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Evaluation of Drip Irrigation Systems on Growth and Physiology of Aerobic Rice

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Drip irrigation studies were conducted in aerobic rice during dry season, 2012 in Coimbatore, Tamil Nadu, India. Three levels of lateral distances (0.6 m, 0.8 m or 1.0 m) with two discharge rates (0.6 or 1.0 lph emitters) were experimented. Among two-discharge rates, 1.0 lph drippers out performed 0.6 lph drippers in terms of water productivity and grain yield. Among the lateral distances, 0.8 m lateral distance was adjudged as optimum spacing for its better performance in growth, physiological and yield attributes than rest of the lateral distances. Interactively, laterals spaced at 0.8 m with 1.0 lph drippers exhibited better performance by way of growth parameters (plant height, tiller density, root biomass and total dry matter accumulation), physiological attributes (Y_w, Chlorophyll content, catalase activity and malondialdehyde content), yield and its components (productive tillers, spikelet numbers, filled grain percentage and harvest Index) along with water productivity. Therefore, it is suggested that the lateral spacing of 0.8 m with 1.0 lph drippers with the plants spaced at 20x10 cm is the best treatment for aerobic rice cultivation in enhancing the values for grain yield and water productivity in the areas of limited water availability.

Key words: Aerobic rice, Discharge rates, Lateral distance and Drip irrigation

Increasing scarcity and rising cost of water threatens the sustainability of irrigated lowland rice. It is expected that by 2025 AD, more than 17 million ha of Asia's irrigated rice would experience "physical water scarcity" and about 22 million ha might experience "economic water scarcity" (Tuong and Bouman, 2003) and, therefore, a newer method to combat water scarcity situation is warranted. Aerobic rice is an agricultural production system utilizing less water than conventional flooded rice. In the current scenario, drip irrigation offers a viable and alternate water-saving system for aerobic rice.

Pressurized irrigation systems have potential to increase water productivity by providing water to match crop requirements, reducing runoff, deep drainage losses, generally keeping soil drier reducing soil evaporation and increasing the capacity to capture rainfall (Camp, 1998). Rice plants under aerobic systems undergo several cycles of wetting and drying conditions (Matsuo and Mochizuki, 2009). Such a mild plant water stress at vegetative growth stage decreased tiller number (Cruz *et al*., 1986). Kondo *et al*. (2003) found significant differences in rooting characteristics, especially deep rooting depth and root biomass, among various (aerobic and upland) rice varieties. There are only few attempts to address the physiological responses of rice and critical analysis of various yield components to aerobic conditions (Bouman *et al*., 2005). Poor root systems and root function limit water absorption and decrease LWP (Matsuo and Mochizuki, 2009). Catalase activity was higher in the treatment of lower maximum allowable depletion (Yao-sheng, 2006). The lipid peroxidation increased with increasing drought stress intensity in the roots of rice (Sharma and Dubey, 2005).Xue *et al.* (2007) reported an average yield of aerobic rice as 4.1 t ha^{-1}with 688 mm of water input and 6.0 t ha^{-1}with 705 mm of water input. Karlberg *et al.* (2007) reported that two low-cost drip irrigation systems with different emitter discharge rates were used to irrigate tomatoes and concluded that combination of drip systems with plastic mulch increased the yield. The application efficiency of different surface and pressurized irrigation methods varies depending on design, management and operation (Holzapfel and Arumí, 2006). Ibragimov *et al.* (2007) compared drip and furrow irrigation in cotton and inferred that 18-42% of the irrigation water could be saved with drip systems with increased Irrigation Water Use Efficiency (35-103%) compared to furrow irrigation. Considering the above, objectives of this experiment were set out to study the performance of aerobic rice, optimize the lateral distance and discharge rate for better grain yield, compare water requirements, water productivity, growth, physiological and yield responses in varied drip-irrigation treatments consisting of three lateral spacings with two levels of emitter discharge rate.

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Materials and Methods

The experiment was conducted during Dry Season (DS) of 2012 in the Wetlands of Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India situated at 11 ^{0}N latitude, 77 ^{0}E longitude and at an altitude of 426.72 m above Mean Sea Level. Field experiment was taken in Randomized Block Design with three replications using ADT(R) 45 as the test variety. The irrigation was given through PVC pipe (40 mm OD) after filtering through the screen filter by 7.5 HP motor from the bore well. The pressure maintained in the system was 1.2 Kg cm $^{-2}$. From the sub-main, in-line laterals were laid out at a spacing of 0.6, 0.8 or 1.0 m with 0.6 or 1.0 lph discharge rate emitters positioned at a distance of 30 cm. Irrigation was given based on the Open Pan Evaporation (PE) values (125% PE).

There were eleven treatments employing three lateral spacings and two discharge rates of emitters. The treatments were: distance between laterals 0.6 m with the spacing of 20 cm between rows of plants and spacing of 10 cm between plants (T_1), distance between laterals 0.6m, spacing between rows of plants from lateral (20x10x10x20) (instead of three rows of 20 cm each) (T_2), lateral distance of 0.8 m, spacing of 20 cm between rows of plants and spacing of 10 cm between plants (T_3), lateral distance of 0.8 m, spacing between rows of plants from lateral (5x20x30x20x5) (instead of four rows of 20 cm each) (T_4), lateral distance of 1.0 m, spacing of 20 cm between rows of plants and spacing of 10 cm between plants (T_5), laterals distance of 1.0 m, spacing between rows of plants from lateral (7.5x15x15xempty bed (25cm) x15x15x7.5) (instead of five rows of 20 cm each) (T_6), laterals distance of 0.8 m, spacing of 20 cm between rows and spacing of 10 cm between plants + 30 percent more water (T_7), lateral distance of 1.0 m, spacing of 20 cm between rows of plants and spacing of 10 cm between plants + 30 percent more water (T_8), lateral distance of 0.8 m, spacing between rows of plants from lateral (5x20x30x20x5) (instead of four rows of 20 cm each) with 0.6 lph drippers (T_9), lateral distance of 1.0 m, spacing between rows of plants from lateral (7.5x15x15xempty bed (25cm) x15x15x7.5) (instead of five rows of 20 cm each) with 0.6 lph drippers (T_{10}) and conventional irrigation at IW/CPE ratio of 1.25 at 30 mm depth of irrigation (conventional irrigation) (T_{11}).

The weather parameters prevailed during cropping season were observed in Agromet Observatory in Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India (Fig. 1). The average values for maximum, minimum temperature were 30.7 ºC, 22.7 ºC, sunshine hours of 5.7 h d $^{-1}$. The total evaporation recorded was 628.3 mm with the total precipitation of 533.0 mm. The effective rainfall was taken into account, while scheduling irrigation under drip and surface methods. The effective rainfall was calculated using water balance sheet method (Dastane, 1974). Measurements of growth parameters were observed at harvest stage of the crop. Plant height was measured from the base of the shoot to the longest leaf and the values expressed in cm. Number of tillers in selected plants in each treatment was counted. Then, the average number of tillers was worked out and based on that tiller density per m^2 was derived. The Total Dry Matter Accumulation (TDMA) was arrived by summing up the dry weights of leaf, culm, root, panicles and TDMA, root biomass values expressed as g m $^{-2}$. The physiological parameters were measured at flowering stage of the crop. Leaf water potential was measured using the Schölander pressure chamber, the methodology described by Schölander *et al*. (1965) and expressed as MPa. Contents of chlorophyll 'a', 'b' were estimated in a fully expanded young leaf at specified time intervals and the total content (a+b) was arrived at and expressed in mg g^{-1} fresh weight (Yoshida *et al.,* 1971). Catalase enzyme activity was determined by consumption of H_2O_2 (Dhindsa *et al*., 1981). The lipid peroxidation of the plasma membrane of leaf sample was evaluated by thiobarbituric acid reaction (Fodor and Marx, 1988).

The yield and its components were recorded at the time of harvest. The number of panicles, number of spikelets, filled grain percentage, 1000 grain weight (Test weight), Harvest Index (HI) were recorded based on the method of Yoshida *et al*. (1971). Harvesting of crop (grain) from each treatment and replication was made from the net plot. After thrashing the grains, weight of the grain was taken. Grain yield per hectare was calculated from the mean plot yield and expressed in kg ha^{-1} at 14 % moisture content. Water productivity was calculated as the weight of grains produced per unit of water input (irrigation and rainfall) as per the formula of Yang *et al.* (2005) and expressed as g grain kg^{-1} of water. The recorded data were subjected to statistical analysis in Randomized Block Design (RBD) using ANOVA Package (AGRES version 7.01) following the method of Gomez and Gomez (1984).

Results and Discussion

The effects of drip irrigation treatment on growth parameters showed a significant relation among the treatments. Increased plant height was recorded in T_3 (78.4 cm) followed by T_1 (77.5 cm) and the least in T_{11} (60.5) (Table 1). The drip irrigation treatments on aerobic rice showed a moderate plant height response. The moderate plant height diverted the assimilates for growth with comparatively lesser share of assimilates available for shoot growth even under moisture limitation (Sangsu *et al*., 1999). Tillering is an important trait for grain production and is thereby an important aspect of rice growth improvement. The tiller density of the crop was significantly different in drip irrigation treatment. Higher tiller production was observed in T_3 (443) and lesser in T_{10} (358) (Table 1). The less tiller

Table 1. Effect of various drip irrigation treatments on growth and physiological parameters in aerobic rice

Treatments	PH	TD	RB	TDMA	Y_w	Chlorophyll content	CAT activity	Leaf malondialdehyde
T_1	77.5	427	199.0	1893.5	1.39	2.90	29.7	35.7
T_2	77.0	411	178.4	1798.2	1.42	2.38	25.5	39.5
T_3	78.4	443	209.2	1926.3	1.50	2.91	30.2	38.6
T_4	76.8	410	173.6	1743.5	1.56	2.32	31.3	43.6
T_5	72.1	399	158.0	1721.3	1.60	2.26	23.8	44.9
T_6	70.9	370	154.7	1659.5	1.64	2.03	21.7	46.7
T_7	77.7	424	184.4	1831.8	1.43	2.56	14.7	41.8
T_8	74.3	410	174.8	1762.5	1.55	2.20	15.2	42.6
T_9	69.9	363	153.7	1577.2	1.59	2.00	21.5	46.1
T_{10}	69.4	358	124.5	1469.9	1.70	1.82	15.1	49.8
T_{11}	60.5	360	173.9	1536.3	1.87	1.95	22.3	48.6
Mean	73.1	398	171.28	1720.0	1.57	2.30	22.8	43.4
SEd	1.62	13.6	7.18	48.63	0.003	0.063	0.56	0.007
CD (P<0.05)	3.38	28.5	5.14	101.43	0.006	0.132	1.16	0.014

PH - Plant Height (cm); TD - Tiller Density (Number m-2); RB - Root Biomass (g m-2); TDMA - Total Dry Matter Accumulation (g m-2); w - Water Potential (-MPa); Chlorophyll Content (mg g-1); CAT-Catalase Activity (enzyme units mg-1 protein h-1); Leaf Malondialdehyde (µmol g-1)

ith plant spacing from lateral (7.5x15x15xempty bed (25cm) x15x15x7.5);
ith 20X10 plant spacing + 30 percent more water;
20X10 plant spacing + 30 percent more water;
ith plant spacing from lateral (5x20x30x20x5) with 0.6 lph drippers;
with plant spacing from lateral (7.5x15x15xempty bed (25cm) x15x15x7.5) with 0.6 lph drippers;
nal irrigation at IW/CPE ratio of 1.25 at 30 mm depth of irrigation (conventional irrigation).

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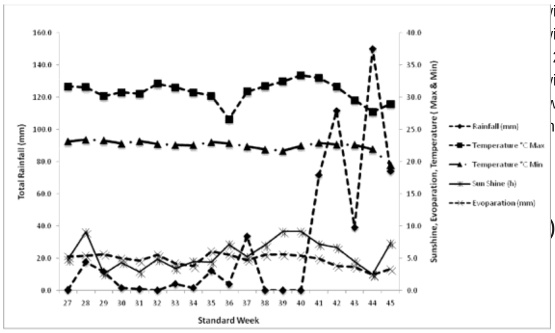

Figure 1. Weather data prevailed during cropping season

square meter might be due to the more availability of nitrogen, which plays a vital role in cell division. The root biomass of T_3 treatment showed significant difference among the drip irrigation treatments. Higher root biomass was noticed in T_3 (209.17 g m^{-2}), followed by T_1 (199.03 g m^{-2}), T_2 (178.43 g m^{-2}), T_4 (173.55 g m^{-2}) and very less root biomass in T_{10} (124.45 g m^{2}) **(Table 1)**. By comparing the T_1, T_3 and T_5 treatments, increase in lateral distance caused reduction in water availability to the root zone of crop. Therefore, root biomass is reduced in aerobic culture primarily on account of fewer adventitious roots (Kato and Okami, 2010). The Total Dry Matter Accumulation (TDMA) of aerobic rice showed a significant difference with various drip irrigation treatments. Significantly higher dry matter was accumulated in treatment T_3 (1926.3 g m^{-2}) and the least in T_{10} (1469.9 g m^{-2}). Comparing the two discharge rates of drip irrigation, the 1.0 lph discharge emitters recorded 31.0 % increase in TDMA over the 0.6 lph discharge emitter treatment. Higher TDMA could be beneficial to grain filling at later stage for improving the grain yield (Wen-Ge *et al*., 2008).

The physiological effects of aerobic rice on various micro irrigation treatments were analysed. Water potential is an indicator of plant water status under limited water supplying environment. Higher water potential (Y_w) was observed in T_1 (-1.39 MPa) and lower observed in T_{11} (-1.87 MPa) (Table 1.). Closer lateral distance showed higher water availability to root zone leading to favourable plant water status. Fukai *et al*. (1999) emphasized the ability of rice plants to maintain higher leaf Y_w to stabilize rice yield even in rainfed areas. Chlorophyll pigments play vital role in crop productivity, since these pigments are highly responsible for photosynthesis in plants. The chlorophyll content were higher in T_3 (2.907 mg g^{-1}), closely followed by T_1 (2.897 mg g^{-1}) and lower in T_{11} (1.952 mg g^{-1}). Enhanced chlorophyll synthesis with nutrient supplied through drip system (fertigation) led to higher chlorophyll (Stevens *et al*., 2001). The chlorophyll contents showed 32.9 % increase in T_3 over conventional irrigation $T_{11.}$ The catalase activity increased with increase in the lateral distance from 0.6 m to 1.0 m. Higher activity used to reduce the H_2O_2 content in peroxisome under low discharge drippers because of lesser water availability. Changes of catalase activity were closely relevant with soil available water by using drip irrigation. The present study followed the results of Bowler *et al*. (1992). Malondialdehyde content was higher in conventional irrigation treatment (T_{11}) and lesser in drip irrigation treatments. Plants in eliminating the

Table 2. Effect of various micro irrigation treatments on yield components in aerobic rice

Treatments	PT	**SN**	FGP	TW	HI
T_1- Lateral distance 0.6m, row spacing 20 cm and plant spacing 10 cm	664.5	142.2	88.1	22.5	41.4
T_2- Lateral distance 0.6m, row spacing from lateral (20x10x10x20)	659.4	138.0	84.4	21.9	41.8
T_3- Lateral distance 0.8m, row spacing 20 cm and plant spacing 10 cm	681.4	142.6	89.0	23.0	42.8
T_4- Lateral distance 0.8m, row spacing from lateral (5x20x30x20x5)	651.3	135.0	83.9	21.7	42.6
T_5- Lateral distance 1.0m, row spacing 20 cm and plant spacing 10 cm	637.6	132.9	83.9	21.2	40.5
T_6- Lateral distance 1.0m, row spacing from lateral (7.5x15x15xempty bed(25cm)x15x15x7.5)	627.9	122.7	82.6	21.0	40.0
T_7- Lateral distance 0.8m, row spacing 20 cm and plant spacing 10 cm + 30% more water	623.8	133.9	89.4	22.0	42.8
T_8- Lateral distance 1.0m, row spacing 20 cm and plant spacing 10 cm + 30% more water	621.4	134.1	87.7	21.8	42.0
T_9- Lateral distance 0.8m, row spacing from lateral (5x20x30x20x5) with 0.6 lph drippers	616.0	128.4	83.7	21.1	38.8
T_{10}-Lateral distance 1.0m, row spacing from lateral (7.5x15x15 x emptybed (25cm)x15x15x7.5) with 0.6 lph drippers	581.9	95.4	71.1	20.3	39.0
T_{11}- IW/CPE ratio of 1.25 at 30 mm depth of irrigation	594.3	119.2	78.7	20.5	41.6
Mean	632.73	129.49	83.9	21.6	41.2
SEd	7.285	6.607	1.49	0.99	1.05
CD (P<0.05)	15.196	13.782	3.11	NS	2.20

PT - Productive Tillers (Panicle m^{-2}); SN - Spikelet Number panicle^{-1}; FGP - Filled Grain Percentage (%); TW- Test Weight; HI - Harvest Index

processes of oxidative damage results in lipid peroxidation and denaturation of proteins under limited or moderate input conditions (Bowler *et al*., 1992).

Effect of drip irrigation treatments on yield components of aerobic rice showed significant differences among the treatments except test weight. Higher number of panicles was produced in T_3 (681.4 panicles m^{-2}), followed by T_1(664.5 panicles m^{-2}), T_2(659.4 panicles m^{-2}), T_4(651.3 panicles m^{-2}) and lesser number in T_{10}(581.9 panicles m^{-2}) (Table 2). The spikelet numbers per panicle recorded significantly more in T_3(142.6) and very less in T_{10} (95.4). Increasing the number of spikelets should be a primary target, as this has helped to increase the yields of rice even under water limitation (Peng *et al*., 2008). The Filled Grain Percentage (FGP) also showed a similar response for the micro irrigation treatments. Significantly superior FGP values were registered in T_3(89.0 %) followed by T_1(88.1 %), T_2 (84.4 %), T_4(83.9 %) and the lower in T_{10}(71.1 %) (Table 2). The reduction in spikelet production under reduced water supply might be due to the abortion of spikelets in the secondary rachis branch (Kato *et al*., 2008). The test weight of aerobic rice on various

Table 3. Effect of various micro irrigation treatments on water parameters, yield and water productivity in aerobic rice

Treatment	IW (mm)	ER (mm)	TWA (mm)	GY (Kg ha^{-1})	WP (g kg^{-1})
T_1- Lateral distance 0.6m, row spacing 20 cm and plant spacing 10 cm	444.6	102.4	547.0	5554	1.015
T_2- Lateral distance 0.6m, row spacing from lateral (20x10x10x20)	444.6	102.4	547.0	5326	0.974
T_3- Lateral distance 0.8m, row spacing 20 cm and plant spacing 10 cm	444.6	102.4	547.0	5793	1.059
T_4- Lateral distance 0.8m, row spacing from lateral (5x20x30x20x5)	444.6	102.4	547.0	5408	0.989
T_5- Lateral distance 1.0m, row spacing 20 cm and plant spacing 10 cm	444.6	102.4	547.0	4475	0.818
T_6- Lateral distance 1.0m, row spacing from lateral (7.5x15x15xemptybed(25cm)x15x15x7.5)	444.6	102.4	547.0	4255	0.778
T_7- Lateral distance 0.8m, row spacing 20 cm and plant spacing 10 cm + 30% more water555.4	76.1	631.5	4896	0.775	
T_8- Lateral distance 1.0m, row spacing 20 cm and plant spacing 10 cm + 30% more water555.4	76.1	631.5	4969	0.787	
T_9- Lateral distance 0.8m, row spacing from lateral (5x20x30x20x5) with 0.6 lph drippers444.6	102.4	547.0	4070	0.744	
T_{10}-Lateral distance 1.0m, row spacing from lateral (7.5x15x15xemptybed(25cm)x15x15x7.5) with 0.6 lph drippers	444.6	102.4	547.0	3819	0.698
T_{11}- IW/CPE ratio of 1.25 at 30 mm depth of irrigation	510.0	187.9	697.9	4612	0.661
Mean	470.7	105.4	576.1	4834	0.845
SEd				82.5	0.0254
CD (P<0.05)				172.2	0.0530

IW - Irrigation water applied; ER - Effective Rainfall; TWA - Total Water Applied; GY - Grain Yield; WP - Water Productivity (g grain kg^{-1} of water applied) micro irrigation treatments has no significant difference among the treatments. The Harvest Index (HI) registered higher value in T_3(42.8 %), followed by T_4(42.6 %), T_{11}(41.6 %), T_2(41.8 %), T_1(41.4 %) and lower in T_9(38.8 %) (Table 2). The T_3treatment possessing higher HI values led to increased contribution for the yield increment. The ability to maintain a higher HI under aerobic conditions has also been reported to be a key factor to higher yields by Lafitte *et al*. (2002). Significantly higher grain yield was registered in T_3 treatment (5793 kg ha^{-1}) followed by T_1 (5554 kg ha^{-1}) with lower yield observed in T_{10}(3819 kg ha^{-1}).

Optimal lateral spacing (0.8 m) was reasoned out for such an increase in yield due to an increased water use efficiency than the wider (1.0 m) or narrower (0.6 m) lateral spacing. The present study is in confirmation with the results of previous work with optimum lateral spacing in maize registering higher yield (Bozkurt *et al.,* 2006). The total water applied to the crop through the irrigation water and effective rainfall for the entire growing season was 547 mm in T_1, T_2, T_3, T_4, T_5, T_6, $T_9$and T_{10}, 631.5 mm in $T_{7,}$ $T_8$and 697.9 mm in T_{11}treatment (Table 3). The Total water applied (TWA) to the crop was comparatively lesser in drip-irrigated treatment than the conventional irrigation method of aerobic rice cultivation in the current study. There was a mean saving of 21.6 per cent of water when applied through the drip system than the conventional irrigation. Bouman *et al*. (2007) reported that the yields of aerobic rice obtained by farmers around North China Plain were 5.5 t $ha^{-1}$with sometimes as little as 566 mm of total water input, and with only one or two supplementary irrigation applications. Similar results were obtained in the present study also.

The Water Productivity (WP) is a measure of the productivity of water used by the crop. Higher WP was recorded (Table 4) in T_3(1.059 g kg^{-1}) followed by T_1(1.015 g kg^{-1}), T_4 (0.989 g kg^{-1}) and T_2 (0.974 g kg^{-1}). The least WP was observed in the conventional irrigation at IW/CPE ratio of 1.25 (T_{11}) (0.661 g kg^{-1}). The WP values differed considerably among the treatments and generally tended to increase with a decline in irrigation (Howell, 2006). The water productivity was higher by 1.6 times in T_3 when compared to T_{11} treatment with 54.4 % reduction in water use (Table 3). Our results are in accordance with the study of Guang-hui *et al.* (2008) who reported 60 % lesser water use coupled with 1.6-1.9 times higher total water productivity as reported in the present study.

Conclusion

Research findings of current study revealed that 1.0 lph drippers excelled 0.6 lph drippers in terms of growth characters, physiological parameters, water productivity, yield and its components. For the lateral distance treatments, 0.8 m lateral distance was found to be the optimum lateral spacing due to better crop performance and yield than 1.0 m lateral distance. The treatment T_3(lateral spacing of 0.8 m with 1.0 lph dripper discharge rate) registered superior performance in terms of growth indices (such as plant height, tiller density, root biomass, Total Dry Matter Accumulation), physiological parameters (such as Y_w, total chlorophyll, catalase activity and leaf malondialdehyde value), yield and its components along with increased WP values. Therefore, drip system with lateral spacing of 0.8 m with 1.0 lph drippers could be recommended for aerobic rice cultivation under limited water availability.

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