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Comparative water budgeting and water use efficiency of irrigated lowland rice under drum culture and AWD-based drum culture techniques in semi-arid tropics of Telangana, India

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ABSTRACT

Evaluation of water balance components through drum culture technique during kharif seasons of 2019 and 2020 was conducted in the clay soils of RARS, Polasa, Jagtial, PJTAU, Hyderabad, Telangana, India. Water balance components were measured through drums on a loss and gain basis using a measuring scale twice daily. Quantification revealed maximum water use efficiency and yield under AWD based drum culture technique than transplanted rice with drum culture technique alone. The study quantified evapotranspiration (ET), evaporation, percolation, seepage, and effective rainfall. AWD significantly reduced percolation and improved irrigation water use efficiency (IWUE) without a yield penalty, showing potential for sustainable rice production in semi-arid tropics. However, challenges such as labor-intensive monitoring of water levels, variability in soil hydraulic properties, dependence on timely rainfall, and the need for farmer training on AWD thresholds were observed, which may limit widespread field adoption. Addressing these constraints is essential for wider field-scale adoption. Water scarcity has become one of the major constraints to sustainable rice production, necessitating the adoption of efficient irrigation management practices. This experiment to evaluate the effect of alternate wetting and drying (AWD)-based drum culture on seasonal water budgeting, irrigation water productivity, and grain yield of transplanted rice compared with conventional puddled transplanted rice (PTR). The experiment comprised two treatments: T_0 – conventional transplanted rice with drum culture technique and T_1 – transplanted rice with optimum water management using AWD through drum culture. AWD substantially reduced seasonal water losses by lowering mean evapotranspiration from 429.0 to 351.2 mm, evaporation from 425.0 to 266.2 mm, and percolation from 511.0 to 289.3 mm. Mean irrigation water application decreased from 998.5 mm under conventional transplanting to 698.5 mm under AWD, resulting in approximately 30% irrigation water saving. Effective rainfall utilization increased, while ineffective rainfall losses were markedly reduced under AWD. The total irrigation water applied, including nursery and puddling water, averaged 1239 mm under conventional transplanting and 938.5 mm under AWD. Irrigation water-use efficiency (IWUE) improved from 3.37 to 5.45 kg ha^{-1} mm^{-1}. In the main field, irrigation water application decreased from 796 to 300 mm, while IWUE increased from 4.26 to 13.00 kg ha^{-1} mm^{-1} and field water-use efficiency (FWUE) increased from 3.23 to 6.01 kg ha^{-1} mm^{-1}. AWD also enhanced crop performance by increasing tiller number, panicle density, filled grains per panicle, and grain yield. The pooled mean grain yield increased from 4258 kg ha^{-1} under conventional transplanting to 5149 kg ha^{-1} under AWD, representing an increase of approximately 20.9%. The study demonstrates that AWD-based drum culture is an efficient irrigation management strategy that conserves irrigation water while improving water productivity and rice yield. Adoption of AWD can therefore contribute to sustainable rice cultivation, particularly in regions experiencing increasing water scarcity.

Keywords: *Rice; Water budgeting; Drum culture; Alternate Wetting and Drying; Water productivity; Irrigation scheduling; Percolation loss; Evapotranspiration; Semi-arid tropics; IWUE; Climate-smart agriculture; Telangana; Soil-water balance; Irrigation efficiency; Lysimeter studies; Water conservation; Sustainable rice production*

1. Introduction

Rice (*Oryza sativa* L.) is a vital food crop but it consumes a substantial portion of freshwater resources. In India, irrigated rice alone accounts for nearly 45% of total irrigation water use [1]. With the increasing pressure on water resources, technologies like Alternate Wetting and Drying (AWD) and precise drum culture methods are critical for quantifying and improving irrigation efficiency [2]. Drum culture enables precise estimation of evapotranspiration and percolation losses under controlled field conditions, providing valuable insights into crop–water relations [3]. AWD alternates between wet and dry phases, helping to save water while maintaining yields.

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The integration of these two methods allows accurate measurement of water balance components and optimization of water productivity for sustainable rice production in semi-arid regions like Telangana. The amount of water available for rice production in India has become critical, particularly in dry seasons. With average annual rainfall of 1250 mm, uneven distribution limits effective water use. Experimental data-based water balance measurements support improved irrigation scheduling. Drum culture is a simple, low-cost method that provides accurate ET estimates. Factors influencing ET include climate, soil evaporation, crop canopy, and sub-layer transport processes. The amount of water available for rice production in India has recently become critical especially during the dry seasons. Average annual rainfall in India is approximately 1250 mm. However, this rainfall is distributed unevenly both temporally and spatially, and the distribution is not optimal for the rice growing seasons. To effectively and efficiently use the available water resources for irrigation supply, studies of crop water requirements for paddy crops based on derived by field measurement are crucial. To improve water management practice, experimental data-based water balance components can be applied for estimation of crop water requirements in rice. On the other hand, evapotranspiration is the one of the important components of the water balance equation in paddy fields. It includes the loss of water from both soil and plant surfaces, playing an important role in both rain-fed and irrigated rice. Evapotranspiration depends upon the evaporative demand of the atmosphere. It also depends on the transport processes of heat and water from soils and plants through the sub layers, which are next to the evaporative surfaces, and through plant canopies to the outer atmosphere (Kutilch and Neilson, 1994). It is mainly affected by climatic factors and, to some extent, is controlled by physiological functions of rice under submerged conditions (Li and Cui, 1996; Peacock et al., 2004; Tsubo et al., 2007). Poor and uneven water distribution are the main problem for improving irrigation efficiency of rice irrigation projects in India. Therefore, a better estimate of evapotranspiration is essential to determine the crop water demand as well as improving the irrigation delivery performance (Rowshon et al., 2003a, Rowshon et al., 2003b and Rowshon et al., 2009). The water requirement of rice is very high because of its semi-aquatic nature, which requires more water than any other crops. Seasonal water requirement for rice ranges between 750 and 2500 mm, having an average value of 1250 mm (Mikkelson and De Datta, 1991). The worldwide estimate of rice ET ranges between 450 and 700 mm/season, depends on the climate and growing season (Doorenbos and Kassam, 1979). In South and South East Asia, ET varies widely from 4.4 to 14.3 mm/day (Tomar and O'Toole, 1980). However, for the most areas in Asia, ET ranges between 4 to 9 mm/day (WicKham and Sen, 1978). There are several techniques used in determining evapotranspiration. These techniques include water balance, empirical formulae or micro-meteorological approaches. Field measurements of evapotranspiration are generally not only tedious also expensive and are therefore, restricted to research plots rather than practical uses in the farms by farmers. On the other hand, micro-paddy lysimeter affords simple and reasonably accurate water accounting device. The drum culture employed in this study is cheaper and has gained more prominence recently. Distance et al (1974) designed and tested drums for estimating evapotranspiration of wetland rice, in which the measurements were done with pan evaporation.

Accurate prediction of rice ET based on the drum culture technique method is an important factor in efficient water management and can optimize irrigation by reducing water loss. Irrigated rice is the major crop cultivated in the lowlands of Sri Ram Sagar (SRSP) command area in Telangana state. Irrigated lowland rice in this region and in general consumes more water and also causes wastage of water resulting in degradation of land. In these conditions' measurement of water balance components, is best way of determining the availability of water in rice crop by assessing ET, percolation and effective rainfall. Therefore, it is aimed to estimate rice ET for a crop cycle using a drum culture approach. To extrapolate the rice ET for irrigation planning on a regional scale, the crop coefficient and reference ET were also determined.

2. Materials and Methods

The experiment was conducted during *kharif* seasons of 2018, 2019 and 2020 at Regional Agricultural Research Station, Polasa, Jagtial (18.8°N, 78.9°E)., Professor Jayashanakar Telangana Agricultural University, Hyderabad, Telangana, India using drum culture technique, a method to study water balance components in rice crop. Iron drums (0.283 m^2, 120 cm height) were used to measure ET, evaporation, percolation, and runoff. The AWD setup included perforated PVC tubes to monitor soil water depth. Rice varieties Bathukamma (2018) and Pranahitha (2019–2020) were transplanted at 30×14 cm spacing. Fertilizer was applied at 120:60:40 N:P_2O_5:K_2O kg ha^{-1}. Water levels were recorded twice daily to estimate each component of the water budget following standard FAO procedures [4]. These drums were installed in rice field and water losses and gains were measured simultaneously. The soil bulk density and crop conditions in these drums were maintained similar to the surrounding field conditions. The soil type was clay soils with a P^H 8.0, EC 0.33dS m^{-1}, OC 0.58%, available N 225 kg ha^{-1}, available P 67.7 kg ha^{-1} and available K_2O 389 kg ha^{-1} (Green manure sun hemp crop was incorporated before taking up of experiment during *Kharif* 2018). The water level in the drums and the field were measured constantly. Also, the water in the drums was maintained equivalent to the surrounding field by adding water to the drums in measured amounts as and when water loss occurs in the drums. Irrigation to surrounding cropped area was also applied in measured quantities. Water lost is obtained from the difference in water level between initial and final readings. The arrangement makes a short duration measurement of 7 hr possible. The measurements were taken in the morning 09:00 am and evening 16.00 pm.

Soil Physico-chemical and Soil-Water Characteristics

The experimental soil at RARS, Polasa (0–30 cm depth) was *loamy sand* in texture, containing 8.78 % clay, 40.98 % silt, and 50.24 % sand. It exhibited a pH of 7.74, electrical conductivity (EC) of 0.27 dS m^{-1}, and organic carbon content of 0.44 %.

Soil-water parameters were estimated using SPAW (Soil Plant Available Water) Software, version 6.02.74 (Saxton, USDA-ARS, Washington DC). The results are summarized below:

Parameter	Value
Field capacity	18.0 % v/v
Permanent wilting point	5.9 % v/v
Saturation	39.2 % v/v
Available soil water	11 cm m^{-1} soil depth
Saturated hydraulic conductivity	23.98 mm hr^{-1}
Bulk density	1.61 g cm^{-3}

([9] http://hydrolab.ars.usda.gov/soilwater/index.html)

3. Results and Discussion

3.1 Seasonal Water Budgeting Components

The seasonal water budgeting components of transplanted rice under conventional transplanting with drum culture (T_0) and alternate wetting and drying (AWD)-based drum culture (T_1) during 2019 and 2020 are presented in Table 1.

Seasonal evapotranspiration (ET) was lower under AWD in 2019 (265.01 mm) than under conventional transplanting (385 mm), indicating a reduction of about 31.2%. During 2020, ET values were comparable between treatments (473.3 mm under AWD and 473 mm under conventional transplanting). On a pooled basis, mean ET was reduced from 429 mm in T_0 to 351.2 mm in T_1, representing an overall reduction of 18.1% under AWD.

Evaporation losses were also lower under AWD, with mean evaporation decreasing from 425 mm in T_0 to 266.2 mm in T_1, a reduction of approximately 37.4%. Evaporation is highest at early growth stages, when the leaf area index (LAI) is small and accounts for most of the evapotranspiration (ET) losses. In most of the tropics, the ET requirements during wet season, on an average, is 4-5 mm day^{-1}. During the dry season, it is 8-10 mm day^{-1} (Abdullahi, 2013).

Percolation losses showed the greatest reduction under AWD, decreasing from a pooled mean of 511 mm in T_0 to 289.3 mm in T_1, corresponding to a 43.4% reduction, demonstrating the effectiveness of AWD in minimizing deep percolation losses. The data align with earlier reports by [2] and [5]. Percolation is largely affected by topography, soil characteristics and depth of water table. In a heavy soil with water table close to the soil surface, percolation loss could be around 1.0 mm day^{-1} as against as high as 10.0 cm day-1 in light soils (Abdullahi, 2013). Sagar et. al., (2017) also observed that the percolation beyond root zone of the crop was the highest under conventional puddle rice (55% and 58% of total water applied during 2013 and 2014, respectively) than direct seed rice and SRI thus highlighting that water loss through deep percolation beyond root zone is the major factor contributing to the high-water requirement in CPR and SRI methods compare to DSR method. Evaporation is highest at early growth stages, when the leaf area index (LAI) is small and accounts for most of the evapotranspiration (ET) losses. In most of the tropics, the ET requirements during wet season, on an average, is 4-5 mm day^{-1}. During the dry season, it is 8-10 mm day^{-1} (Abdullahi, 2013). Percolation losses were almost halved under AWD, aligning with the findings of Bouman and Tuong (2001), who reported that regulated ponded water depth substantially reduces downward water movement in lowland rice. While evapotranspiration (ET) values remained largely stable between treatments, AWD resulted in notable reductions in evaporation due to lower standing water depths. These results correspond with Hidayat et al. (2020), who observed similar reductions in evaporation under AWD-managed rice systems

Effective rainfall utilization increased under AWD, with mean effective rainfall rising from 419 mm in T_0 to 543.4 mm in T_1 (29.7% increase), while ineffective rainfall declined substantially from 111.5 mm to 19.9 mm, indicating better utilization of seasonal rainfall. Rainfall received during both treatments remained similar, while seepage losses were nearly comparable between treatments (59.9 mm in T_0 and 57.9 mm in T_1). Effective rainfall accounted for 22–29% of total water use, underscoring the importance of integrating rainfall-based irrigation planning in monsoon-dependent ecosystems.

A substantial reduction in irrigation water application was achieved under AWD. Mean irrigation water applied decreased from 998.5 mm under conventional transplanting to 698.5 mm under AWD, resulting in a water saving of approximately 300 mm (30.0%).

3.2 Irrigation Water Applied in the Drums

The irrigation water applied inside the nursery drums, total water consumed, and irrigation water-use efficiency (IWUE) are presented in Table 2.

Including the standard 240 mm of water required for nursery raising and puddling, total irrigation water applied averaged 1239 mm under conventional drum culture (T_0), whereas AWD required only 938.5 mm, resulting in an average saving of 300.5 mm (24.3%).

Total water consumed was 1632 mm under T_0 and 1722 mm under AWD. Although total water consumption was numerically higher under AWD, this was mainly due to higher crop productivity rather than increased irrigation input.

Irrigation water-use efficiency improved considerably under AWD. The pooled IWUE increased from 3.37 kg ha^{-1} mm^{-1} under conventional transplanting to 5.45 kg ha^{-1} mm^{-1} under AWD, representing an improvement of approximately 61.6%. The highest IWUE (6.22 kg ha^{-1} mm^{-1}) was recorded during 2020 under AWD.

3.3 Irrigation Water Applied in the Main Field

The irrigation water applied exclusively to the main field, excluding nursery and puddling water, is presented in Table 3.

Mean irrigation water applied in the main field was 796 mm under conventional transplanting compared with only 300 mm under AWD, resulting in a reduction of approximately 62.3%.

Total water consumed averaged 1340 mm under conventional transplanting and 844 mm under AWD. The marked reduction in water consumption clearly demonstrates the efficiency of AWD irrigation management.

Irrigation water-use efficiency in the main field increased dramatically under AWD. Mean IWUE improved from 4.26 kg ha^{-1} mm^{-1} under conventional transplanting to 13.0 kg ha^{-1} mm^{-1} under AWD, corresponding to an increase of approximately 205%.

Similarly, field water-use efficiency (FWUE) increased from 3.23 kg ha^{-1} mm^{-1} under conventional transplanting to 6.01 kg ha^{-1} mm^{-1} under AWD, representing an improvement of approximately 86.4% indicating that evapotranspiration is affected by management and natural factors. These factors may influence crop growth and thereby, amount of water use. Rice consumptive water obtained in the study area was in the range of values obtained for other major areas of rice production in India.

3.4 Yield and Yield Components

The effect of AWD irrigation on yield and yield attributes is presented in Table 4.

The number of tillers increased under AWD, with pooled mean values rising from 303 tillers m^{-2} under conventional transplanting to 330 tillers m^{-2}, an increase of 8.9%.

Similarly, panicle number increased from 293 m^{-2} under conventional transplanting to 305 m^{-2} under AWD, representing an increase of approximately 4.1%.

Filled grains per panicle also improved under AWD, increasing from 214 under conventional transplanting to 235, corresponding to an increase of 9.8%.

Grain yield was consistently higher under AWD during both years. In 2019, grain yield increased from 4032 kg ha^{-1} under conventional transplanting to 4147 kg ha^{-1} under AWD. During 2020, grain yield increased markedly from 4484 kg ha^{-1} to 6150 kg ha^{-1}. On a pooled basis, AWD recorded a mean grain yield of 5149 kg ha^{-1}, compared with 4258 kg ha^{-1} under conventional transplanting, resulting in an overall yield increase of approximately 20.9%. Yield performance under AWD remained comparable with PTR, confirming that AWD—when practiced within safe thresholds—does not impose yield penalties. IWUE improved substantially under AWD, demonstrating the method's potential to enhance water productivity in water-limited environments. Despite these advantages, practical challenges persist, including the need for frequent water-level monitoring, limited accessibility to automation tools, and hesitation among farmers due to perceived risks. Strengthening sensor-based monitoring systems, improving farmer training, and conducting multi-location trials can accelerate wider adoption.

Overall Summary

The adoption of alternate wetting and drying (AWD) through drum culture substantially reduced irrigation water requirement while maintaining or improving crop growth and productivity. AWD reduced percolation and evaporation losses, enhanced effective rainfall utilization, increased irrigation and field water-use efficiencies, and produced approximately 21% higher grain yield while saving about 30% of irrigation water compared with conventional transplanting. These findings demonstrate that AWD-based drum culture is an effective water-saving irrigation strategy for sustainable rice production under transplanted conditions.

Table 1. Seasonal water budgeting components under PTR and AWD-based Drum Culture (2019–2020)

Treatments/Year	T0-PTR	T1-AWD	T0-PTR	T1-AWD	T0-PTR	T1-AWD	T0-PTR	T1-AWD	T0-PTR	T1-AWD	T0-PTR	T1-AWD	T0-PTR	T1-AWD	T0-PTR	T1-AWD
	Evapotranspiration (ET) mm		Evaporation(E) mm		Percolation (P) mm		Effective rainfall mm		Ineffective rainfall (IR) mm		Rainfall (R) mm		Seepage losses (S) mm		Water applied mm	
2019	385	265.01	265	237	505	269.2	392	492	112.3	9.01	492	492	110	115.7	999	649
2020	473	473.3	320	295.4	516	310.45	445	594.8	222.1	30.74	595	595	9.72	-	998	748
Mean	429	351.2	425	266.2	511	289.3	419	543.4	111.5	19.9	544	393.4	59.9	57.9	998.5	

Table 2: Irrigation water applied in the Drums under transplanting method with drum culture technique and transplanting method with optimum water management through drum culture technique under (AWD) Alternate wetting and drying of rice during kharif 2019-20 and 2020-21

Particulars	Water applied (mm)			Total water consumed (mm)			IWUE (kg ha mm^{-1})		
Treatments	2019	2020	Mean	2019	2020	Mean	2019	2020	Mean
T0- Transplanting of rice with drum culture technique (PTR)	999.05 +240= 1239.05	998.43 +240=1238.43	998.7+240=1239	1491.05 +240=1631	1593.43 +250=1633	1543+245=1788	3.25	3.49	3.37
T1- Transplanting of rice with optimum water management (drum culture technique under AWD)	649+240=889	748 +240=988	698.5+240=938.5	1621	1823	1722	4.67	6.22	5.445

*240 mm of water required for nursery and paddling added

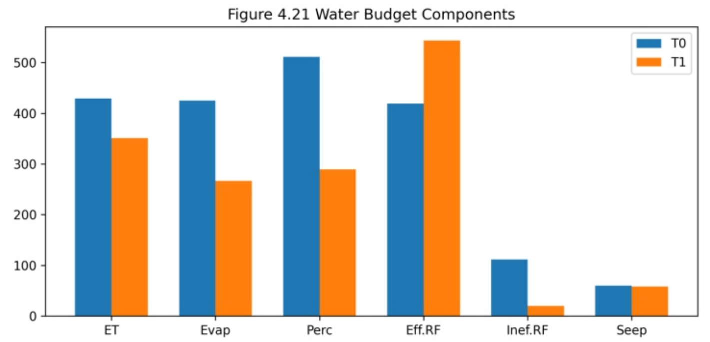
Table 3: Irrigation water applied in the main field under transplanting method with drum culture technique and transplanting method with optimum water management through drum culture technique under (AWD) Alternate wetting and drying of rice during kharif 2019-20 and 2020-21

Particulars	Water applied (mm)			Total water consumed (mm)		IWUE (kg ha mm^{-1})				Field WUE (kg ha mm^{-1})		
Treatments	2019	2020	Mean	2019	2020	Mean	2019	2020	Mean	2019	2020	Mean
T0- Transplanting of rice with drum culture technique (PTR)	966	626	796	966 + 492=1458	625.7+594.8=1220.5	1340	4.032	4.48	4.256	2.78	3.67	3.225
T1- Transplanting of rice with optimum water management (drum culture technique under AWD)	266.134	333.7	300	758	928.9	844	15.58	10.3	13.0	5.47	6.62	6.01

*240 mm of water required for nursery and puddling is not added to main field.

Table 4: Yield and yield components of rice under transplanting method with drum culture technique and transplanting method with optimum water management through drum culture technique under (AWD) Alternate wetting and drying of rice during kharif 2019-20 and 2020-21

Particulars	No.of tillers/m^2			Panicle number/m^2			Filled grains / panicle			Grain Yield kg ha^{-1}		
Treatments	2019	2020	Mean	2019	2020	Mean	2019	2020	Mean	2019	2020	Mean
T0- Transplanting of rice with drum culture technique (PTR)	270	335	303	265	320	293	185	243	214	4032	4484	4258
T1- Transplanting of rice with optimum water management (drum culture technique under AWD)	300	360	330	275	335	305	195	275	235	4147	6150	5149



Overall, AWD-based drum culture demonstrated its efficiency in conserving water while maintaining yield stability, making it a viable strategy for semi-arid rice ecosystems. The results highlight the synergy between technological innovation and water-smart agriculture practices.

Thus, a comparative analysis of water balance components estimated by drum culture method carried out with special emphasis on low land rice crop were found to be more effective in representing the utilizable rainfall. This method can be used for computing effective rainfall and in turn the irrigation requirement for the rice crop. From the study, it is concluded that under practical conditions, the water balance methods can be considered more appropriate and drum culture method is an appropriate one to conduct water budgeting in rice.

4. Conclusion

AWD-based drum culture effectively reduced percolation losses, improved IWUE, and sustained rice yields under the semi-arid tropics of Telangana. It offers a practical and measurable approach for optimizing irrigation scheduling and water productivity in lowland rice. The study concluded that drum culture is an effective and practical method for evaluating rice water budgeting, percolation behavior, ET, and irrigation needs.

1. Alternate wetting and drying (AWD) significantly improved seasonal water management by reducing evapotranspiration, evaporation, and percolation losses compared with conventional puddled transplanted rice.
2. AWD increased effective rainfall utilization and minimized ineffective rainfall losses, thereby improving the overall seasonal water balance.
3. Mean irrigation water application was reduced from 998.5 mm under conventional transplanting to 698.5 mm under AWD, achieving an irrigation water saving of approximately 30%.
4. Including nursery and puddling requirements, total irrigation water applied decreased from 1239 mm to 938.5 mm, indicating substantial savings without compromising crop productivity.
5. In the main field, irrigation water application was reduced by approximately 62% (796 mm to 300 mm), demonstrating the effectiveness of AWD in reducing irrigation demand.
6. Irrigation water-use efficiency improved markedly under AWD, increasing from 3.37 to 5.45 kg ha^{-1} mm^{-1} in the complete production system and from 4.26 to 13.00 kg ha^{-1} mm^{-1} in the main field.
7. Field water-use efficiency increased from 3.23 to 6.01 kg ha^{-1} mm^{-1}, confirming more efficient conversion of irrigation water into grain yield under AWD.
8. AWD enhanced important yield attributes, including tiller number, panicle number, and filled grains per panicle, which collectively contributed to higher grain production.
9. The pooled mean grain yield increased from 4258 kg ha^{-1} under conventional transplanting to 5149 kg ha^{-1} under AWD, representing an increase of approximately 20.9%.

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Conflict of Interest

The authors declare no conflict of interest regarding this publication.

Future Scope

Future research should integrate automated soil moisture sensors, IoT-based water level indicators, and remote sensing tools for real-time water management. Wider validation across different soil types and farmer-managed fields is required to strengthen applicability. Economic and environmental impact assessments will further support policy recommendations for large-scale adoption. Future studies should integrate remote sensing tools and soil moisture sensors for real-time water management.

References

1. Bouman B.A.M., et al. (2007). Water management in irrigated rice: coping with water scarcity. IRRI, Philippines.
2. Sarangi D. et al. (2017). Comparative evaluation of water budgeting parameters under different rice establishment methods. J. Appl. Nat. Sci. 9(3): 1373–1380.
3. Lampayan R.M. et al. (2015). Adoption and economics of alternate wetting and drying water management. Field Crops Res. 170: 95–108.
4. Doorenbos J., Kassam A.H. (1979). Yield response to water. FAO Irrigation and Drainage Paper 33, FAO, Rome.
5. Abdullahi A.S. et al. (2013). Characterization of rice evapotranspiration using micro-paddy lysimeter. Aust. J. Crop Sci. 7(5): 650–658.
6. Bouman B.A.M., Tuong T.P. (2001). Field water management to save water and increase productivity in irrigated lowland rice. Agric. Water Manage. 49(1): 11–30.
7. Rowshon M.K. et al. (2009). GIS-integrated rice irrigation management system for a rice-fed scheme. Water Resour. Manage. 23: 2841–2866.
8. Hidayat Y. et al. (2020). Effect of alternate wetting and drying on rice growth, yield and water use. J. Trop. Agric. 98(3): 215–224.
9. Saxton K.E., USDA Agricultural Research Service, http://hydrolab.ars.usda.gov/soilwater/index.html
10. Cabangon, R.J., et al. (2002). Effect of irrigation method and N-fertilizer management on rice yield, water productivity and nutrient-use efficiency. Agricultural Water Management, 57: 11–31.
11. Carrijo, D.R., et al. (2017). Water-saving irrigation practices reduce greenhouse gas emissions in rice systems. Agricultural Systems, 155: 147–158.
12. Belder, P., et al. (2004). Effect of water-saving irrigation on rice yield and water use in typical lowland conditions. Plant Production Science, 7(3): 242–249.
13. Howell, T.A. (2001). Enhancing water use efficiency in irrigated agriculture. Agronomy Journal, 93: 281–289.

14. Sarangi Dattatraya, A. Sarangi, D.K.Singh, K.K.Bandhyopaddhyay, S.S. Parihar and Dinesh Kumar. 2017. Comparative evaluation of water budgeting parameters under different rice (Oryza sativa L). Journal of Applied and natural Sciences. 9 (3): 1373-1380.
15. Abdullahi Abubakar Sadiq, Mohammad AminMohammad Soom, Desa Ahmad, Abdul Rashid Mohamed Shariff. 2013. Characterization of rice (Oryza sativa) evapotranspiration using micro paddy lysimeter and class “A” pan in tropical environments. Australian Journal of crop science. 7(5):650-658.
16. Rowshon MK Amin MSM, Shariff ARM (2009) GISintegrated Rice Irrigation Management System for a Rice fed Scheme. Water Res Manag. 23(14), 2841–2866.
17. Doorenbos, J Kassam AH (1979) Yield response to water. FAO Irrigation and Drainage Paper No. 33, Food and Agricultural Organization, Rome. Doorenbos J, Pruitt JO (1977) Guidelines for predicting crop water requirement. FAO Irrigation and Drainage Paper No. 27, Food and Agricultural Organization, Rome.
18. Peacock CE, Hess TM (2004) Estimating evapotranspiration from a reed bed using the Bowen ratio energy balance method. Hydrol Processes 18: 247-260.
19. Rowshon MK, Kwok CY, Lee TS (2003a) GIS-based scheduling and monitoring of irrigation delivery for rice irrigation system part I: Scheduling. J Agric water Manage 62, 105–116. 657- 655
20. Rowshon MK, Kwok CY, Lee TS (2003b) GIS-based scheduling and monitoring of irrigation delivery for rice irrigation system part II: monitoring. J Agric water Manage 62, 117–126.

