Short Communication

Water use efficiency and water productivity of aerobic rice under drip irrigation and fertigation system by using daily soil water balance

ANBARASU MARIYAPPILLAI[1*], GURUSAMY ARUMUGAM[2] and KUMARESAN MARAPPAN[1]

[1]School of Agriculture, Vels Institute of Science, Technology & Advanced Studies (VISTAS), Pallavaram - 600117 Chennai, Tamil Nadu, India.
[2]Department of Agronomy, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai - 625104 Tamil Nadu, India.
Corresponding author email: manbarasu102@gmail.com

Rice (*Oryza sativa* L.) is the staple food crop for more than half of the world's population and influences the livelihoods and economics of several billion people. Asia's food security mostly depends on irrigated lowland rice cultivation practices, which produce three-quarters of all the harvested (Pimentel *et al.*, 2004; Bouman *et al.,* 2005). Lowland irrigated rice requires a lot of water for puddling, transplanting and irrigation. Further, significant water losses occur through seepage, percolation and evaporation. It is estimated that it consumes 3000 to 5000 liters of water to produce one kilogram of rice. In India, the annual per capita availability of water may be reduced to 1340 cubic meters in 2025 and 1140 cubic meters in 2030 (Suhag, 2016). India is already water water-stressed country and is moving towards turning into water scarcity. The declining water availability and increasing cost of water endangers 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. Addressing these issues requires an integrated approach to soil-water-plant-nutrient management at the plant rooting zone. The introduction of drip irrigation in aerobic rice is one of the water-saving methods of growing rice by direct seeding in unpuddled conditions without standing water and irrigating similarly to other upland cereal crops. The water use studies on aerobic rice cultivation through the daily soil moisture balance method are very precise in applying the irrigation schedule to maintain the field capacity of the crop.

The present field experiment was conducted during the summer 2020 (22.02.2020 to 31.05.2020) at the AICRP Water Management Scheme research field, Agricultural College and Research Institute, Madurai (9°54'N latitude and 78°54'E longitude), Tamil Nadu, India. The field experiment was laid out in a strip plot design with replication thrice. The spacing of rice sown at 20 × 15 cm in raised beds was formed with top bed width of 90 cm and furrows were formed to a width of 30 cm (120 cm). The laterals were placed in the center of the raised bed with 40 cm emitter spacing with a discharge rate of 5.8 lph. The soil of the experimental site was clay loam (pH-7.04, Ec-0.33 dS m^{-1} and Organic carbon-0.42 percent). Rice variety CO 51 was used for the field experiment. The drip irrigation was scheduled once in 3 days at 120 %, 100 % and 80 % pan evaporation (PE) and fertigation in 100 %, 75 %, and 50 % recommended doses of fertilizer (RDF) was given at weekly intervals from 15 days after sowing (DAS) to 70 DAS and separately maintained the control of surface irrigation at irrigation water / cumulative pan evaporation (IW/CPE) 1.25 with soil application of RDF (150:50:50 NPK ha^{-1}).

The crop evapotranspiration (ETc) was estimated using daily pan evaporation data recorded with the help of USWB class A pan evaporimeter. The daily soil water balance was calculated which is like a bank account. Rainfall and irrigation are on the credit side, while crop evapotranspiration on the debit side leaving soil moisture balance. Precise data on the maximum water holding capacity (170 mm) were determined in experimental soil by the pressure plate apparatus. Any amount above this capacity is a surplus and will be a deep percolation loss or run-off. When the balance reaches nil, no more withdrawal is possible and hence further depletion is treated as water deficiency.

The daily water balance was calculated as follows;

$$RF + IW = PE + \Delta SM$$

where, RF- Rainfall, IW- Irrigation water, PE- Pan evaporation, ΔSM- Change in soil moisture from the previous day

Table 1: Month wise total pan evaporation (mm), effective rainfall and irrigation water (IW) under different treatment and total water use (mm) of aerobic rice crop season of 2020

Month 2020	Effective rainfall (mm)	Pan Evaporation (mm)	Surface irrigation (IW/CPE=1.25)	Drip irrigation at 80% PE	Drip irrigation at 100% PE	Drip irrigation at 120 % PE
February (8 days)	0	45.9	100	82.7	86.2	89.7
March (31 days)	0	186.0	200	144.1	180.2	216.3
April (30 days)	7.2	193.7	200	159.4	199.3	201.0
May (31 days)	82.8	219.2	150	145.1	154.1	133.5
Total (mm)	90.0	644.8	650	531.3	619.8	640.5
Total water use (mm)			740	621.3	709.8	730.5
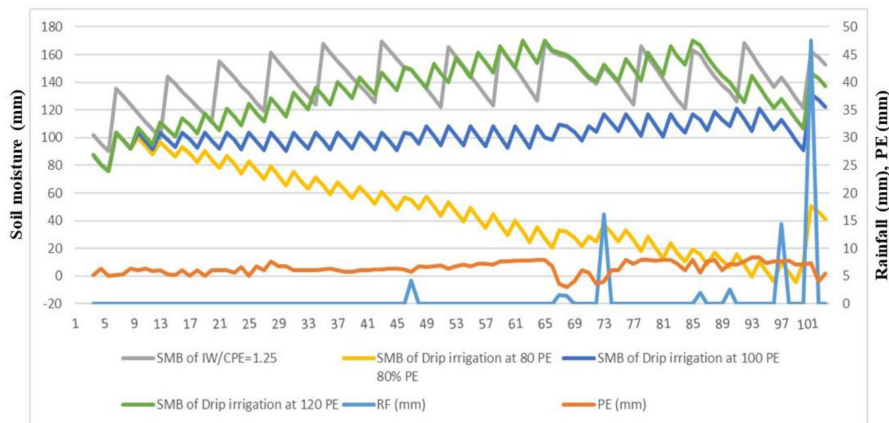
Fig. 1: Rainfall (RF, mm), pan evaporation (PE, mm), soil moisture balance under different treatments from day 1 - 100

The initial soil moisture was determined by the volumetric method: Measurements of soil moisture are made on soil samples based on weight or volume difference before and after oven drying with the following formula

$$\text{Moisture percentage} = \frac{W_1 - W_2}{W_2} \times 100 \times \text{bulk density (1.25 gm/cc)}$$

where, W_1 - the initial weight of the sample (g); W_2 - oven dry weight of the sample (g)

Total water use

The quantity of water applied through the drip system was summed up to estimate the total irrigation water applied and expressed in mm.

Total water used = Number of irrigations x depth of irrigation (mm).

Water use efficiency (WUE)

Water use efficiency (WUE) was estimated by the following formula.

$$\text{WUE (kg ha}^{-1}\text{ mm}^{-1}) = \frac{\text{Economic yield (kg ha}^{-1})}{\text{Total quantity of water applied (mm)}}$$

Water productivity (WP)

Water productivity is a function of gross income and total water used by the crop and is expressed in ₹ ha^{-1} mm^{-1}.

$$\text{Water productivity} = \frac{\text{Gross income (₹ ha}^{-1})}{\text{Total water use (mm)}}$$

Soil moisture balance in aerobic rice

Fig. 1 depicts the daily variation of rainfall, pan evaporation and daily soil moisture balances (SMB) under different drip irrigation treatments during 100 days of aerobic rice cultivation. The effective rainfall was 90 mm during the entire crop season. The total number of irrigations in the IW/CPE=1.25 was 13, drip irrigation at 80% PE is 31, Drip irrigation at 100% PE is 30 and Drip irrigation at 120% PE is 26. The test crop variety is CO 51 is a short-duration of 105 to 110 days. The irrigation was closed for up to 100 days of all the treatments.

The soil moisture balance under 100% PE was found to be quite stable during the growing season, while in treatment 80% PE, the SMB decreased continuously. Under treatments of surface irrigation of IW/CPE=1.25 and drip irrigation of 120% PE, the variation in soil moisture balance was found to be more or less similar. The total water used under surface irrigation treatment of IW/CPE 1.25 was 740 mm, whereas under the drip irrigation treatments of 80% PE, 100% PE and 120% PE, the total water used

Table 2: Effect of drip irrigation and fertigation on grain yield (kg ha^{-1}) of rice

Treatments	Grain yield (kg ha^{-1})			
	F_1 -100 % RDF	F_2 - 75 % RDF	F_3 - 50 % RDF	Mean
I_1 - 120% PE	6062	5894	5318	5758
I_2 - 100% PE	5739	5645	4067	5150
I_3 - 80% PE	4073	3521	3213	3602
Mean	5291	5020	4199	4837
	I	F	I x F	
SEd	129.96	61.56	93.96	
CD (0.05)	361.00	171.00	261.00	
IW/CPE 1.25	5716	5833	5880	5810

were 621.3 mm, 709.8 mm and 730.5mm respectively. The month wise effective rainfall and total water use of rice by using a daily water balance sheet are presented in Table 1.

Grain yield (kg ha^{-1})

The grain yield of rice was found to vary significantly with irrigation and fertigation treatment and their interaction was also significant (Table 2). The maximum grain yield of 6062 kg ha^{-1} 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 1.25) with soil application of RDF (Table 2). Drip fertigation at 120% PE once in true days surpassed the other irrigation regimes i.e. 100 % and 80 % PE by registering significantly the highest grain yield of 5758 kg ha^{-1}. The lowest grain yield of 3602 kg ha^{-1} 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 for a significantly higher yield of 5291 kg ha^{-1} and it was followed by 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) was able to produce the maximum grain yield of 6062 kg ha^{-1} and it was followed by I_1F_2 (5894 kg ha^{-1}). The treatment levels of drip

fertigation (I_3F_3) to rice produced the minimum grain yield of 3213 kg ha^{-1} (Table 2)

Water use efficiency (WUE) and water productivity (WP)

Water use efficiency (WUE) and water productivity (WP) as influenced by drip irrigation and fertigation treatments are presented in Table 3. The drip irrigation of 120% PE was seen with a highest water use efficiency of 7.88 kg ha^{-1} mm^{-1} followed by that of 100% PE treatment with WUE of 7.26 kg ha^{-1} mm^{-1}. Similarly, the highest water productivity of 110.3 Rs ha^{-1} mm^{-1} was obtained under drip irrigation treatment of 120% PE followed by that of 100% PE treatment with WP of 101.5 Rs ha^{-1} mm^{-1}. The lowest WUE (5.80 kg ha^{-1} mm^{-1}) and WP (81.1 Rs ha^{-1} mm^{-1}) were registered in 80% PE treatment.

Regarding drip fertigation doses, 100 percent of RDF significantly registered higher WUE (7.65 kg ha^{-1} mm^{-1}) and WP (107.0 Rs ha^{-1} mm^{-1}) aerobic rice cultivation under the drip fertigation system and it was followed by 75 percent RDF. The lowest WUE (6.06 kg ha^{-1} mm^{-1}) and WP (84.8 Rs ha^{-1} mm^{-1}) were registered at 50 percent RDF (Table 3).

The interaction between drip irrigation and fertigation *viz.*, I_1 - 120 percent PE × F_1 - 100 percent RDF registered the highest WUE (8.30 kg ha^{-1} mm^{-1}) and WP (116.1 Rs ha^{-1} mm^{-1}) of aerobic rice cultivation under drip irrigation and fertigation system and it was on par with $I_1 × F_2$ and $I_2 × F_1$ in both of WUE and WP respectively. The lowest interaction effect on WUE and WP registered in $I_3 × F_3$ both of WUE and WP. Under the control (surface irrigation at IW/CPE 1.25) the mean WUE was 7.07 kg ha^{-1} mm^{-1} and the mean WP was 98.9 Rs ha^{-1} mm^{-1} which were significantly lower than those of obtained under 120% PE and 100% PE treatments and higher than that of treatment 50 % PE (Table 3).

Significant variation was observed in drip irrigation and fertigation levels concerning water use efficiency (WUE) and water productivity (WP) in aerobic rice. During the entire period of crop growth, the drip irrigation system and daily soil water balance were maintained at 50 percent available soil moisture, which leads to enhanced WUE and water productivity under the drip irrigation system (Karuna and Dhaliwal, 2020). The drip irrigation only irrigates in root rhizosphere regions that have higher water use

Table 3: Effect of drip irrigation and fertigation on total water use (mm), water use efficiency (WUE) and water productivity (WP)

Treatments	Total water use (mm)				WUE (kg ha^{-1} mm^{-1})				WP (Rs ha^{-1} mm^{-1})			
	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	730.5	730.5	730.5	730.5	8.30	8.07	7.28	7.88	116.1	112.9	101.9	110.3
I_2 - 100 PE	709.8	709.8	709.8	709.8	8.09	7.95	5.73	7.26	113.2	111.3	80.2	101.5
I_3 - 80 PE	621.3	621.3	621.3	621.3	6.55	5.67	5.17	5.80	91.7	79.3	72.3	81.1
Mean	687.2	687.2	687.2	687.2	7.65	7.23	6.06	6.98	107.0	101.2	84.8	97.7
Control				740.0	6.93	7.26	7.02	7.07	98.5	99.0	99.2	98.9
					I	F	I x F		I	F	I x F	
SEd					0.047	0.079	0.153		1.48	0.91	2.13	
CD (0.05)					0.131	0.219	0.354		4.11	2.53	4.92	

*RDF- Recommended dose of fertilizer

efficiency and water productivity due to better availability of water and nutrient resources during its entire growth period (Anbarasu *et al.,* 2022, Lakhawat *et al.,* 2024). This has enhanced the productivity in terms of seed yield of aerobic rice cultivation under a drip irrigation system. The continuous availability of soil moisture increases the carbon mobilization from vegetative tissues to the economic part and harvest index which is strictly associated with increasing water use efficiency and water productivity. This result is conferred with the findings of Ehdaie and Waines (1993), Basha and Sarma (2017), Haindavi *et al.,* (2018) and Kumar *et al.,* (2019).

The present study revealed that with the highest WUE and WP of aerobic rice cultivation obtained under drip irrigation of 120% PE and fertigation of 100% RDF treatment, the system is a promising one. The method of daily soil water balance is the easiest method to adopt the researchers and farmers to retain their crop of 50% available soil moisture and the treatment effect is the precise and friendly calculation of water requirement.

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