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Research Paper

Aerobic rice (*Oryza sativa*) cultivation under drip irrigation and fertigation system

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ABSTRACT

A field experiment was conducted during the summer of 2019 and 2020 at the research field of (All Indian Coordinated Research Project on Water Management), Agricultural College and Research Institute, Madurai, Tamil Nadu, to assess the effect of drip irrigation and fertigation on aerobic rice (*Oryza sativa* L.) cultivation. The experiment was laid out in strip-plot design, replicated thrice. The irrigation was scheduled once in 3 days at 120, 100, and 80% pan Evaporation (PE), and the fertigation of 100, 75 and 50% recommended Dose of Fertilizer (RDF) was given weekly intervals from 15 days after sowing (DAS) to 70 DAS and the control of surface irrigation at an irrigation water: cumulative evaporation (IW : CPE) 1.25 with soil application of RDF (150 : 50 : 50 kg/NPK/ha) was separately maintained. The results of different irrigation and fertigation practices showed that, 120% PE × 100% RDF along with associated crop management had a significant effect on crop growth, yield and yield-contributing parameters and their values were significantly higher than all the other drip irrigation regimes and fertigation levels. This was mainly owing to continued availability of soil moisture and nutrients throughout the life period of aerobic rice, which led increased growth and yield parameters at the maximum level. Thus, 120% PE drip regimes and 100% RDF fertigation level proved better option in aerobic rice cultivation under drip irrigation and fertigation system in respect of yield and water saving.

Key words: Aerobic rice, Drip irrigation, Drip fertigation, Growth parameters, Water-use efficiency, Yield

Rice (*Oryza sativa* L.) is the staple food crop for more than half of the world population and influences the livelihoods and economics of several billion peoples (Pimentel *et al.,* 2004). Asia's food security mostly depends on irrigated lowland rice-cultivation practices, which produce three-quarters of all the harvested (Bouman *et al.,* 2005). Rice production and food security largely depend on the irrigated lowland rice system, whose sustainability is threatened by freshwater scarcity, water pollution and competition for water use. Water scarcity is the major problem that causes a decrease in crop yield. A flooded and irrigated rice system consumes twice or thrice the amount of water needed for other cereals, such as maize or wheat (Subramanian *et al.,* 2020). India is already water-stressed and is moving towards into a water-scarce. The declining water availability and the increasing cost of water endanger the traditional system of puddled transplanted rice cultivation (Maraseni *et al.,* 2018). This shortage of water is forcing the farmers to adopt water-saving and cost-effective rice cultivation techniques. Aerobic rice is one of the approaches in rice production that leads to a considerable amount of water-saving. It is characterized by an aerated soil environment during the crop-growth period (Bouman and Tuong, 2001). Addressing these issues requires an introduction of drip irrigation in aerobic rice is one of the water-saving methods of growth of rice by direct seeding in unpuddled conditions without standing water and irrigating similar to another upland cereal crop.

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MATERIALS AND METHODS

The field experiment was conducted during the summer of 2019 and 2020 at the research field of All (India coordinated Research Project on Water Management Scheme), Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai (9°54'N, 78°54'E), India. The experimental soil was clay loam with *p*H 7.04, electrical Conductivity (EC) 0.33 dS/m, and organic carbon

0.42%. The field experiment was laid out in strip-plot design, replicated thrice. The treatments consisted of irrigation regimes: I_1, drip irrigation at 120% pan evaporation (PE); I_2, drip irrigation at 100% PE; I_3, drip irrigation at 80% PE; and fertigation levels: F_1, fertigation of 100% recommended dose of fertilizer (RDF); F_2, fertigation of 75% RDF; F_3, fertigation of 50% RDF. Separately, maintained the surface irrigation [irrigation water (IW): cumulative pan evaporation (CPE) of 1.20] with soil application of RDF as the control for the comparison.

The experimental field was thoroughly ploughed with duck foot, cultivator and rotovator to obtain fine tilth. Raised beds were formed manually with 90 cm top bed width and 30 cm furrow width. The rice seeds (var 'CO 51') were dibbled manually on 22 February 2020 at 20 cm × 10 cm spacing and 5 rows were accommodated in a single raised bed. The lateral was laid out in the centre of each bed. Drip irrigation was scheduled once in 3 days and fertigation (RDF of 150 : 50 : 50 kg N P K/ha) was followed as per the treatments. The entire P was applied as basal through single superphosphate. The N and K were fertigated through a mini fertigation unit as urea and white potash at weekly intervals from 15 to 70 days after sowing. In the control plot, surface irrigation to a depth of 5 cm was scheduled by IW: CPE of 1.20. The recommended P along with 50% N and K was applied basally. Remaining 50% N and K were top-dressed in 3 equal splits 25, 45, and 65 days after sowing. The quantity of water was calculated as:

$$WRc = CPE \times Kp \times Kc \times Wp \times A$$

where, WRc, computed water requirement (plant); CPE, cumulative pan evaporation for 3 days (mm); Kp, pan factor (0.8); Kc, crop factor; Wp, wetting percentage (0.2); A, area/plant. The data were statistically analyzed by applying the technique of analysis suggested by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Plant height (cm)

The tallest plants were observed with surface (IW: CPE 1.20) irrigation with soil application of 100% RDF at maturity (99.6 cm), and it was on a par with drip irrigation at 120% PE and fertigation of 100% RDF. Interaction effect of both drip irrigation and fertigation levels on the plant height of rice was significant (Table 1). The treatment combination of drip irrigation at 120% PE and fertigation of 100% RDF (I_1F_1) resulted in the highest plant height at maturity (98.27 cm) and it was followed by drip irrigation at 100% PE and fertigation of 100% RDF (I_2F_1), while the lowest plant height was recorded by drip irrigation at 80% PE and fertigation of 50% RDF (I_3F_3).

Higher plant height was mainly due to the continued availability of water more than the required quantity at all stages of crop growth. The continued availability of soil moisture and nutrients availability to rice increases the plant growth of rice (Govindan and Grace, 2012). Interaction effects of irrigation regimes and fertigation levels had a favourable influence on plant height and the number of tillers by drip irrigation at 120% PE combined with fertigation of 100% RDF (Yadav, 2002).

Tiller production and dry-matter production

Significantly higher the number of tillers/m^2 (300.15) and dry-matter production (9,942 kg/ha) were recorded under the irrigation of 120% PE (I_1) with fertigation of 100 % RDF (F_1) at the maturity stage and it was on a par with surface irrigation at IW: CPE 1.20 with soil application of 100% RDF. The number of tillers produced and dry-matter production were more at higher drip irrigation and fertigation levels than lower irrigation and fertigation levels.

The interaction effect of drip irrigation and fertigation

Table 1. Effect of irrigation and fertigation levels on plant height (cm), tiller production (no./m^2), and dry-matter production (kg/ha) of aerobic rice (pooled data of 2019 and 2020)

Treatment	Plant height (cm)				Tiller production (no./m^2)				Dry-matter production (kg/ha)			
	F_1, 100% RDF	F_2, 75% RDF	F_3, 50% RDF	Mean	F_1, 100% RDF	F_2, 75% RDF	F_3, 50% RDF	Mean	F_1, 100% RDF	F_2, 75% RDF	F_3, 50% RDF	Mean
I_1, 120% PE	98.27	95.22	89.58	94.36	300.15	299.82	275.11	291.69	9,942	9,616	8,346	9,301
I_2, 100% PE	96.44	88.47	85.48	90.13	294.54	282.54	232.19	269.76	9,243	8,750	6,223	8,072
I_3, 80% PE	82.83	80.83	78.08	80.58	248.60	229.14	221.62	233.12	6,110	5,012	4,434	5,185
Mean	92.52	88.17	84.38	88.36	281.10	270.50	242.97	264.86	8,431	7,793	6,334	7,519
	I	F	I × F		I	F	I × F		I	F	I × F	
SEm±	0.72	1.33	1.38		4.518	3.079	4.993		63.94	177.49	127.98	
CD (P=0.05)	2.00	3.69	3.19		12.543	8.549	11.514		177.62	493.04	355.49	
IW: CPE 1.20	100.37	96.50	101.92	99.6	263.91	277.41	282.81	274.71	9,782	9,078	9,279	9,380

PE, Pan evaporation; RDF, recommended dose of fertilizer levels showed a significant influence on tiller production (Table 1). The highest tiller production (300.1 m^2) and dry-matter production (9,942 kg/ha) were observed with drip irrigation to rice at 120% PE and fertigation of 100% RDF at the maturity stage and it was followed by I_1F_2. The lowest values were recorded under drip irrigation at 80% PE combined with fertigation of 50% RDF (I_3F_3).

The conventional aerobic rice had a lesser total plant dry mass that was accompanied by a steep reduction in the rate of photosynthesis and LAI of rice than in the treatments of drip irrigation. The low biomass content in aerobic rice is due to inefficient translocation of assimilates from the source to the sink. The total dry mass of rice was found to be increased by using drip irrigation. The dry matter partitioning between root and shoot is affected by soil moisture (Bibi *et al.,* 2013).

Leaf-area index and Chlorophyll index

Leaf-area index (LAI) and chlorophyll index (SPAD value) of rice varied significantly in response to different irrigation and fertigation levels (Table 2). The higher LAI (5.51) and chlorophyll index (SPAD value of (38.11) were observed with drip irrigation of 120% PE and fertigation of 100% RDF and both were at par with surface irrigation with soil application of 100% RDF, and was higher in surface irrigation with soil application of 100% RDF with on par of 120% PE and 100% RDF. Drip irrigation of 120% PE with fertigation of 100% RDF (I_1F_1) registered significantly higher LAI, SPAD values and crop growth rate (g/m^2/day) and it was followed by I_1F_2 treatment. The lowest LAI and SPAD values were recorded under 80% PE-based irrigation with fertigation of 50% RDF (I_3F_3).

The leaf-area index is the ratio of leaf surface to the ground area occupied by the crop. The steep reduction in values of LAI in the conventional aerobic rice production system was due to the poor leaf ground coverage under minimal levels of water which corroborated the earlier findings of Yadav *et al.,* (2011) in dry-seeded rice. Ben Ali *et al.,* (2017) reported soil moisture under drip irrigation systems to be always higher, which favours enhanced LAI and chlorophyll index in drip-irrigation treatment. This might be due to the soil moisture and nutrient enhancement in the leaf area and these results are in line with Rajwade *et al.,* (2018), who reported increased rice growth.

The LAI and chlorophyll index of rice was observed superior under drip irrigation of 120% PE with fertigation of 100% RDF (I_1F_1) treatment. This was owing to the maintenance of availability of moisture and nutrients near the root zone and agrees with the findings of Adebo and Olaoye, (2010) in rice. Conventional aerobic rice had a lesser rate of growth by a reduction in canopy photosynthesis due to greater soil compaction, which affects the root proliferation as reported by Parthasarathi *et al.,* (2017), leading to reduced water uptake by the root system.

Grain yield

The maximum grain yield (6,062 kg/ha) was obtained under drip irrigation of 120% PE with fertigation of 100% RDF (I_1F_1) which was comparable with the yield obtained under surface irrigation (IW : CPE 1.2) with soil application of RDF (Table 2).

Drip fertigation at 120% PE once in 3 days surpassed the other irrigation regimes, i.e. 100% and 80% PE by registering the significantly highest grain yield of 5,758 kg/ha. The lowest grain yield of 3,602 kg/ha was obtained under 80% PE-based drip irrigation. Among the fertigation levels tried, fertigation of 100% RDF (F_1) at weekly intervals excelled the other levels by accounting significantly higher yield of 5,291 kg/ha and it was followed by a fertigation of 75% RDF (F_2). When we compare the response of aerobic rice to drip irrigation and fertigation levels, drip irrigation of 120% PE along with fertigation of 100% RDF (I_1F_1)

Table 2. Effect of irrigation and fertigation levels on leaf-area index, chlorophyll index (SPAD value), and grain yield (kg/ha) of aerobic rice (pooled data of 2019 and 2020)

Treatment	Leaf area index				Chlorophyll index (SPAD value)				Grain yield (kg/ha)			
	F_1, 100% RDF	F_2, 75% RDF	F_3, 50% RDF	Mean	F_1, 100% RDF	F_2, 75% RDF	F_3, 50% RDF	Mean	F_1, 100% RDF	F_2, 75% RDF	F_3, 50% RDF	Mean
I_1, 120% PE	5.51	4.96	4.92	5.13	38.11	36.58	34.59	36.43	6,062	5,894	5,318	5,758
I_2, 100% PE	4.92	4.34	4.30	4.52	36.83	36.00	32.12	34.98	5,739	5,645	4,067	5,150
I_3, 80% PE	4.26	4.23	4.19	4.23	33.27	30.56	29.79	31.21	4,073	3,521	3,213	3,602
Mean	4.90	4.51	4.47	4.63	36.07	34.38	32.16	34.21	5,291	5,020	4,199	4,837
	I	F	I × F		I	F	I × F		I	F	I × F	
SEm±	0.050	0.061	0.085		0.630	0.848	0.615		129.96	61.56	93.96	
CD (P=0.05)	0.139	0.170	0.236		1.745	2.348	1.704		361.00	171.00	261.00	
IW: CPE 1.20	5.43	5.07	5.33	5.28	38.31	37.80	38.16	38.09	5,716	5,833	5,880	5,810

PE, Pan evaporation; RDF, recommended dose of fertilizer could able to result in the maximum grain yield of 6,062 kg/ha and it was followed by I_1F_2 (5894 kg/ha). The treatment levels of drip fertigation (I_3F_3) to rice resulted in the minimum grain yield of 3,213 kg/ha. The higher irrigation and fertigation levels gave higher grain yield. Among the treatments, drip irrigation of 120% PE with fertigation of 100% RDF (I_1F_1) recorded a higher grain yield. This might be owing to enhancement in growth characteristics, viz. plant height, LAI, dry-matter production, and tillers/m^2 observed under high moisture regimes. These findings confirm the results of Pawar *et al.* (2003). And also, the higher grain yield was owing to an increase in yield-attributing characters, viz. panicles/m^2, grain/panicle, filled grains/ panicle, and test weight under a high soil moisture regime as a result of irrigation frequency (Danierhan *et al.,* 2013). The lowest grain yield was obtained in the lowest irrigation and fertigation scheduled due to reduced tillers/m^2, panicle number/ m^{2}and low dry-matter production as evident in the above treatment as a result of less frequent irrigations leading to moisture stress and iron deficiency prevailing in dry weather conditions during the crop-growth period (Sudhir *et al.,* 2011).

Total water use and water saving (%) in aerobic rice

The total water use of drip irrigation levels, using a daily water balance sheet and surface irrigation, was calculated and presented in Table 3. Total water use of aerobic rice under drip irrigation at 120% PE, 100% PE and 80% PE was 695.4, 679.7 and 571.8 mm, respectively, while the surface irrigation with IW: CPE 1.20 consumed 749.7 mm.

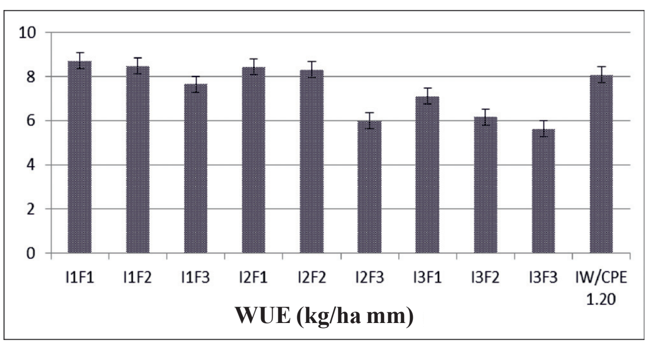

Fig. 1. Effect of drip irrigation and fertigation on water-use efficiency of aerobic rice
(ANOVA, $P < 0.05$, n = 5)

Water use efficiency

Water-use efficiency (WUE) is the yield that can be obtained from a unit quantity of water and this was worked out by yield (kg/ha)/total water used (mm) expressed in kg/ ha-mm (Viets, 1962). The higher water-use efficiency was noted under drip irrigation compared to surface irrigation. The WUE of 8.28 kg/ha-mm was recorded under drip irrigation at 120% PE (I_1) and 8.09 kg/ha-mm under drip fertigation at 100% RDF (F_1). The highest WUE (8.72 kg/ ha-mm) was accounted for fertigation of 100% RDF under 120% PE-based drip irrigation (I_1F_1) (Fig. 1). Water-use efficiency was higher under drip irrigation at 120% PE with 100% drip fertigation owing to a reduction in the application of water and nutrient compared to conventional aerobic irrigation treatment (Zhang *et al.,* 2009; He *et al.,* 2013). The water-use efficiency values differed considerably among the treatments and generally tended to increase with a decline in irrigation (Howell, 2006). Thus, water saving achieved under drip irrigation was 7.8, 10.3 and 31.1%, respectively, over surface irrigation in the present study.

It was concluded that, drip irrigation at 120% PE once in 3 days to aerobic rice improved the growth and yield attributes compared to surface irrigation (IW: CPE 1.20). Fertigation of 100% RDF (150 : 50 : 50 kg N: P: K/ha) at a weekly intervals from 15 to 70 DAS resulted in higher growth and yield of aerobic rice. The combination of drip fertigation of 100% RDF with irrigation of 120% PE (I_1F_1) revealed the higher growth, yield (6,062 kg/ha) and WUE (8.72 kg/ha-mm) compared to surface irrigation (IW: CPE 1.20) with soil application of RDF.

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Table 3. Monthly rainfall (RF, mm), pan-evaporation (PE, mm), irrigation water and effective rainfall (pooled data of 2019 and 2020)

Month	RF (mm)	PE (mm)	Surface irrigation (IW: CPE=1.20)		Drip irrigation at 80% PE		Drip irrigation at 100% PE		Drip irrigation at 120% PE	
			IW(mm)	ERF(mm)	IW(mm)	ERF(mm)	IW(mm)	ERF(mm)	IW(mm)	ERF(mm)
February	0	45.9	100	0	63.44	0	66.8	0	70.16	0
March	0	186	200	0	158.72	0	198.4	0	238.08	0
April	7.2	168.6	200	7.2	139.84	7.2	174.8	7.2	169.68	7.2
May	82.8	219.2	200	42.5	119.76	82.8	149.7	82.8	135	75.32
Total	90	619.7	700	49.7	481.76	90	589.7	90	612.92	82.52
Total water use	749.7	571.76	679.7	695.44						

IW, Irrigation water; ERF, effective rainfall

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