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Enhancing growth, yield and water use efficiency of rice (*Oryza sativa*) through drip irrigation

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ABSTRACT

A field experiment was conducted during rainy (*kharif*) season of 2018 and 2019 at the research farm of Tamil Nadu Rice Research Institute, Aduthurai, Tamil Nadu to evaluate the impact of drip irrigation on rice (*Oryza sativa* L.) growth, productivity and water use efficiency. The experiments were laid out in a strip plot design with 4 varieties/hybrids in the horizontal strip and 6 irrigation regimes in the vertical strip with 3 replications. The findings reveal that drip irrigation at 125% Pan Evaporation (PE) resulted in superior growth, yield parameters and grain yield. KRH 2 with 125% PE recorded the maximum grain yield (4200 kg/ha), followed by ADT 45 (4140 kg/ha) with 125% PE. All yield attributes, except ill-filled grains/panicle, increased with increasing irrigation level from 50 to 125% PE. Rice yield attributes, viz. tillers/m^2 (r=0.86), panicles/m^2 (r=0.90) and grains/panicle (r=0.84) showed positive correlation with grain yield. Irrespective of the variety and irrigation levels the row closer to the drip line recorded higher grain yield at all the irrigation levels compared to rows farthest. Among the irrigation regime the highest total water use (671 mm) was recorded in 125% PE while the highest water use efficiency (6.5 kg/ha-mm) was recorded in 75% PE up to tillering stage, 100% PE during flowering phase and 75% PE during maturity phase. Among the variety, ADT 45 recorded the highest water use efficiency (7.15 kg/ha mm). The study recommends KRH 2 hybrid and ADT 45 variety for drip irrigation with 125% PE in areas with limited water availability, especially in well-irrigated areas.

Keywords: Drip irrigation, Irrigation regime, Rice, Water use efficiency, Yield

The water availability to agriculture is expected to reduce from 87 to 73% by 2020 in developing countries (Khan *et al.* 2006). The groundwater table is declining in many rice growing regions at an alarming rate and 60% of the total irrigation water is diverted for rice cultivation (Vijayakumar *et al.* 2018). The water use efficiency of conventional transplanted rice is very low (3–4 kg/ha mm). In Tamil Nadu, the irrigated rice area in *kharif* was reduced by 56 thousand ha between 2001 and 2006, due to the non-availability of canal water in time. Shifting from double-crop to single crop is reported in many regions due to erratic water availability. If this trend continues, the *kharif* crop could disappear entirely (Srimathi *et al.* 2018). The development and adoption of water-saving technologies is crucial to overcome the declining irrigation water availability for the agricultural sector (Subramanian *et al.* 2008, Vijayakumar *et al.* 2019a).

Drip irrigation can reduce water use (>50%) and provide higher productivity in many crops (Parthasarathi *et al.* 2018, Singh *et al.* 2019a, Subramanian *et al.* 2021). This technique eliminates conveyance losses, seepage and deep percolation while maintaining soil moisture at saturation levels throughout time (Nayak *et al.* 2020). Surface (1607–1733 litres) and subsurface (938–1110 litres) drip irrigation significantly reduced quantity of water needed to produce 1 kg of paddy compared to conventional continuous flooding (4658–5508 litres) (Singh *et al.* 2019a). Low-pressure subsurface drip irrigation reduced irrigation input by 80% compared to conventional flood irrigation at the University of Missouri Marsh Farm (Ottis *et al.* 2006). The subsurface drip system laid out at 0. 8 m lateral distance with 1.0 L per hour dripper discharge was found to improve rice growth, physiology and yield (Parthasarathi *et al.* 2018). Only very few studies are conducted on rice with drip irrigation in India. A study on drip irrigation in rice reported a delay in rice maturity by 2 weeks compared to conventional flood irrigation with a minimal difference in yield (Subramanian *et al.* 2021). Thus, we conducted field trails to assess the feasibility of growing rice under drip irrigation in Tamil Nadu.

MATERIALS AND METHODS

A field experiments were conducted at the research

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farm of Tamil Nadu Rice Research Institute, Aduthurai during rainy (*kharif)* season of 2018 and 2019 to assess the feasibilities of drip irrigation on the growth and yield of rice. This study was carried out to screen suitable variety/ hybrid and optimum irrigation regime under drip irrigation. The experiments were laid out in a strip plot design with 3 replications. Horizontal strip consists of 4 varieties/hybrids (ADT 43, ADT 45, CORH 3 and KRH 2) and vertical strip consist of 6 irrigation regimes (50%, 75%, 100% and 125% Pan Evaporation (PE) during entire cropping period) and changes in irrigation regime according to the crop stage [(Tillering – 50%, Flowering – 75% and Maturity – 50% PE) and (Tillering – 75%, Flowering – 100% and Maturity – 75% PE)]. The plot size was 40 m^2. The 16 mm laterals were laid out at 80 cm distance between the laterals and the emitter's spacing was 30 cm. The emitter discharge rate was 1.6 litre/h. Based on the evaporation value from the open pan evaporimeter the drip irrigation was given every alternate day as per the treatments. The field was ploughed and harrowed properly for sowing. Rice was sown in dry soil with the spacing of 20 cm × 10 cm. Thinning and gap filling was done at 15 days after sowing. A common fertilizer dose of 150:50:50 kg N; P_2O_5:K_2O/ ha was adopted. Pre-emergence herbicide pendimethalin at 0.75 kg a.i/ha was applied at 3 DAS (days after sowing). The growth attributes (plant height, leaf area index (LAI) and dry matter production), root attributes (root length, root volume and root weight), yield parameters (panicles/m^2), panicle length, grains/panicle and ill filled grains/panicle) were recorded at flowering and grain yield was recorded at 15% moisture content. The plants were uprooted carefully without any root damage at flowering for the measurement of root length (from the base to tip of the longest root). The soil particles adhering to the uprooted plants were removed carefully and air dried. These roots were immersed in 500 ml water taken in 1000 ml measuring cylinder. The increases in the volume were recorded and expressed in cubic centimetre (cc). The irrigation water was applied based on the PE and quantified by using water meter. The water use efficiency (WUE) was calculated by dividing the grain yield with total amount of irrigation water applied including effective rainfall. The rainfall received during the cropping was measured by an automatic rain gauge installed in the automatic weather station. The rainfall received during the period is 239 to 253 mm and the effective rain was worked out by using the daily water balance sheet method. The two years pooled mean data on various characters were statistically analyzed as suggested by Gomez and Gomez (1984). Wherever statistical significance was observed critical difference (CD) at 0.05 level of probability was worked out for comparison.

RESULTS AND DISCUSSION

Growth parameters: Irrigation regimes and varieties/ hybrids caused significant variation in growth parameters, viz. plant height and LAI. At flowering stage, drip irrigation at 125% PE recorded higher growth parameters, viz. plant height (73.7 cm) and LAI (6.1). This was followed by 75% PE up to tillering stage, 100% PE during flowering phase and 75% PE during maturity phase and 100% PE during the entire crop period. The increased levels of irrigation regime (125% PE) through drip system favoured plant height positively and increase in leaf area index under 125% PE could be due to uptake of nutrients under higher moisture conditions resulting in more number of leaf and higher leaf area coupled with more dry matter accumulation (Mondal and Pramanik 2020). Among varieties/hybrids, KRH 2 hybrid recorded higher growth parameters, viz. plant height (74.0 cm) and LAI (6.1) at flowering. This was followed by hybrid CORH 3 and ADT 45. These results showed that hybrids performed better than variety in terms of plant growth parameters. The popular rice variety, ADT 43 cultivated during the *kharif* season, produced shorter plants with lesser LAI under drip irrigation.

Root characters: The root character of rice was very much influenced by different irrigation regimes under drip irrigation. Drip irrigation at 125% PE recorded significantly longer roots of 17.4 cm at flowering stage (Table 1). This was followed by 75% PE up to tillering stage, 100% PE during flowering phase and 75% PE during maturity phase. This was mainly attributed to optimum moisture present in the upper 30 cm soil layer in drip irrigation due to higher rate of PE. Moreover, at the higher PE irrespective of the variety, the roots tend to grow faster rate than the lower PE (Karthika *et al.* 2019). Among the variety/hybrid, KRH 2 recorded significantly longer roots of 17.0 cm at flowering stage and was followed by hybrid CORH 3 and ADT 45 variety. Vijaykumar (2009) stated that under water deficit situation; even the susceptible varieties produced slender and longer roots to absorb moisture from lower layers. In the present study hybrid KRH 2 might have put forth deep and lengthy roots which increased root volume and dense root proliferation at top. Similarly, the higher root volume of 36.4 cc was recorded in rice crop irrigated with 125% PE and it was significantly superior than other irrigation regimes. The increased root volume and length, in turn, increased the root weight. It is clear from the results that at a high level of irrigation rice roots react positively and produce lengthier roots with higher root volume and root weight. Among the varieties/hybrids, the ADT 45 recorded higher root volume and root weight.

Yield attributes and yields of rice: The yield attributes of rice under various drip irrigation regimes were affected significantly during both the year of the experiment (Table 1). Tillering of rice varied significantly with different irrigation regimes under drip irrigation. At flowering stage, the irrigation regime of 125% PE recorded the highest number of tillers. This was followed by the application of irrigation at 100% PE. Minimum tillers were observed at 50% irrigation regime. Among the variety/hybrid, ADT 45 produced the highest number of tillers per unit area followed by KRH 2 and CORH 3. The higher plant height, LAI and tillers/m^2 at irrigation regimes 125% PE resulted in higher DMP (6.86 t/ha) and it was significantly higher

than the other irrigation regimes. Among the rice variety, ADT 45 produced the highest dry matter because of its effective root systems with more tillers per unit area. The maximum number of panicles/m^2 (322), panicle length (25.9), grain/panicle (144) and lowest number of ill-filled grain/panicle (11.5) were obtained with 125% PE followed by irrigation at 100% PE. The higher number and better growth of yield attributes in 125% PE and 100% PE might be due to the availability of more water. The yield attributes of rice tend to be reduced when irrigation was applied at lesser PE rates. Exposure of rice plants to even mild water stress causes tiller mortality and spikelet sterility which, in turn, reduce productive tillers/m^2 and filled grains/panicle (Vijayakumar *et al.* 2019a). The lowest number of panicles/m^2 (242), panicle length (20.9), grain per panicle (115) and highest number of ill-filled grain per panicle (25.4) were recorded with irrigation at 50% PE. Among the variety, ADT 45 produced the maximum number of panicles/m^2, panicle length and lowest number of ill-filled grains per panicle. The ADT 45 produced a lengthier panicle with higher number of grains per panicle and even higher than the hybrids. Among the variety, ADT 45 recorded the lesser number of ill-filled grains per panicle and it was found to be the ideal rice variety under reduced water conditions.

The grain yield was significantly influenced by irrigation regimes and varieties/hybrids (Table 2). Irrigation at 125% PE recorded a significantly higher grain yield of 3893 kg/ha. This was followed by irrigation at 100% PE. This was mainly attributed to better growth and yield parameters which might be due to uninterrupted and continuous soil moisture availability throughout the crop growth period resulting in a taller plant, higher LAI, more tillers/m^2, larger panicle and less number of ill-filled grains. The production of higher biomass is a prerequisite for higher grain yield. The deficit of water to rice plant at 50% PE and 75% PE reduced the plant growth and dry-matter significantly which in turn reduced the grain yield in these treatments. Among the rice variety/hybrid, ADT 45 recorded a higher grain yield of 3654 kg/ha and was comparable with hybrids KRH 2 and CORH 3. Irrespective of the variety and irrigation levels, the variation in growth, yield parameters and grain yield of rice was noticed between rows closer and rows farther to the drip line. Hence, the yields were recorded separately with row closer to the drip and row farther from the drip and it was analyzed by using mean values for better understanding (Table 3). Row closer to the drip line recorded higher grain yield at all the irrigation levels compared to rows farthest. This might be due to better availability of soil moisture and nutrients in the crop rows which are nearer to the drip line than rows farthest to the drip line. Hence, better availability of nutrients in rows closer to drip led to more uptake and better growth and development of plants resulting in remarkably higher grain yield of rice (Mohan 2017). The lowest yield variation of

Table 1 Effect of drip irrigation regimes on rice root and yield at flowering (two years pooled data)

Treatment	Root length (cm)	Root volume (cc)	Root weight (g)	Tillers/ m^2	DMP (t/ha)	Panicle/ m^2	Panicle length (cm)	Grains/ panicle	Ill-filled grains/ panicle	Total water used (mm)
Irrigation regimes										
50% PE	16.0	24.5	3.55	384	5.52	242	20.9	115	25.4	488
75% PE	16.1	29.6	4.21	408	6.05	269	21.4	129	20.2	549
100% PE	16.8	32.5	4.48	455	6.45	299	24.5	138	15.6	610
125% PE	17.4	36.4	4.82	471	6.86	322	25.9	144	11.5	671
Tillering–50% Flowing–75% Maturity–50% PE	16.7	31.5	4.32	405	5.69	244	21.2	131	19.8	502
Tillering–75% Flowing–100% Maturity–75% PE	16.3	30.5	4.29	451	6.22	264	21.8	134	19.2	545
SEd	0.30	1.01	0.12	15.65	0.17	10.83	0.58	2.17	0.58	14.54
CD (P=0.05)	0.62	2.1	0.25	32.4	0.35	22.42	1.2	4.5	1.2	30.08
Variety/Hybrid										
ADT 43	16.0	22.4	2.52	409	5.48	215	22.4	135	34.5	542
ADT 45	16.8	35.6	4.79	455	6.78	318	25.4	128	12.5	549
CORH 3	16.4	32.4	4.52	440	6.24	292	24.2	122	13.2	569
KRH2	17.0	33.7	4.55	446	6.32	304	24.8	125	12.9	582
SEd	0.33	1.35	0.14	17.58	0.20	12.21	0.72	2.56	0.87	16.79
CD (P=0.05)	0.68	2.8	0.29	36.4	0.41	25.27	1.5	5.3	1.8	34.74

DMP, Dry matter production; PE, Pan evaporation.

10% was recorded in ADT 45 rice variety with 125% PE levels. The highest yield variation was observed in ADT 43 rice variety. Increasing irrigation levels showed a lesser difference in grain yield between rows closer and rows farther to the drip line. Whereas, the lower levels recorded higher variations between rows close and row farthest to the drip line. Hence, in drip irrigated rice the lateral spacing and dripper spacing with dripper outlets need to be studied for uniform application of water to the entire plant system.

Water use efficiency: Irrigation at 125% PE registered higher amount of total water used (671 mm) including irrigation water plus effective rainfall (Table 1). This was followed by irrigation at 100% PE (610 mm). The total water used by the crop at 125% PE was 10.0% higher than the drip irrigation at 100% PE. Among the varieties/hybrids, hybrid KRH 2 recorded higher total water use (582 mm) and was followed by CORH 3 (569 mm), ADT 45 (549 mm) and ADT 43 (542 mm). The highest water use efficiency of 6.5 kg/ha mm was noticed with irrigation regime of 75% PE up to tillering stage, 100% PE during flowering phase and 75% PE during maturity phase, irrespective of varieties/hybrids the highest value of 7.15 kg/ha-mm was recorded in ADT 45 (Table 2). This was closely followed by irrigation regime of 50% PE up to tillering stage, 75% PE during flowering phase and 50% during maturity phase in all the varieties. These results were in accordance with Rekha (2014) and Gururaj (2013). These studies revealed that supplying water to soil and nearer to plant with sufficient quantities resulted in higher water use efficiency. Among the varieties, ADT 45 recorded higher grain yield per unit quantity of water used (6.65 kg/ha mm). This was followed by CORH 3 and KRH 2. This might be due to superiority in expressing different growth and yield attributes with well-developed root system, which facilitated better utilization of soil moisture from the root foraging zone (Anusha 2015).

Correlation and regression studies: Yield attributes

Table 2 Effect of irrigation levels and rice varieties/hybrids on grain yield and water use efficiency of rice (two years pooled data)

Treatment	Grain yield (kg/ha)					Water use efficiency (kg/ha mm)				
	ADT 43	ADT 45	CORH 3	KRH 2	Mean	ADT 43	ADT 45	CORH 3	KRH 2	Mean
Irrigation level										
50% PE	2442	2980	2830	2830	2771	5.14	6.21	5.75	5.60	5.67
75% PE	2640	3564	3370	3360	3234	4.96	6.62	6.05	5.90	5.88
100% PE	3080	3950	3860	3890	3695	5.24	6.62	6.22	6.13	6.05
125% PE	3260	4140	3970	4200	3893	5.06	6.31	5.79	6.01	5.79
Tillering–50%, Floweing–75% and Maturity–50% PE	2710	3470	3230	3216	3156	5.54	7.03	6.38	6.19	6.28
Tillering–75%, Floweing–100% and Maturity–75% PE	3050	3820	3539	3790	3550	5.78	7.15	6.41	6.70	6.51
Mean	2864	3654	3466	3548		5.28	6.65	6.10	6.08	
	SEd		CD (P=0.05)			SEd		CD(P=0.05)		
I	90.98		188.2			0.158		0.326		
V	105.5		217.9			0.182		0.377		
I × V	181.9		376.4			0.316		0.653		

Table 3 Effect of irrigation levels on grain yield (kg/ha) variation in rows in rice (two years pooled data)

Variety/Hybrid	ADT 43			ADT 45			CORH 3			KRH 2		
	RC	RF	Variation (%)	RC	RF	Variation (%)	RC	RF	Variation (%)	RC	RF	Variation (%)
Irrigation level												
50% PE	2862	2022	29.4	3400	2560	24.7	3250	2410	25.8	3250	2410	25.8
75% PE	2990	2290	23.4	3984	3144	21.1	3790	2950	22.2	3780	2940	22.2
100% PE	3380	2780	17.8	4270	3630	15.0	4280	3440	19.6	4310	3470	19.5
125% PE	3480	3040	12.6	4360	3920	10.1	4350	3550	18.4	4620	3780	18.2
Tillering–50%, Flowering–75% and Maturity–50% PE	3000	2420	19.3	3820	3120	18.3	3650	2850	21.9	3636	2796	23.1
Tillering–75%, Flowering–100% and Maturity–75% PE	3300	2800	15.2	4040	3600	10.9	3959	3119	21.2	4210	3370	20.0

PE, Pan evaporation; RC, Rows closest; RF, Rows furthest.

(tillers/m^2, panicles/m^2 and grains/panicle) of rice showed a significant positive correlation with grain yield. The highest positive correlation was observed between grain yield and panicles/m^2 (0.903) and grain yield and tillers/m^2 (0.867). Similarly, correlation between grains/panicle and tillers/m^2 (0.963) found positive (0.963). A lowest positive correlation was observed between grain yield and grains/panicle (0.837). Whereas, a negative correlation was observed between grain yield and ill-filled grains (-0.864). In regression analysis a positive and linear relationship of grain yields with tillers/m^2 and panicles/m^2 was observed.

From this study, drip irrigation at 125% PE throughout the crop period exhibited superior growth, yield parameters and grain yield during *kharif* seasons. The maximum grain yield of 4200 kg/ha was recorded in KRH 2 hybrid with 125% of pan evaporation followed by ADT 45 produced 4140 kg/ha with 125% of pan evaporation. Hence, the rice hybrid KRH 2 and ADT 45 can be recommended for drip irrigation with 125% PE. Compared with lowland rice, water consumption in drip irrigated rice was lesser (48%) even in irrigation at 125% pan evaporation. At the same time yield reduction was up to 15% in drip irrigated rice compared to low land rice. Because of its low water use with reasonable yield, drip irrigated rice has greater scope in areas where water availability is limited especially in well irrigated area. However, the yield levels are still lower than the aerobic rice (the yield range in aerobic rice are 4 to 6 t/ha). Hence, more focus is needed to increase the yield level in drip irrigated rice for its sustainability.

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