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Performance of rice (*Oryza sativa* (L.)) under different rice production systems and water saving irrigation methods: A review

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Abstract
Manual transplanting is the most common practice of rice cultivation in South and South East Asia. In India, 44 per cent area (19.6 M ha) is under transplanting in irrigated lowlands. It is not only time consuming, but also laborious requiring about 30 man days ha^{-1} besides causing drudgery to women folk. In all rice growing countries, there is an acute shortage of human labour during transplanting period due to diversion of labour to non-agricultural sectors resulting in delay of transplanting, reduced yield and lesser profit. To overcome these difficulties in transplanting can be substituted by direct seeding and machine transplanting which could reduce labour needs and increase the yields. Irrigated lowland rice not only consumes more water but also causes wastage of water resulting in degradation of land. In recent years to tackle this problem, many methods of cultivation have been developed. Among the different methods of water-saving irrigation, the most widely adopted is alternate wetting and drying (AWD) irrigation method.

Keywords: Rice production systems, yield, water use efficiency, AWD

Introduction
Rice is one of the greatest water user among crops, consuming about 80 per cent of the total irrigated fresh water resources in Asia, but water is becoming scarce and its availability for agriculture is decreasing because of high competition among different users. In India, 45 million ha area under rice production which is being grown traditionally under flooded conditions. Increasing demand for water and growing population necessitate searching for the water saving rice production system without any adverse effects on yield. Irrigated lowland rice not only consumes more water but also causes wastage of water resulting in degradation of land. In recent years to tackle this problem, many methods of cultivation have been developed. Among the different methods of rice production systems, the available literature on direct seeding (with drum seeder), transplanting with machine and conventional transplanting and water saving methods of Alternate wetting and drying (AWD) and disappearance of ponded water (DPW) are reviewed in this paper.

Rice production systems
Growth characters in different rice production systems
Direct sowing over the puddled field by seed drill (Drum seeder) can be successfully adopted in irrigated lands. The practice can replace transplanting method of rice cultivation without any reduction in yield and yet reducing the cost of cultivation and labour requirement to one third (Pradhan, 1969) [91]. The experiment was conducted in Punjab Agricultural University Ludhiana with clayey loam soils. Drilling sprouted seeds in puddled soil by paddy row seeder gave more number of (32-33) hills m^{-2} than broadcasting sprouted seeds (Singh and Garg, 1983) [115]. Anoop Dixit *et al.* (2007) [6] reviewed on comparative performance of different paddy trans planters developed in India. Farm implements and machinery (FIM) centre (2000) conducted feasibility trails on Mechanical transplanters at 14 locations of Hissar. The number of hill m^{-2} was 28-32 with 3-4 plants $hill^{-1}$. While self -propelled riding type (Chinese design) planted 2-4 seedlings $hill^{-1}$ and 18-24 hills m^{-2}.

Number of tillers m^{-2}
Direct seeding of rice under puddled soil performed as efficiently as transplanted rice (Sharma and Bisht, 1981) [109].

Wet seeded rice starts tillering earlier than transplanted rice because its growth proceeds without the setback caused by uprooting injury to the root of seedlings (Yoshida, 1981) [142]. Early establishment of direct seeded crop in the absence of transplantation shock with better coincidence of nutrient requirement of the crop resulted in higher vegetative growth (Sharma *et al.*, 1989) [110]. This method of sowing is being practiced in many parts of South East Asian countries (Singh and Bhattacharya, 1989) [119]. Dingkuhn *et al.* (1990) [40] reported that row sown wet seeded rice showed faster and greater vegetative growth due to absence of transplantation shock. Tiller number and leaf area index (LAI) were also greater than in transplanted rice. Direct seeded rice produced significantly higher number of tillers than transplanted one (Shekar and Singh, 1991; Sharma and Sharma, 1994; Prabhakar and Reddy, 1997) [111, 108, 90]. Prasad *et al.* (2001) [92] reported by transplanting method recorded higher number of tillers m^{-2} (271.6) over direct seeding (184.5). This experiment was conducted at the research farm of Rajendra Agricultural University, Pusa and Bihar with silt loam and calcareous soils. Anbumani *et al.* (2004) [3] reported that line planting registered significantly more number of tillers m^{-2} (522.5) compared to direct sowing (515.3) and random transplanting (507.7) The experiment was conducted at Annamalai University, Tamil Nadu, under moderately drained clay loam soil. Hugar *et al.* (2009) [53] reported that maximum number of total tillers m^{-2} (412) in SRI method followed by transplanted (397) and lower (319) in case of zero tillage method. The experiment conducted at A.R.S Kathalagere U.A.S Bangalore with red clay loam soil.

Dry matter accumulation

Rachel (1994) [95] reported higher dry matter production with wet seeded rice than with transplanted rice. Direct seeded rice accumulated more dry matter than transplanted rice upto 45 DAS but beyond this the reverse was true (Pal *et al.*, 1999) [85]. Nabheerong (1995) [77] found higher root length and total dry weight in wet seeded rice than in transplanted rice. Prasad *et al.* (2001) [92] reported that significantly higher plant dry matter recorded with transplanting (401.3 g m^{-2}) than puddle sowing (214.8 g m^{-2}) and dry drilling (209 g m^{-2}). Anbumani *et al.* (2004) [3] reported that higher dry matter production (13.5 t ha^{-1}) compared to random transplanting (13.2 t ha^{-1}) and direct sowing (12.1 t ha^{-1}) at harvest. This was mainly due to maintenance of optimum plant population and plant geometry in line planting.

Root volume

Significantly higher mean root length was observed in broadcast seeded flooded rice over transplanted rice. At all the depths, the root length was significantly higher except at 5-10 cm depth. The average increase was 38 per cent (De Datta *et al.*, 1988) [38]. Shallow root establishment was noted in puddle broadcasting which consequently resulted in crop lodging and uprooting of plants during harvesting (Khan *et al.*, 1989). Thiyagarajan *et al.* (2002) [132] observed that root volume increased from planting to the flowering stage and decreased at the grain filling stage. At the active tillering stage the root volume of conventional transplanting and young seedlings (SRI method) were almost comparable. The increase in root volume from active tillering to panicle initiation was 110% with young seedlings (SRI) and 73% with conventional seedlings. Priyanka *et al.* (2013) [93] reported that highest root volume (225.8 cc per 0.3 m^2) in top 15 cm soil depth was recorded in SRI followed by conventional transplanting (212.1cc) and double transplanting (214.1cc) at IARI, New Delhi under sandy loam soil. It was attributed to higher root growth and activity under SRI relates to increased root oxidation activity and root -source cytokinins. This experiment was conducted at Bengaluru, Karnataka with clay loamy soils. Higher root volume and longer root length help to absorb the moisture and nutrient from soil to reduce drought stress (Sridhara, 2008) [123].

Yield attributes of different rice production systems

Yogeshwar Rao *et al.* (1981) [141] recorded that significantly higher number of grains per panicle (75.7) and 1000 grain weight (23.8 g) were observed in transplanting over direct sowing (71.8 and 23.8 g), although panicle length (19.8 cm) and number of grains per panicle (72.8) were slightly reduced in direct sowing (seeding). De Datta (1986) [37] reported increased number of panicles m^{-2} and spikelets $panicle^{-1}$ in direct sown conditions. Direct seeding of sprouted seeds under puddled conditions resulted in significant improvement in yield attributes like number of effective productive tillers, proportion of spikelets fertility, test weight and grain yield (Shekar and Singh, 1991) [111].

Bhuiyan *et al.* (1995) [16] noticed that wet seeded rice had consistently higher number of panicles per unit area, lower number of spikelets per panicle, higher percentage of filled grains and 24 per cent higher grain yield than transplanted crop. Rice established through drum seeder recorded significantly more number of panicles m^{-2} than transplanted rice (Narasimman *et al.*, 2000 and Subbaiah *et al.*, 2000) [78, 125]. Drum seeding gave a slightly higher grain yield. The yield parameters were not affected by the method of crop establishment *viz.*, transplanting, sowing sprouted seeds in lines manually and drum seeding of sprouted seeds (Santhi *et al.*, 1998) [102]. Yield parameter such as number of panicles, panicle length, number of filled and immature grains and 1000 grain weight were not affected by the method of crop establishment (Thakur, 1993; Santhi *et al.*, 1998 and Yashwant Singh, 1999) [131, 102, 140]. Prasad *et al.* (2001) [92] reported that significantly higher panicles m^{-2} filled grains $panicles^{-1}$ and 1000 grain weight were recorded with transplanting (259, 76.5 and 20.9 g) than puddle sowing (214.8, 64.4 and 20.3 g) and dry drilling (163.7, 49.5 and 20.3 g). Anbumani *et al.* (2004) [3] reported that line planting registered significantly more number of panicles m^{-2} (267.8) and number of filled grains $panicles^{-1}$ (133.1) compared to random transplanting (261.2 and 130.8) and direct sowing (244.7 and 123.4). Gill *et al.* (2006) [49] found that the panicle length and test weight did not differ significantly on account of method of crop establishment. This experiment was conducted at Ludhiana, PAU with loamy sand soils. Chandrapala (2009) [26] reported that number of panicle m^{-2} did not vary significantly due to crop establishment methods (SRI, direct sowing and normal transplanting) further he reported that highest number of filled grains $panicle^{-1}$ and 1000 grain weight were recorded by SRI (121.4 and 21.93 g) method over the direct sowing (106.7 and 21.43 g) and NT (110.0 and 21.11 g) and these were found significantly at par. This experiment was conducted at DRR, Hyderabad with sandy clay loam soils. Singh *et al.* (2009) [120] reported that sowing in rows recorded significantly higher panicle number (341 m^{-2}) and panicle weight (2.59 g) over broadcast method

(228 m^{-2}) in puddled condition at DRR, Hyderabad with sandy clay loam soils. Hugar *et al.* (2009) [53] observed that among six establishment methods *viz*., zero tillage, drum seeder, normal transplanting, transplanted (manual) method, SRI and aerobic methods, SRI method recorded significantly higher number of total tillers (448 m^{-2}), effective tillers (376.5 m^{-2}), panicle length (23.5 cm), no. of seed $panicle^{-1}$ (94.5), 1000 grain weight (27.5 g) compared to other methods.

Yield of different rice production systems

Direct seeding using drum seeder enhanced early crop establishment and reduced the crop duration by 2-14 days and report higher yield as compared to manual broadcasting and traditional transplanting methods (Bharathi, 1996; Subbaiah *et al*., 1999) [15, 126]. Average yield of 2.48 t ha^{-1} was obtained with puddled seeder (CRRI, 1995) [32]. Higher grain yield was recorded with direct seeding than with transplanting during *kharif* under better management (CRRI, 1998). According to Santhi *et al.* (1999) [102], drum seeder gave the highest yield even though there was no marked difference between establishment methods. Similarly, increase in grain yield due to surface line seeding compared to broadcast and transplanted crop was reported by many researchers (Singh and Singh, 1993; Bhuvaneswari, 1998 and Angadi *et al*., 2000) [116, 18, 5]. Wet seeding produced almost similar grain yield as transplanted rice (Singh and Garg, 1983; Singh and Bhattacharya, 1989; Sharma and Sharma, 1994) [115, 119, 108]. Drill or direct seeding of sprouted seeds in line gave significantly higher grain yield than broadcasted and transplanted crop (Singh and Singh, 1993; Bhuvaneswari, 1998; Angadi *et al*., 2000) [116, 18, 5]. Prasad *et al.* (2001) [92] reported that significantly higher grain yield recorded with transplanting (30.04 q ha^{-1}) than puddle sowing (23.16 q ha^{-1}) and dry drilling (14.97 q ha^{-1}) and higher straw yield recorded with transplanting (40.85 q ha^{-1}) than puddle sowing (30.54 q ha^{-1}) and dry drilling (19.16 q ha^{-1}). Manjappa and Kataraki (2004) [67] evaluated establishment methods of rice for three years (1999-2001) and reported the maximum grain yield recorded with machine transplanting (7432 kg ha^{-1}) followed by manual transplanting (7371 ka ha^{-1}) which were on par with each other. The lowest yield was obtained with broad casting method (6261 kg ha^{-1}) and drum seeding (6721 kg ha^{-1}). Straw yield was significantly high with machine transplanting (10598 kg ha^{-1}) followed by manual transplanting (9130 kg ha^{-1}) which were on par with each other. The lowest straw yields were obtained with broadcast seeding method (8943 kg ha-1) and drum seeding (8561 kg-ha^{-1}). The experiment conducted at research farm of IARI, New Delhi of semi-arid area in silty clay loam indicated that maximum grain yield was observed in mechanical transplanting followed by manual transplanting, direct dry sowing and direct sprouted sowing. Mechanical transplanting significantly increased grain yield by 23, 37 and 63 per cent; straw yield by 17, 14 and 22 per cent; and biological yield by 20, 24 and 39 per cent over manual transplanting, direct dry sowing and direct sowing of sprouted rice in puddled conditions, respectively (Singh *et al*., 2006) [118]. Jayadeeva and Shetty (2008) [56] reported that the SRI establishment technique recorded significantly higher grain yield (10171 kg ha^{-1}) followed by transplanting (8697 kg ha^{-1}') compared to aerobic technique (7478 kg ha^{-1}) due to large root volume, profuse and strong tillers with large panicles, more and well filled spike lets with higher grain weight in SRI. Manjunatha *et al.* (2009) recorded that the grain yield data over three year period revealed that there was no grain yield difference between manual and mechanical transplanting. The mean grain yield of three years was 5.377 and 5.401t ha^{-1} for manual and mechanical transplanting respectively. In case of straw yield in transplanting method of establishment (6.83 t ha^{-1}) than drum seeding (6.5 t ha^{-1}) but remained on par with broadcasting (6.78 t ha^{-1}). He revealed that marginal increase of 0.77 t $ha^{-1}$of mean straw yield was recorded in case of mechanical transplanting than manual transplanting. This may be attributed to higher number of tillers $hill^{-1}$ due to transplanting of more seedlings $hill^{-1}$ in case of mechanical transplanting. This experiment was conducted at ARS Gangavati, Karnataka. The soil of the experimental site was medium deep black clay. Similar results were also reported by Ved Prakash and Varshney (2003) [136]. Hugar *et al.* (2009) [53] reported that SRI method of cultivation recorded significantly higher grain yield (6140 kg ha^{-1}), machine transplanter method (4847 kg ha^{-1}) and aerobic method (5368 kg ha^{-1}) and zero tillage method (4107 kg ha^{-1}). Straw yield (9306 kg ha^{-1}), and followed by machine transplanter method (7371 kg ha^{-1}) and aerobic method (7357 kg ha^{-1}). Lowest straw yield was noticed in zero tillage method (3918 kg ha^{-1}).

Venkateswarlu *et al.* (2011) [137] recorded that significantly higher grain yield was obtained with machine transplanter (7969 kg ha^{-1}) which is 13 per cent higher than manual planting (7059 kg ha^{-1}). The higher grain yield in machine planting was associated with an average 25 hills m^{-2} which is 25 per cent more than 20 hills m^{-2} in manual planting (less when compared to the recommended 33 hills m^{-2} which remains an extension gap). Average number of productive tillers (16 per hill) was also higher in machine planting than in manual planting (13 per hill) which was attributed to the early age of seedlings planted. This experiment was conducted at China in alluvial sandy clay loam soils. Among four rice establishment methods transplanting (TP), seedling casting (SC), mechanical transplanting (MT) and direct seeding (DS), system of rice intensification (SRI) produced significantly higher grain yield than conventional management (CM) under TP and MT but not under DS or SC. DS and SC produced much higher seedling quality than TP or MT, suggesting that robust seedlings with vigorous roots weaken the positive effect of SRI on rice yield (Song Chen *et al*., 2013) [121]. Study conducted on farmers field in Visakhapatnam of Andhrapradesh on red clay loam soils indicated that the average grain yield for three years in mechanized paddy cultivation and mechanized paddy cultivation with incorporation of *Dhaincha* before direct sowing of paddy seed was enhanced by 10 per cent and 14 per cent respectively when compared with farmer practice and average cost of cultivation was reduced by 25 per cent in mechanized paddy cultivation where green manuring crop (*Dhaincha*) was grown and incorporated in soil with indigenous plough before paddy seeding (Malleswara Rao *et al*., 2014) [66]. A field experiment was conducted during *kharif*, 2011 on sandy loam soils of Agricultural College Farm, Naira. Maximum grain yield (5406 kg ha^{-1}) was recorded with transplanting (C_4), which was however, on a par with semi- dry (C_1) (5296 kg ha^{-1}) and drum seeding of sprouted seed (5071 kg ha^{-1}) (C_2), while it was the lowest with broadcasting of sprouted seed (4432 kg ha^{-1}) (C_3). (Sandhya Kanthi *et al*., 2014) [101]. Machine transplanting recorded (14.7%) and (10.5%) higher grain and straw yield (6088 and 6954 kg ha^{-1} respectively) which was significantly superior to drum seeding method (5308 and 6295 kg ha-1respectively). However conventional transplanting method (5926 and 6886 kg ha^{-1}) was found on par to machine transplanting method with 2.7 and1.0 per cent variation respectively (Sathish *et al.*, 2017) [104].

Effect of rice production systems on nutrient up take

Chandra and Pandey (1997) [25] observed that N (112.8 kg kg ha^{-1}), P (17.0 kg ha^{-1}) and K (172.3 kg ha^{-1}) up take by rice were significantly higher under transplanting than direct seeded rice under puddle condition. This experiment was conducted at Bhubaneswar, Orissa. The soil of the experimental site was sandy loam of medium fertility. Anbumani *et al.* (2004) [3] found that line transplanted rice registered significantly higher NPK up take (136.2, 39.3 and 169.2 kg ha^{-1}) than direct seeded rice (126.4, 3.3 and 158.2 kg ha^{-1}). Chandrapala (2009) [26] reported that significantly higher mean NPK uptake of rice at 50 per cent flowering was observed under SRI (121.5, 20.04 and 90.33 kg ha^{-1}) followed by direct sowing (107.09, 170.80 and 79.5 kg ha^{-1}). A field experiment was conducted during *kharif*, 2011 on sandy loam soils of Agricultural College Farm, Naira. Uptake of nitrogen, phosphorus and potassium by rice at flowering and harvesting was found to be the maximum with transplanting method (C_4), which was comparable with semi- dry system (C_1). While, the lowest uptake was associated with broadcasting of sprouted seed (C_3), which was however, on a par with drum seeding of sprouted seed (C_2). (Sandhya Kanthi *et al.*, 2014) [101].

Effect of rice production systems on water saving and WUE

Gill *et al.* (2006) [49] reported that the direct seeded rice crop was applied 108,114 and 108 cm irrigation water when sown on 1 June, 10 June and 20 June respectively. The corresponding water applied to transplanted crop was 132, 120 and 118 cm when transplanted on 25 June, 5 July and 15 July. The water productivity of direct seeded rice varied from 0.40 to 0.46 kg m^{-3} against transplanted rice 0.29 to 0.39 kg m^{-3} of irrigation water, thus showing superiority in productivity and saving in irrigation water under direct seeded rice. Senthilkumar and Thilagam (2012) [105] conducted an experiment at Varappur village, in Tamil Nadu during *kharif* season and reported that water saving was up to 35 per cent in drum seeder than other methods because of early maturity of crop and there was 90 per cent saving in labour usage with the drum seeder method when compared to the other two methods of SRI method of planting and conventional method of planting. Sathish *et al.* (2017) [104] reported that the significantly higher water use efficiency (4.7kg mm^{-1}) was recorded in case of machine transplanting as compared to drum seeding (4.0 kg mm^{-1}) and was on par with conventional transplanting (4.6 kg mm^{-1}). This was due to higher grain yield and comparatively lower irrigation water used in MTP.

Economics of rice under different production systems

In Philippines, experiments showed that considerably less labour was warranted in producing broadcast seeded flooded rice than transplanted rice mainly due to labour saving in broadcasting (Coxhead, 1984; Luman, 1988) [31, 63]. On the other hand, land preparation and water control costs were higher for broadcast seeded flooded rice than for transplanted rice (De Datta and Ampong-Nyarko, 1988) [38]. However, the net effect favoured direct seeded rice. Erguiza *et al.* (1990) [44] suggested that a decline in the real price of rice, when other prices were hold constant, would encourage farmers to adopt cost saving innovations to sustain farm profit. Purohit *et al.* (1990) [94] found that drill sowing maximized net return ha^{-1} relative to broadcasting. However, cost benefit ratio was almost the same under both direct seeding and transplanting (Thakur, 1993) [131]. Narasimman *et al.* (2000) [78] concluded that among different establishment methods, direct seeding recorded the highest benefit cost ratio of 2.4 as compared to 1.6 for line transplanted and 1.3 for random transplanting. Anoop Dixit *et al.* (2007) [6] reported that transplanting mat type seedling is becoming more popular due to its superior performance and reduced labour requirement (50 man-h ha^{-1}). The 6-row manually operated machine was found to be the most economical. Manjappa and Kataraki (2004) [67] reported that the higher gross and net returns were realized with machine transplanting (₹ 51874 & 40265 ha^{-1}) followed by manual planting (₹ 49971 and 36284 ha^{-1}') being at par with each other. The lowest gross and net returns were obtained with broad cast seeding method and drum seeding method. Manjunatha *et al.* (2009) recorded that the mean gross returns remained on par between the manual and mechanical transplanting (₹ 33,872 and 34,209 ha^{-1} for manual and mechanical transplanting respectively). He also reported that the self- propelled 8 row paddy transplanter could be used successfully with a labour saving of about 30 man days per hectare and eliminating the drudgery on the part of labourers with the field capacity of the transplanter being 0.19 ha hr^{-1}, an area of 1.5 ha can be transplanted in a day of 8 working hours. The maximum area that could be covered by the mechanical transplanter in a year is 144 hectares as the transplanting operations are seasonal. If the machines are used for the maximum of 90 hectares in a year, the cost of mechanical transplanting would be ₹ 789 ha^{-1} as against ₹ 1625 ha^{-1} in case of manual transplanting. Hugar *et al.* (2009) [53] reported that among six establishment methods *viz*., zero tillage, drum seeder, normal transplanting, transplanter (manual) method, SRI and aerobic methods, SRI method fetched the maximum gross returns (₹ 1,17,432 ha^{-1} yr^{-1}), net profit (₹ 79,912 ha^{-1} yr^{-1}) and B:C ratio (2.13). Less gross returns (₹ 63,512 ha^{-1} yr^{-1}), net profit (₹ 36,312 ha^{-1} yr^{-}) and B.C ratio (1.33) were recorded in zero tillage method. Zahide Rashid *et al.* (2010) [143] found that the advantage with mechanical transplanters was that one can transplant without searching for labourers which ultimately means that the cost of cultivation was reduced. If farming activity under taken in the traditional way by using manual labourers, an expenditure of ₹ 8000 Per acre would be incurred only for transplantation including nursery maintenance, pulling and transplanting whereas the use of machine, entire operation right from raising the nursery cost only ₹ 3000/-. Venkateswarlu *et al.* (2011) [137] reported that the higher net income ₹ 62295 ha^{-1} was recorded with machine planting which was 29 per cent more compared to ₹ 48458 ha^{-1} with manual planting. The higher net income was due to reduced cost of cultivation of ₹ 1250 ha^{-1} and an increased grain and straw yield of 910 kg ha^{-1} and 1667 kg ha^{-1} respectively in machine planting. The reduced cost of cultivation, increased grain as well as straw yield resulted in better cost benefit ratio of 1:2.47 in machine planting than 1:2.11 recorded in manual planting. Machine planting hence is a viable alternative at times of scarce availability and higher cost of labour.

Water saving irrigation practice in rice

Alternate wetting and drying and Field water tube irrigation practice

Numerous studies conducted on the manipulation of depth and intervals of irrigation intended to save water, had demonstrated that continuous submergence was not essential for obtaining higher rice yields (Guerra *et al.*, 1998) [50]. Bhuiyan and Tuong (1995) [16] after several years of experimentation concluded, that maintaining a significant depth of water throughout the season was not needed for high rice yields. The practice of irrigation immediately after the disappearance of previously ponded water was most suitable under limited water supply and the yield reduction was only marginal (3 to 5%), but it helped to save about 28.7 per cent of irrigation water compared to continuous submergence (Wahab *et al.*, 1996) [138]. Alternate wetting and drying irrigation (AWDI) also called intermittent irrigation a water saving technology that reduces the water use in rice fields. In AWDI, water applied to flood the field in certain number of days after the disappearance of previously ponded water and field kept in alternately flooded and non-flooded condition (Bouman and Tuong, 2001) [21]. Success of AWDI largely depends on irrigating the field at right time, when plant needs water. But determination of right irrigation timing during the dry cycles of AWDI was very hard due to different soil physical properties such as soil structure, soil texture, bulk density, soil pore space, and different hydraulic conductivity like movement of water, infiltration, water holding capacity. Even without ponded water, the rice roots could able to access the water in the subsurface soil, which remains saturated. The practice of safe AWDI as a water saving technology entails irrigation when water depth falls to a threshold depth below the soil surface. Safe AWDI resulted in saving of irrigation water, increased water productivity, and no decline in rice yield (Bouman *et al.*, 2007a) [22]. The management of AWDI was generally practised with 5, 7 and 10 days interval, but the predetermined days of interval could not be treated as the demand driven approach perfectly (Abdul Latif, 2010) [1]. This experiment was conducted in University of Tokyo, Japan. Shaibu *et al.* (2014) [106] conducted a study to evaluate performance of two rice (*Oryza sativa* L.) varieties *viz.*, Nunkile and NERICA 4 under water saving irrigation of sandy clay loams of Southern Malawi (1) continuous flooding with surface water level kept at approximately 5 cm throughout crop duration (CFI), (2) alternate wetting and drying up to start of flowering after which continuous flooding was applied (AWD1), (3) alternate wetting and drying up to start of grain filling after which continuous flooding was applied (AWD2) and (4) alternate wetting and drying throughout the crop duration (AWD3) and reported that seasonal crop water requirement was 690 mm, total irrigation depths were 1923.61, 1307.81, 1160.61 and 807.87 mm for the four regimes respectively. The CFI treatment used 32%, 40% and 58% more water than AWD1, AWD2, and AWD3 regimes respectively. In the same treatment order, the average yields per treatment for Nunkile were 4.92, 4.75, 4.74, and 4.47 t ha^{-1} with significant yield differences among CFI, AWD2 and AWD3 treatments. Bouman *et al.* (2007b) [23] recommended the Field Water tube to monitor the water depth and determine the irrigation timing. The tube is made of 40 cm long plastic pipe or bamboo with diameter of 15 cm or more and perforated with holes on all sides and placed vertically inside the soil. The tube can be placed in a flat area of the field close to a bund for easy monitoring of the ponded water depth change. Tuong (2007) [134] conducted an experiment on the application of field water tube in AWDI management regime showed that field water tube worked successfully to monitor the water depth and capable to indicate the right time of irrigation and saved water, without any yield penalty. Oliver *et al.* (2008) [83] used the field water tube in their research, which was 4 cm in diameter and 40 cm in length and installed in the field keeping 7 cm length above the soil and the remaining 33 cm perforated zone underneath the surface to measure the depletion of soil water in the field and found effective. Observed that applying irrigation when water level depletes to 10 cm below ground level in field water tube was good among the AWDI treatments. This experiment was conducted at Bangladesh Agricultural University farm. The soil of the experimental site was silty loam. Miah and Sattar (2009) [71] reported that to adopt need based AWDI irrigation effectively required 10 cm diameter and 25 cm long PVC pipe or hollow bamboo pieces or even waste bottles of cool drinks like Coca-Cola *etc*., were to be installed vertically with its perforated portion under the ground level. Bouman *et al.* (2007b) [23] observed that the water level in the tube is 15 cm below the surface of the soil was the optimum time to re flood the soil with a depth of around 5 cm which was the threshold level for safe AWDI that would not cause any yield decline. When the water level dropped to 15 cm below the surface of the soil, it should be re flooded with 5 cm depth of ponded water. Especially during week before and after flowering, the field should be kept under submergence. After flowering, during grain filling and ripening, the water level could drop again to 15 cm below the surface before re irrigation.

Effect of water saving irrigation methods on growth

This experiment was conducted on a non-cracking loamy sand soils at Ludhiana. Growth in terms plant height was found to be higher in rice, when irrigation was given two days after subsidence of ponded water at vegetative phase and 4 days of subsidence at reproductive phase (Uppal *et al.*, 1991) [135]. Chandrasekaran (1996) [27] observed the increased plant height, root dry weight and dry matter production when rice was irrigated to 5 cm depth one day after disappearance of ponded water (DADPW). Similarly leaf area index, leaf area duration, crop growth rate and relative growth rate were also found to be higher for irrigation one day after disappearance of ponded water. Rice grown in a flooded condition, at least during reproductive growth, was reported to produce considerably more roots than rice grown without flood but with supplemental irrigation (Beyrouty *et al.*, 1997) [14]. Balasubramanian and Krishnarajan (2000) [9] observed highest number of tillers in plots which received irrigation 5 cm depth at one DADPW. They also concluded that irrigating 2.5 cm depth at 3 DADPW recorded the lowest grain yield because of the moisture stress effect in this irrigation regime. Geethalakshmi *et al.* (2009) [48] confirmed that maximum number of tillers m^{-2}, higher shoot and root length recorded under SRI method of irrigation (intermittent irrigation) compared to 5 cm depth at one day after disappearance of ponded water (DADPW) and to 5 cm depth at two DADPW. This experiment was conducted in sandy clay loam soil at Agriculture College and Research Institute, Tamil Nadu Agriculture University, Coimbatore. Maragatham and James Martin (2010) [69] reported that the AWDI method were comparatively more effective by recording higher plant height, tillers, root length, root volume and dry matter than the aerobic rice and flooded rice. The SRI irrigation practice during vegetative growth stage improved the root length density and root activity rate as well as shoot growth and delayed senescence of plants, leading to higher grain yield (Mishra and Salokhe, 2010) [72]. Thakur *et al.* (2011) [30] observed that the SRI irrigation practice registered the increased plant height (124.2 cm) and number of tillers m^{-2} (450.1) than the conventional practice of irrigation. Continuous flooding has been proved to be detrimental to rice root growth. Free Fe^{2+} and S_2 are potentially toxic to rice plants as they can inhibit root growth and impair nutrient uptake (Sahrawat, 2000) [99]. Rice plants that grow on lowland paddy soils therefore must have strategies to cope with these conditions. Intermittent irrigation is believed to improve oxygen supply to rice root system with potential advantages for nutrient uptake (Stoop *et al.*, 2002) [124], and to avoid accumulation of toxic concentrations of reduced substances such as ferrous iron (Fe^{2+}) or hydrogen sulphide (H_2S). Chowdhury *et al.* (2014) [30] observed that leaf area index, dry matter production and crop growth rate (CGR) were significantly influenced by 2.5 cm irrigation 0 days after disappearance of ponded water (DAD) over 6 DAD but were at par with 3 DAD. This field experiment was conducted at research farm, Rajendra Agricultural University, Bihar. The soil of the experimental plot was sandy loam in texture. Kumar *et al.* (2014) [58] recorded that more number of tillers m^{-2} (145.96) was obtained with 7 cm irrigation at 1 DADPW which was found significantly superior to 7 cm irrigation at 3 (130.06) and 5 (113.61) DADPW. Dry matter accumulation (17.54 g) with 7 cm irrigation 1 DADPW which was found significantly superior to 7 cm irrigation 3 and 5 DADPW at harvest stage.This experiment was conducted in Faizabad, Uttar Pradesh with silt loam soils.

Effect of water saving irrigation methods on water stress parameters

Yadav *et al.* (2001) [139] conducted pot experiments on ten rice cultivars to determine the effects of 10 days drought stress during tillering and flowering stages. They found that water stress lowered the relative water content (RWC), leaf water potential (LWP) and osmotic potential (OP) but increased leaf diffusive resistance (LDR) at both tillering and flowering stages. Upon dewatering the plants i.e. after revival of moisture content the RWC, LWP, OP and LDR of the leaves recovered but could not reach the values of pressurised plant up to 72h. Higher recovery was observed at tillering than flowering stage. Ten days duration of drought at flowering stage resulted in a drop in OP along with LWP in all the cultivars.

Relative Water Content

Sinclair and Ludlow (1985) [114] noted that leaf relative water content (RWC) is a better indicator of water status than leaf water potential. Changes in the water balance and the amount of water available in soil can be crucial for crop yield (Fuhrer 2003) [46]. On the other hand, physiological characteristics of plants are correlated with the water potential (Hsiao 1973) [52]. Low water potential due to reduced water availability negatively affects plant growth (Ohashi *et al.* 2000) [82], photosynthesis (Ogen and Oquist 1985) [85], plant cell enlargement (Nonami *et al.* 1997) [80], and hormone balance (Munns and Gramer 1996) [74]. Downey and Miller (1971) determined an empirical relationship between RWC and water uptake for maize, using small discs of constant area. Blum *et al.* (1989) [19] reported that higher leaf relative water content allows the plant to maintain turgidity and this would exhibit relatively less reduction in biomass and yield. As observed by David (2002) [35] Leaf relative water content had a significant influence on photosynthesis, by reducing the net photosynthesis by more than 50% when relative water content was less than 80%. Relative water content is the ability of plant to maintain high water in the leaves under moisture stress conditions and has been used as an index to determine drought (Barrs and Weatherly, 1962) [10] tolerance in crop plants. During plant development, drought stress significantly reduced relative water content values (Siddique *et al.*, 2000) [112]. Flore *et al.* (1985) [45] stated that relative water content was considered as an alternative measure of plant water status, reflecting the metabolic activity in tissues. Reduced soil water availability leads to low plant water potential. Consequently, among the first plant responses to avoid excessive transpiration, the leaves lose turgescence, the stomata close, and cell elongation is halted (Souza *et al.*, 2010) [122]. There is a negative relationship between the net photosynthetic rate and water stress expressed (Peri *et al.*, 2011) [89]. Water stress induces decrease in the shoot dry weight and relative water content (RWC) (Martiınez *et al.*, 2004) [70]. Inadequate soil moisture leads to water deficits in leaf tissues, which affects many physiological processes and ultimately reduces the yield (Mahmood *et al.*, 2012) [64].

Leaf Water Potential

Leaf water potential estimation is considering one of the important quantitative measurements of drought resistance of crop (Ekanayake *et al.*, 1985; O'Toole and Moya, 1978 and Bashar *et al.*, 1990) [42, 84, 11]. Cowman (1965) predicted that leaf water potential will vary diurnally because of the dynamic nature of and complex interaction between the various components of the soil plant atmosphere system. Some plant species can adapt to water stress by adjusting osmotically, so that, the physiological activity is maintained at low leaf water potential (Samuel and Paliwal, 1993) [100]. Leaf water potential is considered to be a reliable parameter for quantifying plant water stress response (Siddique *et al.*, 1999) [113]. Cruz *et al.* (1986) [33] reported that the photosynthetic rate of rice leaves is highly susceptible to drought stress and it is decreased by 60% when leaf water potential decreased from -0.6 to -1.3 MPa. Tanguilig *et al.* (1987) [128] observed that the high transpiration rate in rice leaves may have caused the rapid decline in leaf water potential if proper amount of water is not supplied to the growing medium. Various morphological and physiological traits are reported as the components of the drought resistance mechanisms by many researchers (Chang *et al.*, 1972; Loresto *et al.*, 1976; Blum, 1989 and Bashar *et al.* 1990) [29, 62, 19, 11] and also the drought resistance score was found highly correlated with leaf water potential (O'Toole and Moya, 1978) [84]. The significant varietal differences of mid-day leaf water potential was observed in rice under field condition (O'Toole and Moya, 1978; Ekanayake *et al.*, 1985) [84, 42] as well as in green house condition (Begum, 1985) under differential water stresses. On the other hand, a varietal difference of pre-dawn leaf water potential of rice at different level of moisture stresses was observed under greenhouse condition (Ahmed *et al.*, 1978) [2].

Without any stresses, the mid-day leaf water potential was reported to differ significantly among the upland cultivars grown under flooded field condition (Bashar *et al.*, 1990) [11]. Boonjung and Fukai (1996) [20] found that younger plants with smaller canopies took up water more slowly and were able to maintain higher LWP than those with larger canopies.

Effect of water saving irrigation methods on yield attributes

In the initial stages of crop growth in rice *i.e.*, from ten days after planting to active tillering stage, it is beneficial to maintain rice fields just at moist condition rather than keeping the fields under flooded condition to get more number of productive tillers and more number of grains per panicle (Murthy and Ramakrishnayya, 1978) [75]. Panda *et al.* (1980) [86] and Patel (2000) also observed more tiller production per unit area, filled grains per panicle and 1000 grain weight when the irrigation in the order of saturation upto tillering followed by submergence till ripening in rice. This field experiment was conducted at Baronda farm, Raipur (M.P.). The soil of the experimental site was well-drained loamy soils. Ramamoorthy *et al.* (1993) [97] and Chandrasekaran (1996) [27] found that the rice varieties had given significantly higher productive tillers and panicle length with the rice crop which received irrigation to a depth of 5 cm one day after disappearance of ponded water (DADPW).

Rezaei *et al.* (2009) [98] reported that interval irrigation (full irrigation, 5 and 8 days interval) did not affect number of panicle in square meters, panicle length, weight of 1000-grain and harvest index but it affect total number of grains in panicle. This experiment was conducted at Rice Research Institute of Iran, Rasht, Iran. Pandey *et al.* (2010) [87] revealed that the significant increase in sterility percent was noted under the application of irrigation at 3 DAD of ponded water. The irrigation given under 3 DAD might be failed to meet the evaporative demand during dry season thus reduced yield attributes. This experiment was conducted at Chhattisgarh on clayey soils. Ramakrishna *et al.* (2007) [96] reported that Continuous submergence registered higher number of panicles hill^{-1} (10.4 and 10.5), grains panicle^{-1} (135.6 and 139.4) and panicle length (25.9 cm and 26.4 cm) 3-day after drainage panicles hill^{-1} (9.1 1nd 9.4), grains panicle^{-1} (128.4 and 134.9) and panicle length (25.0 and 25.5 cm). This field experiment was conducted at Indian Agricultural Research Institute New Delhi. The soil of the experimental plot was sandy clay- loam in texture. The maximum number of panicles m^{-2}, weight of grains panicle^{-1}, filled grains panicle^{-1} and panicle length was observed in irrigation after one day after disappearance of water and it was statistically at par with irrigation after two days after disappearance of ponded water at Ludhiana in loamy sand with alkaline soil. Significantly higher test weight (28.03 g) in 5 days interval irrigation compare to submergence (27.36) treatment at Iran (Azarpour *et al.*, 2011) [8]. Among moisture regimes, the highest number of effective tillers m^{-2} (121.54), length of panicles (22), number of grains panicles^{-1} (180.14) and weight of grains panicles^{-1} (4.34 g) were recorded with application of 7 cm irrigation 1 DADPW, which was significantly superior over the 7 cm irrigation 3 and 5 DADPW. This experiment was conducted at Agronomy Research Farm, Faizabad Uttar Pradesh, during 2010 *kharif* season with sandy loam soils. (Kumar *et al.*, 2014) [58].

Effect of water saving irrigation methods on yield

Ramamoorthy *et al.* (1993) [97] and Chandrasekaran (1996) [27] found that the rice varieties had given significantly higher grain and straw yields under lowland transplanted condition with the application of 5 cm water a one day after disappearance of ponded water. Irrigation to rice two days after disappearance of ponded at vegetative phase was found to be the best irrigation practice for getting higher grain yield (Uppal *et al.*, 1991; Patel 2000) [135, 88]. Chinese researchers Zhang *et al.* (1994) [144] and Li *et al.* (1999) [61] stated that higher rice yield could be obtained without the need of continuous flooded irrigation. Das *et al.* (2000) [34] revealed that frequent irrigation at 3 days after disappearance of ponded water (DADPW) either 7 or 5 cm depth recorded higher grain and straw yields over wide intervals *i.e.*, 5 DADPW of similar depth of irrigations. Observed higher rice yield levels where water saving method of AWDI was practiced and the total rice production had not been adversely affected, indicating that AWDI had contributed higher productivity. Chandrasekaran *et al.* (2002) [27] concluded that irrigation scheduled to 5 cm depth at one DAD was optimum to obtain higher yields in rice-rice cropping system. Cabangon *et al.* (2004) [24] and Belder *et al.* (2004) [13] reported that water inputs decreased by around 15 to 30 per cent without significant yield reduction.

Avil Kumar *et al.* (2006) [7] reported that the total dry matter, grain and straw yield were significantly influenced by different irrigation schedules. Maximum grain yield (4240 kg ha^{-1}) was recorded with irrigation daily (continuous submergence) and it was significantly superior to the remaining treatments, irrigation once in 4 days (3710 kg ha^{-1}), irrigation once in 5 days (3350 kg ha^{-1}), irrigation once in 6 days (3020 kg ha^{-1}), irrigation for 5 days and no irrigation for 5 days (3800 kg ha^{-1}) and irrigation for 7 days and no irrigation for 7 days (3610 kg ha^{-1}) but irrigation once in 2 days for which grain yield was comparable (4011 kg ha^{-1}).this experiment was conducted at RARS, Jagtial Telangana in red sandy loam soils. Reported that yield attributes, yield, harvest index and benefit cost ratio were higher under 7 cm irrigation one day after disappearance of ponded water followed by CF. Dhar *et al.* (2008) [39] opined that at Jammu, the maximum grain yield of rice under SRI methods was recorded (5.29 t ha^{-1}) when the crop was irrigated at 7 DADPW which was significantly higher than the yield obtained from other treatments like AWD, applying irrigation at 3, 5 and 9 DADPW, but similar to the yield obtained from continuous submergence (4.93 t ha^{-1}). Rezaei *et al.*, 2009 [98] reported interval irrigation (full irrigation, 5 and 8 days interval) caused less water use and increased water productivity. Yield in water treatments fluctuated between 4002 to 4457 kg ha^{-1}. Since yield difference between interval irrigation and full irrigation was not significant. Zhao *et al.* (2010) [145] reported 26.4 per cent higher yield under SRI intermittent irrigation as against traditional flooding. The yield increase was due to increase in chlorophyll content, delayed leaf senescence and more biomass accumulation at later stages of rice crop. Latheef Pasha *et al.* (2012) [60] observed that SRI recorded highest grain yield during 2008 and 2009 (6461 and 7017 kg ha^{-1}) followed by rotational system of irrigation (6242 and 6429 kg ha^{-1}) as compared to farmers practice of growing rice with continuous flooding. SRI also resulted in irrigation water saving over farmer practice of flood irrigation. This experiment was conducted in two villages in Nalgonda district of Telangana. The soils were sandy clay loam in texture. The grain yield was higher under saturated condition (7.6 t ha^{-1}) than flooded condition (7.1 t ha^{-1}) At Malaysia (Sariam and Anuar, 2010) [103]. Likewise, Singh and Ingram (2000) observed that maintaining saturated soil moisture condition produced higher yield over stress given at different stages of the crop growth. Majid (2014) [65] reported that the effect of irrigation regimes on grain yield were significant.I_1, I_2, I_3 and I_4 with 7342, 7079, 7159 and 5168 kg ha^{-1} had the highest and lowest average, respectively. Irrigation interval 5, 8 days and Continuous submergence produced same grain yield but in irrigation interval 11 days decreased.

Effect of water saving irrigation methods on water saving and water productivity and WUE

Muthukrishnan and Purushothaman (1992) [76] found that intermittent irrigation gave higher WUE than continuous submergence. This experiment was conducted at Tamil nadu with clay loam soils. Narendra Pandey *et al.* (1992) [79] observed about 25 per cent saving in irrigation water under one DADPW compared to continuous submergence without reduction in grain yield. Hitlal *et al.* (1992) [51] and Singh *et al.* (2006) [118] reported that maintaining a very thin layer at saturated soil condition or alternate wetting and drying could reduce the water required for irrigation by about 40 to 70 per cent compared to continuous submergence without significant yield loss. Chandrasekaran (1996) [27] found that the WUE was of 6.02 kg per ha mm under irrigation practice of one DADPW. Anbumozhi *et al.* (1998) [4] observed increased water productivity (1.26 kg m^{-3}) in AWDI plot at 9 cm ponding depth compared to continuous flooding (0.96 kg kg m^{-3}). This experiment was conducted at Japan, in sandy loamy soils. Ganesh and Hakkali (2000) [47] found that the application of irrigation once in 3 to 5 days with 5 cm submergence coincided with giving irrigation immediately after disappearance of ponded water or 1 to 2 days later and saved the water to the extent of 49 per cent over the existing practice of continuous submergence without reducing grain and straw yields. Patel (2000) [88] observed a higher WUE of 3.04 kg grain per ha mm in rice when continuous saturation level irrigation was followed. This experiment was conducted in well drained loam soil at Baronda farm, Raipur (M.P.). Bouman and Tuong (2001) [21] reported that in 92 per cent of the cases, the AWDI treatments resulted only lower yield reductions compared with flooded checks, but with higher water productivity. This experiment was conducted at experimental farm of IRRI Los Banos Philippines in silty clay loamy soils. Thiyagarajan *et al.* (2002) [132] reported that limited irrigation of 2 cm depth after crack development recorded higher productivity (0.732 kg m^{-3}) with 56 per cent saving in irrigation water compared to CF of 5 cm standing water without any significant reduction in grain yield. This experiment was conducted in sandy clay loam soil at Agriculture College and Research Institute, Tamil Nadu Agriculture University, Coimbatore. Cabangon *et al.* (2004) [24] reported based on experimentation with AWDI in lowland rice areas with heavy soils and shallow ground water tables in China and Philippines, there could be water saving to the tune of 15 to 20per cent in rice through AWDI without a significant impact on yield. Li and Baker (2004) reported that AWDI was a mature technology that has been widely adopted in China and a recommended practice of North West India and was tested by farmers in Philippines. Belder *et al.* (2004) [13] calculated that evaporation losses in rice fields decreased by 2-33 per cent in AWDI compared with continuously flooded condition. This experiment was conducted in irrigated lowland rice areas located in China with silty clay loamy soils. Swarup *et al.* (2008) [127]. reported that different water management practices (continuous submergence, irrigation supplied 1, 2 and 4 days after subsidence of standing water) under saving of irrigation water and enhancement of water use efficiency were highest when irrigation water was given 4 days after disappearance of standing water. The yield decrease due to intermittent flooding was not significant. This experiment was conducted at CRRI, Cuttack, in sandy loamy soils. Tran Thi Ngoc Huan *et al.* (2008) [133] reported that AWDI recorded the highest water productivity and while the lowest water productivity was with flooded rice. Geethalakshmi *et al.* (2009) [48] recorded water savings under SRI to the tune of 12.6 and 14.8 per cent respectively during summer and *kuruvai* seasons. Impounding of 2.5 cm of irrigation water and irrigation after formation of hairline cracks have shown considerable water saving besides better root environment under SRI. This experiment was conducted in sandy clay loam soil at Agriculture College and Research Institute, Tamil Nadu Agriculture University, Coimbatore. Suresh Kulkarni (2011) reported that using of field water tube in AWDI was safe to limit the water use to 25 per cent without reduction in rice yield. Tejendra Chapagain and Eiji Yamaji (2010) [129] reported higher water productivity (1.74 g l^{-1}) in AWDI compared to continuously flooded rice (1.23 g l^{-1}). The experiment conducted at different locations Kharagpur (West Bengal) lateritic sandy loam soils, Hyderabad (Andhra Pradesh) sandy loam soils and Chakuli (Orissa) sandy loam soils. Saving of irrigation water and enhancement of water use efficiency was the highest when irrigation water was given 4 days after disappearance of standing water and the yield decrease due to intermittent flooding was not significant Mohamed Yasin and Duraisamy (2012) [73] reported that intermittent submergence led to 34-43 per cent saving of irrigation water for rice in addition to higher yields and increased water use efficiency index up to 37.6 per cent by saving water input to 26.1 per cent as compared to CF. Shantappa (2014) [107] reported that significant improvement in WUE to the tune of 39 per cent under intermittently irrigated SRI over continuously flooded NTP. This field experiment was conducted at DRR farm with clay loam soils.

Economics

The AWDI based cultivation has an impact on costs as the technology reduces irrigation costs; it saved 30 litre diesel ha^{-1}, reduced irrigation frequency by 4 to 20 depending on soil type, while harvesting 500 kg ha^{-1} extra yield with one extra weeding, but the cost of extra weeding was more than offset by the extra yield and also the saving of fuel (Miah, 2008). Lampayan *et al.* (2009) [59] reported that the practice of AWDI with the same yield level as that of continuous flooding but saved 16 to 24 per cent of water cost and 20 to 25 per cent of production costs. The experiment conducted at Philippines. found that B: C ratio was the highest (1.09) with irrigation at 3 days after disappearance of ponded water in system of rice intensification. The experiment site located at tarai (young alluvial soils with shallow to medium water table) belt of India and is characterized by a sub-humid and sub-tropical climate at G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand.

Conclusion
From the literature reviewed above, due to labour shortage, the traditional method of transplanting becomes rather difficult to ensure timely planting with optimum age of seedling. To overcome these difficulties transplanting can be substituted by direct seeding and machine transplanting which could reduce labour needs by more than 20 per cent and increase the yields. Among the different transplanting methods machine transplanting produced higher yield and yield attributes compared to direct seeding with drum seeder and conventional transplanting systems. In different water-saving irrigation methods, the most widely adopted is alternate wetting and drying AWD irrigation method. In that recommended submergence of 2-5 cm water level recorded significantly higher grain and straw yield and N, P, K uptake and was on par with irrigation of 5 cm when water falls below 5 cm from soil surface in field water tube.

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