Indian Journal of Agronomy **67** (3): 221—226 (September 2022)

Research Paper

Productivity and water-use efficiency of rice (*Oryza sativa*) cultivars under different irrigation regimes and systems of cultivation

G.V. VENKATARAVANA NAYAKA[1], G. PRABHAKARA REDDY[2], R. MAHENDER KUMAR[3], K. SUREKHA[4] AND P. SUDHAKAR[5]

ICAR-Indian Institute of Rice Research, Hyderabad, Telangana 500 030

Received: November 2020; Revised accepted: March 2022

ABSTRACT

A field experiment was conducted on clay loam soils of the Indian Institute of Rice Research, Hyderabad, Telangana, during the rainy (*kharif*) seasons of 2017 and 2018, to study the performance of rice (*Oryza sativa* L.) cultivars under different irrigation regimes and systems of cultivation. The treatments consisted of 2 irrigation regimes, viz. alternate wetting and drying (AWD), and saturation as main plot treatments, while 3 systems of cultivation, viz. system of rice intensification (SRI), drum seeding (DS) and normal transplanting (NT) as subplot treatments and assessed 4 cultivars, viz. 'DRR Dhan 42', 'DRR Dhan 43', 'MTU 1010' and 'NLR 34449' as sub-subplot treatments. Total 24 treatment combinations were laid out in split-plot design with 3 replications. Application of water through the AWD method saved around 11–14% of the total water requirement during the crop-growth period. Irrigation by AWD resulted in significantly higher irrigation water productivity and water-use efficiency (WUE). The SRI method required the lowest amount of water (11.61% and 13.21% less of mean applied than drum seeding and normal transplanting respectively). Significantly higher water productivity and WUE were registered with SRI. 'DRR Dhan 43' recorded higher water productivity as well as WUE as compared to the other cultivars during both the years of study owing to higher productivity.

***Key words*:** Irrigation regimes, Relative water content, Systems of cultivation, Water Productivity, Water-use efficiency, Yield

Rice (*Oryza sativa* L.) is grown in an area of 2.218 million ha with a production of 12.60 million tonnes, with an average productivity of 5,702 kg/ha in Andhra Pradesh (ASG, 2019). By 2025 nearly 2 million ha of Asia's irrigated rice fields may suffer from water shortage because of extreme consumption of water in lowland rice, which consumes 70 to 80% of the irrigated water resources in the major part of the rice-growing regions in Asia including India. To safeguard and sustain food security in India, it is necessary to enhance the productivity of rice with reduced resources, particularly land and water. To produce 1 kg of the unmilled rice grain, the virtual water use was up to 5,000 litres (Saddam *et al.,* 2021). Several strategies are in vogue to reduce rice water requirements, such as saturated soil culture, the system of rice intensification (SRI), aerobic rice, raised beds, drum seeding (DS), *etc.* could facilitate to reduce water losses and improve productivity. Many efficient irrigation strategies had been tested, applied and spread in different rice-growing regions of the world viz*.,* alternate wetting and drying (AWD), semi-dry cultivation (SDC), aerobic rice (AR), combining shallow water depth with wetting and drying (SWD) and non-flooded mulching cultivation (NFMC), as an alternative system of irrigation that requires a lesser amount of water but stable or rising grain yield (Poddar *et al.,* 2021).

In India, the rice area is decreasing year by year because of varied factors like urbanization, increased input and labour expenses and migration of labour from agriculture to the non-agriculture sector (Yadav *et al*., 2013). Various physiological and agronomic character contribute to higher grain yield in rice, such as larger sink size as a result of more spikelets per panicle, greater source activity which is characterized by a higher leaf-area index (LAI), larger leaf area duration, slower leaf senescence, and higher photosynthetic rate (Huang *et al*., 2016), better root biomass, stronger lodging resistance, particularly at a high N rate and higher N-use efficiency at low N application

[1]**Corresponding author's Email:** venkat05iirr@gmail.com

[1]Assistant Professor, [2]Principal Scientist and Head, Department of Agronomy; [3]Principal Scientist and Head, Department of Soil Science, ICAR-Indian Institute of Rice Research, Hyderabad, Telangana 500 030; [4]Associate Dean (Agronomy), Agricultural College, Mahanadi, Andhra Pradesh 518 502; [5]Registrar (Incharge), Acharya N.G. Ranga Agricultural University, Lam Guntur, Andhra Pradesh 522 034

(Wu *et al*., 2016), in relative to the choice of check cultivars. However, little is known whether rice has better productivity and higher water-use efficiency (WUE) under either water scarcity or water-saving irrigation. Drought or water deficit is the major abiotic stress factor limiting crop productivity worldwide. Among the field crop, rice is particularly susceptible to soil water deficit and about 50% of the world rice production is affected more or less by water deficit. It is believed that breeding techniques and selecting a drought-resistant cultivar and adoption of proper water management are the effective approaches to mitigate the effect of water deficit on rice yield. Understanding plant traits that are associated with high grain yield and strong drought resistance is very important in a breeding programme to develop the cultivar with high WUE and in making strategy for water management. AWD irrigation is regarded as a novel water-saving irrigation technique in which water will not be wasted but it will aid the root growth, facilitate higher nutrient uptake, and increase land and water productivity (Haefele *et al*., 2016).

Precise crop management depends on the growth characteristics of different varieties to get the maximum yields. Recently some of the high-yielding rice cultivars, viz. 'DRR Dhan 42', 'DRR Dhan 43', 'MTU 1010', 'NLR 34449' were released for Telangana and Andhra Pradesh. Several rice cultivars may vary in their performance under different systems of cultivation. This paper discusses strategies and options to make rice production more sustainable water-efficient with integrative use of crop improvement and management tools.

MATERIALS AND METHODS

A field experiment was conducted during the rainy (*kharif*) season of 2017 and 2018 in the field of ICAR-Indian Institute of Rice Research, Hyderabad, (17°19' N, 78°23' E, 542.3 m above mean sea-Level). The experimental site falls under Semi-Arid Tropics. The soil samples were collected randomly from the experimental field, from 0–30 cm depth and analyzed for their physico-chemical properties by adopting standard procedures. Texturally clay loam with an average of 8.05 soil *p*H, 0.185 dS/m electrical conductivity, 0.485% organic carbon, 226.4, 27.25, and 508 kg/ha available nitrogen, phosphorus, and potassium, respectively. The treatments consisted of 2 irrigation regimes - alternate wetting and drying (AWD) and saturation as main plot treatments, 3 systems of cultivation, viz. the system of rice intensification (SRI) with a spacing of 25 cm × 25 cm, drum seeding (DS) with the spacing of 20 cm × 10 cm and normal transplanting (NT) with the spacing of 20 cm × 15 cm as subplot treatments; and 4 cultivars, viz. 'DRR Dhan 42', 'DRR Dhan 43', 'MTU 1010'and 'NLR 34449' as sub-subplot treatments, laid out in split-plot design with 3 replications. The area of each gross plot was 7 m × 3 m. In drum seeding, sprouted seeds were sown with manually operated rice drum seeder. Seedlings were transplanted with an average of 1 seedling per hill in the SRI method of planting. In normal transplanting method 25-day old rice seedlings were transplanted, with 2 to 3 seedlings/hill. Farmyard manure at @ 10 t/ha was uniformly applied to all the plots before final puddling and leveling. The recommended dose of phosphorus @ 25.8 kg P/ha as single superphosphate (SSP) was applied basal to all the treatments uniformly and potassium @ 33.2 kg K/ha as muriate of potash (MoP) was applied in 2 split–75% basal and the remaining 25% at 75 days after sowing (DAS)/ days after transplanting (DAT). The recommended dose of nitrogen (120 kg/ha) was applied through urea in 3 splits–50% basal, 25% at 50 DAS/DAT, and the remaining 25% at 75 DAS/DAT.

The water content relative to that at full saturation was measured and expressed as relative water content (RWC). For the estimation of RWC, 10-leaf blade discs of 10 mm diameter punched with borer were taken into a pre-weighed sealed vial. After taking the fresh weight (FW), the discs were floated for 24 h on distilled water in covered Petri–dishes, kept at low light intensities and constant room temperature (20°C) until they became fully turgid. The discs were surface dried, kept in the same vial, and re-weighed to obtain the turgid weight (TW). Finally, the leaf discs were oven-dried at 80°C to a constant weight and weighed again to obtain dry weight (DW). The RWC was calculated using the formula as given below.

$$\text{RWC (\%)} = \frac{(\text{FW–DW})}{(\text{TW–DW})} \times 100$$

Plants in the net plot area (m^2) were harvested separately in each plot, threshed and the grains were separated, dried under the sun and the grain yield per plot was recorded after cleaning. From this, the yield per hectare was computed and expressed in kg/ha. After threshing the grain, the remaining straw was dried under the sun and the yield per plot was recorded and the yield per hectare was computed and expressed in kg/ha.

Each plot was irrigated separately, which was bunded with fibre sheet of a depth of 1 m. The amount of irrigation water was measured by using a water meter. The depth of irrigation water (mm) applied was computed by dividing the volume of water applied by the area of the plot. During heavy rainfall, the excessive water was drained-off to keep the ponded water within the maximum allowable depth. Total rainfall of 990.4 mm was received during the crop growth period (24 June 2017 to 16 December 2017) in the year 2017 and 375.6 mm was received (24 June 2018 to 16 December 2018) in the year 2018. The effective rainfall (mm) was calculated 24 h after rainfall, following the field water balance sheet.

The water productivity was calculated for each treatment and expressed in kg/m^3. The following formula was used to calculate the water productivity.

$$\text{Water productivity} = \frac{\text{Grain yield (kg/ha)}}{\text{Quantity of water applied (m}^3\text{)}}$$

Water-use efficiency was expressed in kg/ha-mm.

$$\text{Water-use efficiency} = \frac{\text{Grain yield (kg/ha)}}{\text{Quantity of water applied (mm)} + \text{effective rainfall (mm)}}$$

The data were analyzed statistically by the method of analysis of variance as per the procedure outlined for the split-plot design. Statistical significance was tested by F value at 0.05 level of probability and the critical difference was worked out wherever the effects were significant.

RESULTS AND DISCUSSION

Relative water content (RWC)

The relative water content (RWC %) as influenced by different irrigation regimes, systems of cultivation and cultivars are presented in the Table 1. Among the irrigation regimes, saturation registered significantly higher relative water content at 30, 60, and 90 DAT as compared to alternate wetting and drying (AWD). The normal transplanting (NT) recorded significantly higher relative water content at 30, 60, and 90 DAT over the other systems of cultivation (Table 1). However, the system of rice intensification (SRI) method recorded significantly lower relative water content at 30, 60, and 90 DAT compared with the other systems of cultivation (Table 1). However, the system of rice intensification (SRI) method recorded significatly lower relative water content at 30, 60 and 90 DAT compared with the other systems of cultivation. Among the different cultivars, 'DRR Dhan 43' exhibited significantly higher RWC values at 30, 60, and 90 DAT, whereas 'MTU 1010'and 'NLR 34449' varieties obtained on par RWC values at all the crop-growth stages during both the years of study and in pooled mean (Table 1). On the other hand, 'DRR Dhan 42' recorded numerically lower values of RWC than the other cultivars. Increased RWC helped the plants to perform physiological processes like stomatal conductance, photosynthesis, transpiration and biochemical metabolism to continue effectively even under stress conditions. The cultivars that have more RWC and chlorophyll content are more resistant to drought stress and their yields are stable.

Irrigation water applied

Of the 2 irrigation regimes, throughout the crop-growth period, saturation required more quantity of irrigation water than AWD. Saturation required 11.55, 10.98, and 11.26% more irrigation water during 2017, 2018, and in

Table 1. Effect of irrigation regimes, systems of rice cultivation and cultivars on relative water content (RWC) of rice during the rainy season of 2017 and 2018

Treatment	RWC (%)								
	30 DAT			60 DAT			90 DAT		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
Irrigation regimes (I)									
I_1, AWD	87.71	89.22	88.47	81.25	79.80	80.61	83.51	84.26	83.93
I_2, Saturation	96.74	97.45	97.10	83.32	88.04	85.68	87.23	87.37	87.55
SEm±	0.342	0.383	0.365	0.732	0.601	0.683	0.612	0.654	0.592
CD (P=0.05)	1.21	1.32	1.28	1.93	1.78	1.81	1.72	1.83	1.74
Systems of rice cultivation (S)									
S_1, SRI	85.68	86.94	86.71	82.73	87.65	85.19	80.58	82.00	81.29
S_2, DS	88.37	89.83	89.10	82.12	88.57	85.34	81.59	83.28	82.43
S_3, NT	90.63	91.24	90.83	84.28	90.55	87.41	92.94	91.17	91.84
SEm±	0.737	0.572	0.571	0.855	0.610	0.704	0.793	0.685	0.766
CD (P=0.05)	2.40	1.85	1.85	2.12	1.87	1.96	2.48	2.20	2.37
Cultivars (C)									
C_1, 'DRR Dhan 42'	84.02	84.28	84.15	80.46	83.99	82.13	79.92	81.34	80.63
C_2, 'DRR Dhan 43'	90.71	91.17	90.44	86.36	87.89	87.48	83.53	82.87	83.03
C_3, 'MTU 1010'	87.25	89.26	88.24	83.07	85.91	84.68	78.93	84.62	82.77
C_4, 'NLR 34449'	85.02	87.28	86.15	82.46	85.99	83.53	80.92	81.34	81.63
SEm±	1.233	1.392	1.294	1.181	1.212	0.911	0.122	0.301	0.175
CD (P=0.05)	2.50	2.96	2.67	2.36	2.44	2.57	1.34	1.84	1.57
Interactions (I × S × C)	NS	NS	NS	NS	NS	NS	NS	NS	NS

DAT, days after transplanting; AWD, alternate wetting and drying; SRI, system of rice intensification; DM, drum seeding; NT, normal transplanting pooled mean, respectively over AWD (Table 2). It might be because of more number of irrigations given in saturation as compared to AWD (Thirupathi, 2017). The higher effective rainfall was recorded in AWD than saturation during 2017, 2018 and in pooled means. This may be due to irrigation with Bouman tubes (field water tube) in the AWD method which received irrigation at 3 to 4 days interval that leads to the formation of a hairline crack in the AWD technique that may increase the effective rainfall. Among the irrigation regimes, saturation recorded higher total water applied (1,358 and 994 mm during 2017 and 2018, respectively) as compared to AWD (Table 2).

Among the systems of cultivation, the mean irrigation water applied was higher in NT (880 mm) as compared to SRI (666 mm) and drum seeding (773 mm). The SRI method required 11.61% and 13.21% of mean irrigation water applied lesser than DS and NT, respectively, during 2017 and 2018 (Table 2). The results confirm the findings of Sathish *et al.* (2017) and Thirupathi (2017). System of rice intensification received higher effective rainfall than DS and NT during 2017, 2018, and pooled means (Table 2). The mean quantity of total water applied was higher in NT (1,268 mm) as compared to SRI (1,079) mm and drum seeding (1,166 mm). The SRI method required a lesser quantity of mean total water applied than DS and NT during 2017 and 2018. All the rice cultivars received the same quantity of irrigation water, effective rainfall, and total water applied during 2017 and 2018 (Table 2).

Grain and straw yield

Among the irrigation regimes, AWD irrigation practice throughout the crop-growth period resulted in higher grain yield (5.86 t/ha) (in pooled means) than saturation (5.43 t/ha) (Table 3). This could be because of favourable vegetative growth and development, as they received intermittent and sufficient moisture in the proper amount and at critical stages during the entire period of growth. Thus maintained favourable soil water balance under AWD helped the crop plants to improve performance over-saturation because water plays a vital role in the carbohydrate metabolism, protein synthesis, cell-division, cell enlargement, and partitioning of photosynthates to sink for enhanced development of growth characters. Frequent irrigations created favourable moisture regimes which enabled the crop to grow luxuriantly by providing conducive micro-climate and increasing solubility, absorption, translocation, and assimilation of nutrients by the plants for various physiological processes. On the other way, hairline crack formation in the AWD technique of irrigation resulted in a higher level of yield (Majid, 2014; Saddam *et al.,* 2021). Within irrigation regimes, the AWD method resulted in significantly higher straw yield (6.42 t/ha in pooled means) than saturation (5.99 t/ha) (Table 3). This is owing to adequate moisture availability that contributed to enhanced dry matter accumulation. The results are in confirmity with the findings of Kumar *et al*. (2014).

Among the different systems of cultivation, SRI resulted in significantly higher grain yield (6,041 kg/ha in pooled mean) over the NT method (5.20 t/ha). This was however on par with the drum-seeding method (5.80 t/ha) (Table 3). The SRI method provides wider spacing, better aeration, and limited competition, which enabled the plants to grow luxuriantly. The enhanced seed yield in SRI can be attributed to the more root growth that enabled them to access nutrients from a larger volume of soil. It helped capture all the essential nutrient elements for plant growth and thereby resulting in higher tillering and dry matter production (Rajendran *et al*., 2013). The SRI method recorded higher

Table 2. Irrigation water applied, effective rainfall and total water applied in rice as influenced by different irrigation regimes, systems of rice cultivation and cultivars during the rainy season of 2017 and 2018

Treatment	Irrigation water applied (mm)			Effective rainfall (mm)			Total water applied (mm)		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
Irrigation regimes (I)									
I_1, AWD	651	713	682	581	268	425	1,232	981	1,107
I_2, Saturation	752	783	768	575	242	409	1,358	994	1,176
Systems of rice cultivation (S)									
S_1, SRI	643	688	666	583	243	413	1,226	931	1,079
S_2, DS	768	778	773	565	220	393	1,333	998	1,166
S_3, NT	869	891	880	545	231	388	1,414	1,122	1,268
Cultivars (C)									
C_1, 'DRR Dhan 42'	715	771	743	578	265	422	1,293	1,036	1,165
C_2, 'DRR Dhan 43'	715	771	743	578	265	422	1,293	1,036	1,165
C_3, 'MTU 1010'	715	771	743	578	265	422	1,293	1,036	1,165
C_4, 'NLR 34449'	715	771	743	578	265	422	1,293	1,049	1,165

AWD, Alternate wetting and drying; SRI, system of rice intensification; DS, drum seeding; NT, normal transplanting straw yield (6.39 t/ha in pooled mean) over the other systems of cultivation. This might be owing to a higher number of tillers/hill because of transplanting younger seedlings in the case of SRI. The NT method resulted in the lowest straw yield than other systems of cultivation, which was due to uneven plant stand and fewer numbers of seedlings/hill and less number of tillers/unit area (Thirupathi, 2017) number of productive tillers, leaf area duration, leaf photosynthetic rate, dry-matter accumulation, crop-growth rate, non-structural carbohydrate (NSC) in the stem at heading and its remobilization during grain filling, root biomass, and root-oxidation activity (Zhou *et al*., 2017).

Among the different rice cultivars, higher grain yield was noticed in 'DRR Dhan 43' (6.08 t/ha in pooled mean), followed by 'MTU 1010' (5.68 t/ha) and 'NLR 34449' (5.53 t/ha). However, significantly lower grain yield was recorded in 'DRR Dhan 42' (Table 3). The rice cultivars which produce more effective tillers, grains/panicle, test weight, and reduced sterility percentage gave higher seed yield. 'DRR Dhan 43' gave significantly higher straw yield than the other cultivars (6.62 t/ha in pooled means). The lower straw yield was observed in 'DRR Dhan 42' (5.80 kg/ha in pooled means). However, cultivars 'MTU 1010', 'NLR 34449', and 'DRR Dhan 42' were at par with each other.

Water productivity and water-use efficiency

Among the irrigation regimes, the water productivity recorded was significantly higher with AWD than saturation (Table 3). This was because of the lower quantity of irrigation water applied in the AWD method than saturation (Ghosh *et al*., 2014) that increased water productivity (kg/m^3 of water consumed) significantly. Among the different systems of cultivation, the SRI method registered significantly superior values of water productivity than DS and NT during 2107 and 2018. Water productivity was higher in SRI than NT and DS methods (Table 3). This was because of higher grain yield and reasonably lower irrigation water used in SRI than the other systems of cultivation (Kumar *et al*., 2014). Biomass formation (yield) is essentially a linear function of water consumed by the crop, so that production increases are associated with commensurate increase in water consumption (Perry *et al*., 2017; Poddar *et al.,* 2021). Among the different rice cultivars, 'DRR Dhan 43' noticed significantly higher irrigation water productivity than the other cultivars (Table 3). However, 'DRR Dhan 42' recorded the lowest irrigation water productivity during both 2017 and 2018.

Water-use efficiency

Between the irrigation regimes, AWD resulted in superior water-use efficiency (WUE) to saturation during 2017 and 2018. A higher value of WUE was recorded in AWD (5.24 kg ha-mm in pooled mean) than saturation (4.62 kg ha-mm in pooled mean) (Table 3). This is attributed to higher grain yield by utilization of less water, which re-

Table 3. Influence of irrigation regimes, systems of rice cultivation and cultivars on grain yield, straw yield, water productivity and water-use efficiency of rice during the rainy season of 2017 and 2018

Treatments	Grain yield (kg/ha)			Straw yield (kg/ha)			Water productivity (kg/m^3)			Water-use efficiency (kg/ha-mm)		
	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled	2017	2018	Pooled
Irrigation regimes (I)												
I_1 AWD	5.75	5.95	5.85	6.28	6.55	6.42	0.88	0.82	0.85	4.66	5.97	5.24
I_2 Saturation	5.34	5.49	5.43	5.87	6.11	5.99	0.69	0.73	0.71	3.97	5.52	4.62
SEm±	0.11	0.12	0.13	0.12	0.12	0.12	0.01	0.02	0.02	0.11	0.16	0.13
CD (P=0.05)	0.36	0.38	0.37	0.36	0.36	0.36	0.04	0.07	0.06	0.32	0.46	0.38
Systems of rice cultivation (S)												
S_1 SRI	5.95	6.12	6.04	6.24	6.54	6.39	0.93	0.89	0.91	4.86	6.58	5.60
S_2 DS	5.78	5.82	5.80	5.88	6.12	6.00	0.75	0.75	0.75	4.34	5.84	4.98
S_3 NT	5.14	5.25	5.20	5.62	5.87	5.75	0.59	0.59	0.59	3.64	4.69	4.10
SEm±	0.12	0.13	0.13	0.16	0.15	0.16	0.01	0.03	0.02	0.10	0.23	0.14
CD (P=0.05)	0.33	0.41	0.37	0.42	0.43	0.42	0.04	0.11	0.07	0.32	0.75	0.47
Cultivars (C)												
C_1, 'DRR Dhan 42'	4.94	5.17	5.06	5.71	5.89	5.80	0.69	0.67	0.68	3.82	5.00	4.34
C_2, 'DRR Dhan 43'	6.05	6.12	6.08	6.45	6.98	6.62	0.85	0.79	0.82	4.68	5.91	5.23
C_3, 'MTU 1010'	5.63	5.73	5.68	6.30	5.93	5.92	0.79	0.74	0.76	4.35	5.53	4.88
C_4, 'NLR 34449'	5.47	5.59	5.53	5.82	6.15	5.98	0.77	0.73	0.74	4.24	5.33	4.75
SEm±	0.16	0.18	0.20	0.21	0.19	0.19	0.03	0.02	0.02	0.22	0.16	0.13
CD (P=0.05)	0.48	0.53	0.51	0.60	0.55	0.20	0.08	0.07	0.06	0.63	0.46	0.35
Interactions (I × S × C)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

AWD, Alternate wetting and drying; SRI, system of rice intensification; DM, drum seeding; NT, normal transplanting sulted in higher water-use efficiency under the AWD irrigation regime (Ghosh *et al*., 2014). Among the different systems of rice cultivation, the SRI method revealed higher WUE values (4.86, 6.58, and 5.60 kg/ha mm during 2017, 2018, and in pooled means, respectively) than other systems of cultivation. It is because of higher grain yield and relatively lower water used for production than other systems of cultivation. The findings confirmed the observations made by Kumar *et al*. (2014). Among the different rice cultivars, higher WUE was with 'DRR Dhan 43' than the other rice cultivars. The lower WUE was recorded in 'DRR Dhan 42'. However, the cultivars 'MTU 1010' and 'NLR 34449' were at par with each other during 2017 and 2018.

Among the irrigation regimes, the highest quantity of irrigation water was applied in the saturation method and higher effective rainfall was recorded under AWD. Application of water through the AWD method saved around 11–14% of total water requirement during the crop growth period. Irrigation by AWD exhibited significantly higher irrigation water productivity and water-use efficiency. The SRI method required the lowest amount of water (11.61% and 13.21% less of mean applied water than drum seeding and normal transplanting, respectively). Significantly higher water productivity and WUE were registered with SRI. The highest quantity of water was applied under the normal transplanting method. 'DRR Dhan 43' showed higher water productivity as well as WUE than the other cultivars during both the years of study.

The first author is greatful to the Ministry of Tribal Affairs, Government of India, for the financial help in the form of National Fellowship and Scholarship for Higher Education of Students, during the study period (2017–18 NFST-KAR-00149). Authors are greatful to the Indian Council of Agricultural Research, New Delhi and Acharya N.G. Ranga Agricultural University; Lam, Guntur; Indian Institute of Rice Research (IIRR), Rajendranagar, Hyderabad, for providing facilities during the course of this field research programme.

REFERENCES

ASG. 2019. *Agricultural Statistics at a Glance.* Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi, pp. 79–81.

Ghosh, M., Swain, D.K., Jha, M.K and Tewari, V.K. 2014. Precision nitrogen management using chlorophyll meter for improving growth, productivity and N use efficiency of rice in subtropical climate. *Jounal of Agricutural Sciences* **5**(2): 253–266.

Haefele, S.M., Kato, Y. and Singh, S. 2016. Climate ready rice: Augmenting drought tolerance with best management practices. *Field Crops Research* **190**: 60–69.

Huang, M., Shan, S.L., Zhou, X.F., Chen, J.N., Cao, F.B., Jiang, L.G. and Zou, Y.B. 2016. Leaf photosynthetic performance related to higher radiation use efficiency and grain yield in hybrid rice. *Field Crops Research* **193**: 87–93.

Kumar, S., Singh, R.S. and Kumar, K. 2014. Yield and nutrient uptake of transplanted rice (*Oryza sativa*) with different moisture regimes and integrated nutrient supply. *Current Advances in Agricultural Sciences* **6**(1): 64–66.

Majid, A. 2014. Water use efficiency, irrigation management and nitrogen utilization in rice production in the North of Iran. *APCBEE Procedia* **8**: 70–74.

Perry, C. Pasquale, S. and Karajeh, F. 2017. Does improved irrigation technology save water: A review of the evidence. Discussion paper on irrigation and sustainable water resources management in the near east and north africa. Food and Agriculture Organization of the United Nations, Cairo, pp. 1–57.

Poddar, R., Acharjee, P.U., Bhattacharyya, K. and Patra, S.K. 2021. Effect of irrigation regime and varietal selection on the yield, water productivity, energy indices and economics of rice production in the lower Gangetic Plains of Eastern India. *Agricultural Water Management* **262**: 1–17.

Rajendran, K., Raja, K.G. and Balasubramanian, R. 2013. Evaluation of crop establishment techniques and weed management practices under system of rice intensification. *Madras Agricultural Journal* **100**(7–9): 698–702.

Saddam, H., Zubair, Aslam., Muhammad, R., Adeel, Abbas, Muhammad, S., Abdur, R., Christophe, H., Mohamed, A. and El-Esawi, 2021. Impact of different water management regimes on the growth, productivity, and resource use efficiency of dry direct seeded rice in central Punjab-Pakistan. *Agronomy* **11**: 1–13.

Sathish, A., Reddy, P.R., Kumar, A.K and Umadevi, M. 2017. Effect of different crop establishment methods and irrigation regimes on rice (*Oryza sativa*) yield and water use efficiency. *International Journal of Current Microbiology and Applied Sciences* **6**(9): 90–95.

Thirupathi, I. 2017. Assessment of production potential and green house gas emissions from rice fields with irrigation regimes and nitrogen management practices under different establishment methods. Ph.D. Thesis, Professor Jayashankar Telangana State Agricultural University, Hyderabad, Telangana.

Wu, L.L., Yuan, S., Huang, L.Y., Sun, F., Zhu, G.L., Li, G.H., Fahad, S., Peng, S.B. and Wang, F. 2016. Physiological mechanisms underlying the high-grain yield and high-nitrogen use efficiency of elite rice varieties under a low rate of nitrogen application in China. 2016. *Front Plant Sciences* **7**: 1,024.

Yadav, S.K., Babu, S., Singh, Y., Yadav, G.S., Singh, K., Singh, R and Singh, H. 2013. Effect of organic nitrogen sources and biofertilizers on production potential and energy budgeting of rice (*Oryza sativa*)-based cropping systems. *Indian Journal of Agronomy* **58**(4): 459–464.

Zhou, Q., Cheng, X.J., Wang, Z.Q., Zhang, H., Liu, L.J., Yang, J.C. and Zhang, J.H. 2017. Grain yield and water use efficiency of super rice under soil water deficit and alternate wetting and drying irrigation. *Journal of Integrative Agriculture* **16**(5): 1,028–1,043.