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# Effect of Drip Irrigation on Growth, Physiology, Yield and Water Use of Rice

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**Abstract**

The field experiment was conducted to investigate the effect of drip irrigation treatments such as three lateral distances (0.6 m, 0.8 m or 1.0 m lateral distance) on growth parameters physiological characters, yield and water use of rice under two discharge rates drippers (0.6 or 1.0 litre per hour emitters). Among the lateral distances, 0.8 m lateral distance adjudged as optimum spacing for its better performance in growth, physiological and yield attributes than rest of the lateral distances. Between two-discharge rates, 1.0 lph drippers out performed 0.6 lph drippers in grain yield. Interactively, laterals spaced at 0.8 m with 1.0 lph drippers exhibited better performance by way of growth parameters (such as plant height, tiller density, root biomass, total dry matter accumulation), physiological attributes (such as $\Psi_w$, Chlorophyll content, Catalase activity and Malondialdehyde content), yield and its components (such as productive tillers, spikelet numbers, filled grain percentage, Harvest Index) along with water productivity. Drip irrigation confirms to increase in water productivity in the present study with water saving of 27.4% over the conventional aerobic rice cultivation. Enhanced physiological activities showed increased growth and yield in rice under 0.8 m lateral distance drip irrigation which is a viable tool for balanced source sink relation. Our results indicated that the lateral spacing of 0.8 m with 1.0 lph drippers is best for rice cultivation in enhancing the growth, physiology, grain yield and water productivity.

**Keywords:** aerobic rice, discharge rates, drip irrigation, lateral distance, physiology

## 1. Introduction

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 & Bouman, 2003). For producing rice, a tremendous amount of water is used for the rice irrigation under the traditional irrigation method called as a continuous deep flooding irrigation technique 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. Rice plants under aerobic systems undergo several cycles of wetting and drying conditions (Matsuo & 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 (Bouman, Peng, Castaneda, & Visperas, 2005) and drip irrigated condition. Poor root systems and root function limit water absorption and decrease in leaf water potential (Matso & Mochizuki, 2009) under aerobic cultivation. In the current scenario, drip irrigation offers a viable and alternate water-saving system for 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. Karlberg, Rockstrom, Annandale, and Steyn (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. Application efficiency of different surface and pressurized irrigation methods varies and depends on design, management and operation (Holzapfel & 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.

The drip irrigation treatment had more effective tillers, more roots in topsoil, higher WUE, and greater economic benefit in rice (He, Ma, Yang, Chen, & Jia, 2013), but less yield compare with conventional flooding irrigation. Drip irrigation maintained a competitive grain yield and water productivity, and greatly reduced pollution risk to the environment. Considering the conservative amount of fertilizer application, less than the amount of fertilization in normal paddy field, the yield potential of rice could be improved by increasing the amount of fertilizer as top application in drip irrigation system (Adekoya et al., 2014).

Considering the above, objectives of this experiment were set out to study the performance of 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.

## 2. Method

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$^{o}$ N latitude, 77$^{o}$ 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.

### *2.1 Field Preparation*

The experimental plots were dry-ploughed and harrowed. Raised flat beds were formed and laid out with double channels around all the plots to prevent subsoil lateral water flow.

### *2.2 Sowing and Spacing*

Sprouted seeds (ADT (R) 45) were dry-sown by hand dibbling at 3cm depth in rows of 20 cm apart at seeding rate of 30 kg ha$^{-1}$.

### *2.3 Irrigation*

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).

### *2.4 Treatment Details*

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 (20 × 10 × 10 × 20) (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 (5 × 20 × 30 × 20 × 5) (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 (7.5 × 15 × 15 × empty bed (25cm) × 15 × 15 × 7.5) (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 (5 × 20 × 30 × 20 × 5) (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 (7.5 × 15 × 15 × empty bed (25cm) × 15 × 15 × 7.5) (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) ($T_{11}$).

*2.5 Weather Parameters during Cropping Period*

The weather parameters prevailed during cropping season was observed in Agromet Observatory in Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India (Figure 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).

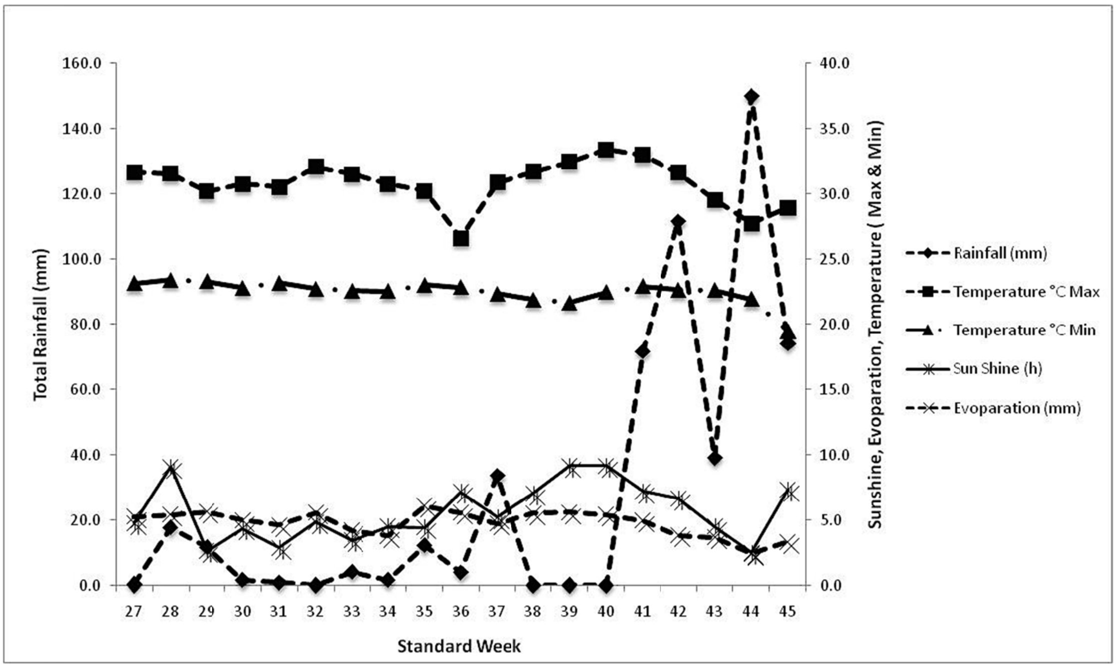


Figure 1. Weather data prevailed during cropping season (DS, 2012) in Coimbatore, India

*2.6 Growth Measurements*

Measurements of growth parameters were observed at harvest stage of the crop. Plant height of each plant 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$^{-2}$.

*2.7 Physiological Observations*

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, Bradstreet, Hemmingsen, and Hammel (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, Foron, & Cock, 1971). Catalase enzyme activity was determined by consumption of $H_2O_2$ (Dhindsa, Plumb-Dhindsa, & Thorpe, 1981). The lipid peroxidation of the plasma membrane of leaf sample was evaluated by thiobarbituric acid reaction (Fodor & Marx, 1988).

*2.8 Yield and Yield Traits*

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.

### *2.9 Research Design*

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).

## 3. Results

### *3.1. Growth parameters*

The effects of drip irrigation treatment on growth parameters showed a significant relation between the treatments. Increased plant height was recorded in $T_3$ treatment (78.4 cm) followed by $T_1$ (77.5 cm) and least in $T_{11}$ (60.5) (Table 1). The tiller density of the crop was significantly different in drip irrigation treatment. Higher tiller production was observed in $T_3$ (443) treatment and lesser in $T_{10}$ (358) (Table 1). Higher tiller production was observed in $T_3$ (443) treatment and lesser in $T_{10}$ (358) (Table 1). 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).

Table 1. Effect of various drip irrigation treatments on Growth parameters of rice

| **Treatments** | **PH** | **TD** | **RB** | **TDMA** |
|---|---|---|---|---|
| $T_1$ | 77.5 | 427 | 199.0 | 1893.5 |
| $T_2$ | 77.0 | 411 | 178.4 | 1798.2 |
| $T_3$ | 78.4 | 443 | 209.2 | 1926.3 |
| $T_4$ | 76.8 | 410 | 173.6 | 1743.5 |
| $T_5$ | 72.1 | 399 | 158.0 | 1721.3 |
| $T_6$ | 70.9 | 370 | 154.7 | 1659.5 |
| $T_7$ | 77.7 | 424 | 184.4 | 1831.8 |
| $T_8$ | 74.3 | 410 | 174.8 | 1762.5 |
| $T_9$ | 69.9 | 363 | 153.7 | 1577.2 |
| $T_{10}$ | 69.4 | 358 | 124.5 | 1469.9 |
| $T_{11}$ | 60.5 | 360 | 173.9 | 1536.3 |
| **Mean** | **73.1** | **398** | **171.28** | **1720.0** |
| SEd | 1.62 | 13.6 | 7.18 | 48.63 |
| CD ($P < 0.05$) | 3.38 | 28.5 | 5.14 | 101.43 |

*Note*. PH: Plant Height (cm); TD: Tiller Density (Number $m^{-2}$); RB: Root Biomass (g $m^{-2}$); TDMA: Total Dry Matter Accumulation (g $m^{-2}$).

Table 2. Effect of various drip irrigation treatments on physiological parameters of rice

| Treatments | $\Psi_w$ | Chlorophyll Content | CAT Activity | Leaf Malondialdehyde |
|---|---|---|---|---|
| $T_1$ | 1.39 | 2.90 | 15.2 | 35.7 |
| $T_2$ | 1.42 | 2.38 | 14.7 | 39.5 |
| $T_3$ | 1.50 | 2.91 | 15.1 | 38.6 |
| $T_4$ | 1.56 | 2.32 | 22.3 | 43.6 |
| $T_5$ | 1.60 | 2.26 | 23.8 | 44.9 |
| $T_6$ | 1.64 | 2.03 | 25.5 | 46.7 |
| $T_7$ | 1.43 | 2.56 | 22.4 | 41.8 |
| $T_8$ | 1.55 | 2.20 | 21.7 | 42.6 |
| $T_9$ | 1.59 | 2.00 | 29.7 | 46.1 |
| $T_{10}$ | 1.70 | 1.82 | 31.6 | 49.8 |
| $T_{11}$ | 1.87 | 1.95 | 30.2 | 48.6 |
| **Mean** | **1.57** | **2.30** | **22.9** | **43.4** |
| SEd | 0.003 | 0.063 | 0.53 | 0.007 |
| CD ($P < 0.05$) | 0.006 | 0.132 | 1.10 | 0.014 |

*Note*. $\Psi_w$: Water Potential (-MPa); Chlorophyll Content (mg $g^{-1}$); CAT: Catalase Activity (enzyme units $mg^{-1}$ protein $h^{-1}$); Leaf Malondialdehyde (μmol $g^{-1}$).

By comparing the $T_1$ (0.6 m LD), $T_3$ (0.8 m LD) and $T_5$ (1.0 m LD) treatments, increase in lateral distance caused reduction in water availability to the root zone of crop. Significantly higher dry matter was accumulated in treatment $T_3$ (1926.3 g $m^{-2}$) and the least in $T_{10}$ (1469.9 g $m^{-2}$).

### 3.2 Physiological Parameters

The physiological effects of aerobic rice on various micro irrigation treatments were analyzed and results were furnished below. The water potential is an indicator of plant water status under limited water supplying environment. Higher water potential ($\Psi_w$) was observed in $T_1$ (-1.39 MPa) and lower observed in $T_{11}$ (-1.87 MPa) (Table 2). The chlorophyll content was 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 $g^{-1}$). Activity of Catalase enzyme was found higher in conventional aerobic rice (30.2 enzyme units $mg^{-1}$ protein $h^{-1}$) and lesser activity was noted in treatment $T_2$ (14.7 enzyme units $mg^{-1}$ protein $h^{-1}$), $T_3$ (15.1 enzyme units $mg^{-1}$ protein $h^{-1}$) followed by $T_1$ (15.2 enzyme units $mg^{-1}$ protein $h^{-1}$).

Regarding the lipid peroxidation of leaf was observed by using leaf melondialdehyde content. Lesser leaf melondialdehyde content was recorded in the best treatment $T_3$ (38.6 μmol $g^{-1}$) which is closer to the treatment $T_1$ and $T_2$ than the conventional aerobic rice treatment ($T_{11}$: 48.6 μmol $g^{-1}$).

### 3.3 Yield and Yield Components

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 3). 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 3). 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 3). 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 $ha^{-1}$).

### 3.4 Water Parameters

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 4). 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 $kg^{-1}$).

Table 3. Effect of various micro irrigation treatments on yield components of rice

| Treatments | PT | SN | FGP | TW | HI |
|---|---|---|---|---|---|
| $T_1$ | 664.5 | 142.2 | 88.1 | 22.5 | 41.4 |
| $T_2$ | 659.4 | 138.0 | 84.4 | 21.9 | 41.8 |
| $T_3$ | 681.4 | 142.6 | 89.0 | 23.0 | 42.8 |
| $T_4$ | 651.3 | 135.0 | 83.9 | 21.7 | 42.6 |
| $T_5$ | 637.6 | 132.9 | 83.9 | 21.2 | 40.5 |
| $T_6$ | 627.9 | 122.7 | 82.6 | 21.0 | 40.0 |
| $T_7$ | 623.8 | 133.9 | 89.4 | 22.0 | 42.8 |
| $T_8$ | 621.4 | 134.1 | 87.7 | 21.8 | 42.0 |
| $T_9$ | 616.0 | 128.4 | 83.7 | 21.1 | 38.8 |
| $T_{10}$ | 581.9 | 95.4 | 71.1 | 20.3 | 39.0 |
| $T_{11}$ | 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 |

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

Table 4. Effect of various micro irrigation treatments on water, yield of rice

| Treatments | IW (mm) | ER (mm) | TWA (mm) | GY (Kg ha$^{-1}$) |
|---|---|---|---|---|
| $T_1$ | 444.6 | 102.4 | 547.0 | 5554 |
| $T_2$ | 444.6 | 102.4 | 547.0 | 5326 |
| $T_3$ | 444.6 | 102.4 | 547.0 | 5793 |
| $T_4$ | 444.6 | 102.4 | 547.0 | 5408 |
| $T_5$ | 444.6 | 102.4 | 547.0 | 4475 |
| $T_6$ | 444.6 | 102.4 | 547.0 | 4255 |
| $T_7$ | 555.4 | 76.1 | 631.5 | 4896 |
| $T_8$ | 555.4 | 76.1 | 631.5 | 4969 |
| $T_9$ | 444.6 | 102.4 | 547.0 | 4070 |
| $T_{10}$ | 444.6 | 102.4 | 547.0 | 3819 |
| $T_{11}$ | 510.0 | 187.9 | 697.9 | 4612 |
| **Mean** | **470.7** | **105.4** | **576.1** | **4834** |
| SEd | | | | 82.5 |
| CD ($P < 0.05$) | | | | 172.2 |

*Note*. IW: Irrigation water applied; ER: Effective Rainfall; TWA: Total Water Applied; GY: Grain Yield.

The least Water Productivity was observed in the conventional irrigation at IW/CPE ratio of 1.25 ($T_{11}$) (0.661 g kg$^{-1}$). 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$^{-1}$) (Table 4).

## 4. Discussion

Increased plant height observed in 0.8 LD, 1.0 lph dripper treatment ($T_1$) that was due to the availability of soil moisture to root zone in this system. This moderate plant height diverted all 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.

These results were obtained by more number of tillers per square meter due to more availability of nitrogen, which plays a vital role in cell division at tillering phase. Mirza, Ahamed, Rahmatullah, Akhter, and Rahman (2010) also reported increase in number of tillers in rice plants due to influence of different fertilizer and irrigation practice. The root biomass of $T_3$ treatment showed significant difference among the drip irrigation treatments. The less tiller density in conventional aerobic rice is due to the mild plant water stress at vegetative growth stage as reported by Cruz et al. (1986). Therefore, root biomass is reduced in aerobic culture primarily on account of fewer adventitious roots (Kato & Okami, 2010). The Total Dry Matter Accumulation (TDMA) of aerobic rice showed a significant difference with various drip irrigation treatments.

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). Closer lateral distance showed higher water availability to root zone leading to favourable plant water status. Fukai, Pantuwan, Jongdee, and Cooper, (1999) emphasized the ability of rice plants to maintain higher leaf $\Psi_w$ 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 contents showed 32.9% increase in $T_3$ over Conventional irrigation $T_{11.}$ Enhanced chlorophyll synthesis with nutrient supplied through drip system (fertigation) and reduced leaf cholorophyllase activity led to higher chlorophyll content (Stevens, Dunn, Birmingham, Moylan, & Sheckell, 2001) in rice. The catalase activity increased with increase in the lateral distance from 0.6 m to 1.0 m. Higher catalase activity in leaf 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 Yao-sheng (2006) under drip irrigation. Reduced catalase activity due to inhibition of enzyme synthesis or change in assembly of enzyme subunits in aerobic rice condition. These results corroborated with previous work of Abedi and Pakniyat (2010). Malondialdehyde content was higher in conventional irrigation treatment ($T_{11}$) and lesser in drip irrigation treatments. Plants in eliminating the processes of oxidative damage results in lipid peroxidation and denaturation of proteins under limited or moderate input conditions (Bowler, Van Montagu, & Inz, 1992).

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, Khush, Virk, Tang, & Zou, 2008). The reduction in spikelet production under reduced water supply might be due to the abortion of spikelets in the secondary rachis branch (Kato, Kamoshitab, & Yamagishia, 2008). The test weight of aerobic rice on various micro irrigation treatments has no significant difference among the treatments. The $T_3$ treatment 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, Courtois, and Arraudeau (2002).

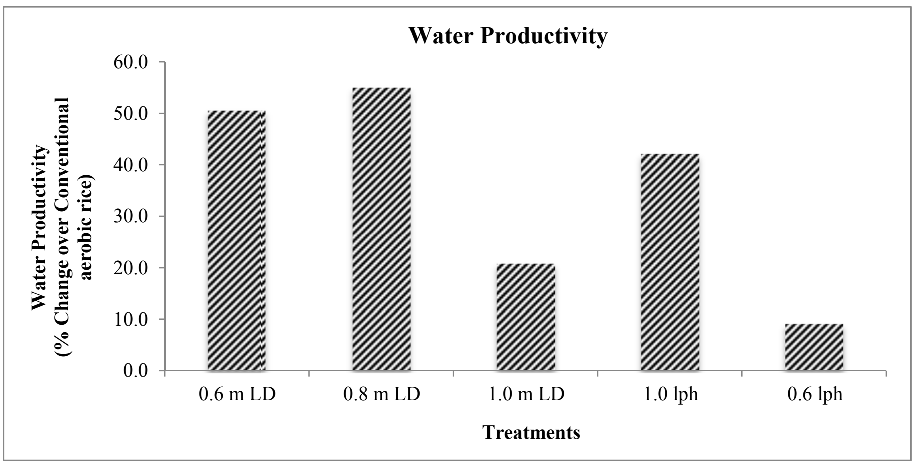


Figure 2. Effect of various micro irrigation treatments on water productivity of rice

Optimal lateral spacing (0.8 m) was reasoned out for such an increase in yield due to 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, Yazar, Gencel, & Sezen, 2006). 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 percent 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 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 (Figure 2). Our results are in accordance with the study of Guang-hui, Jun, Hua-qi, and Bouman, (2008) who reported 60% lesser water use coupled with 1.6-1.9 times higher total water productivity in the present study.

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 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 $\Psi_w$, total chlorophyll, catalase activity and leaf malondialdehyde value), yield and its components along with increased WP values. Drip irrigation confirms to increase in water productivity in the present study with water saving of 27.4% over the conventional aerobic rice cultivation. Enhanced physiological activities showed increased growth and yield in rice under 0.8 m lateral distance drip irrigation which is a viable tool for balanced source sink relation. Our results indicated that the lateral spacing of 0.8 m with 1.0 lph drippers is best for rice cultivation in enhancing the growth, physiology, grain yield and water productivity.

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