducted on silt loam soil at Pusa (Bihar) reported that the maturity period was reduced by 7 days in direct-seeded rice as compared to transplanted rice with the same yield level (Thakur 1993). Martin et al. (2007) conducted an experiment at Coimbatore and observed the response of 12 upland rice varieties under aerobic conditions. It was found that the variety PMK 3 with duration of 137 days registered the highest water productivity (70.6 Kg ha^{-1} cm^{-1}) and the White Ponni which matured in 184 days recorded the lowest water productivity (15 Kg ha^{-1} cm^{-1}). Combined amount of rainfall and irrigation water from sowing to harvest varied from 470 to 650 mm, compared with 1200-1300 mm in lowland rice. Compared with lowland rice, water consumption in aerobic rice was lower than 50 per cent and water productivity was 60 per cent higher. Early crop vigour, short stature and short duration improve water productivity in rice.

HD277 and H58 are currently the most extensively grown aerobic rice varieties in China (Wang Huaqi *et al*. 2002). Han Dao (temperate aerobic rice varieties) achieve yields of 4.7-5.3 t ha^{-1} with soil moisture tensions in the root zone going up to 90 KPa and above (Wang Huaqi *et al*. 2002, Yang *et al*. 2005). These two new varieties have stronger drought tolerance, reduced plant height, increased lodging resistance to blast, higher grain yield and better grain quality. At the Indian Agricultural Research Institute (IARI), New Delhi Apo, IR55419-04 (IRRI varieties), Pusa RH10, Pusa 834 (IARI varieties) yielded about 4 t ha^{-1} under aerobic conditions and the water use efficiency of these varieties ranged from 42-47 Kg ha^{-1} cm^{-1} with irrigation at 20 KPa soil water tension, while it was 50-55 Kg ha^{-1} cm^{-1} at 40 KPa soil water tension (Singh and Chinnusamy 2007).

Photoperiod-insensitive cultivars may also perform well under the direct-seeded rice system. Patel *et al*. (2010) reported that the water use efficiency of aerobic rice was significantly higher than that of the rice grown under flooded condition. It was also found that the grain yield of rice under aerobic condition was 27.5 per cent lower than that recorded under flooded condition and the yield gap could be narrowed down by some varieties such as Sahsarang 1, Jaya and aerobic rice line IR 72176 that are more adapted to aerobic conditions. Higher water productivity of aerobic rice compared to other establishment methods has been reported by Belder *et al*. (2007) and Singh *et al*. (2008). Budhar *et al*. (1990) reported increased number of panicles and early maturity in rice under direct seeded condition compared to transplanted rice in case of short duration cultivars. The drought resistant rice variety 'Sahabhagi' (yield about 3.8-4.5 t ha^{-1}, matures in 68 days) especially developed for rainfed areas by IRRI, Philippines. Valarmathi and Leenakumary (1988) observed yield increase in short duration varieties, namely, Jyothi and Jyathi under direct seeded conditions and it was mainly due to increased number of productive tillers per plant compared to transplanted rice. Moletti *et al*. (1992) reported that short duration cultivars were better under dry sowing. Peng *et al*. (1996) reported that water use efficiency was some 25-30 per cent higher for tropical japonica than for indica rice types. Some tropical rice varieties also have a relatively high yield under aerobic soil conditions. Bouman *et al*. (2004) carried out an experiment in Phillipines and reported that the improved upland variety Apo yielded up to 5.7 t/ha and the lowland hybrid rice Magat up to 6 t ha^{-1} in the dry season and it was found that water inputs were 44 per cent lower and water productivity 35 per cent higher.

Bouman *et al*. (2005) conducted an experiment at International Rice Research Institute in Philippines during six seasons in 2001-2003 to observed the effect of different tropical upland varieties (Apo, IR43, UPLR15) under irrigated aerobic conditions during dry season (DS) and it was found that water use efficiency and grain yields were highest in Apo as compared to IR43 and UPLR15. De Datta et al. (1973) grew lowland variety IR20 in aerobic soil under furrow irrigation at the International Rice Research Institute in the Philippines and observed that water savings were 55 per cent compared with flooded conditions. Dingkuhn *et al*. (1987) observed that direct seeding of rice resulted in shorter crop cycle and had better initial growth due to absence of transplanting shock. Seed priming approach has been applied to overcome the drought stress effects in a range of crop species. Harris *et al*. (1999) reported that primed crops emerge faster and more completely, produce more vigorous seedlings, flower and mature earlier, and yield better than non-primed crops. Farooq *et al.* (2006) also reported that for rice sown in aerated soils, seed priming enhances seedling emergence, kernel quality and yield. Aerobic rice culture is expected to offer a substantial reduction in water use without loss of yield (Bouman *et al*. 2006, Haryanto et al. 2008), but the technology is still immature. Bouman and Tuong (2001) observed that most of the water saving technologies, including aerobic rice results in some yield losses. Yun *et al*. (1997) reported that the maximum yield of aerobic rice that has been reported is 30 per cent lower than that of flooded rice. However, it is unclear whether the yield gap is inherent to the two systems or simply a result of the different yield potentials of the varieties that are used. Currently, research is underway to study the water use and yield potential of aerobic varieties under well-defined hydrological conditions (Yang *et al*. 2005). Direct seeding on day of nursery sowing of rice with short or medium duration variety gave rice grain yield similar to transplanted crop and pre and post emergence herbicides is desirable for achieving effective weed control in dry seeded rice.

Conclusion

This review has focused on the effects of improved technologies for rice cultivation systems on components of the water balance, grain yield, and water productivity with respect to irrigation and evapotranspiration (ET). The productivity of rice has stagnated or, in some cases, declined remarkably in both rice–rice and rice–wheat cropping system (Padre and Ladha 2006). DSR with suitable conservation practices has potential to produce slightly lower or comparable yields as that of TPR and appears to be a viable alternative to overcome the problem of water and labour shortage. Despite controversies, if properly managed, comparable yield may be obtained from DSR compared with TPR. If not managed efficiently, weeds may cause partial to complete failure of DSR crops. This transition from TPR to DSR also changes the mineral nutrients dynamics of soil. Research is needed on soil ecology in rice soils. Under different rice production zones across the continents need to develop a site-specific package of production technologies for different rice production systems.

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