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Research Article

Impact of Water Management on Rice Varieties (*Oryza Sativa* L.), Yield and Water Use Efficiency under Alternate Wetting and Drying Method in Puddled Soil

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Abstract

This study was aimed to investigate water saving strategies in the paddy field and to evaluate the performance of some newly released rice varieties. Alternate wetting and drying method is a water saving method to improve yield and water use efficiency (WUE). A field experiment was conducted on sandy clay soil at Agricultural College farm, PJTSAU, Rajendranagar, Hyderabad during *kharif*, 2016 in a split plot design with three replications**.** The treatments comprised of three irrigation regimes (irrigation of 5 cm when water level falls below 5 cm from soil surface in field water tube i.e alternate wetting and drying irrigation - AWDI, irrigation of 5 cm, at one day after disappearance of water on the surface of the soil- DADSW and recommended submergence of 2-5 cm water level as per crop stage) as main treatments and four rice varieties (Telangana sona, KunaramSannalu, Bathukamma and Sheethal) as sub plots treatments. The data recorded indicate that recommended submergence of 2-5 cm water level recorded significantly higher grain and straw yield over AWDI of 5 cm and was at par with AWDI of 5 cm at one DADSW. Water productivity was higher with irrigation of 5 cm at one DADSW and was at par with irrigation of 5cm when water level falls below 5cm.Bathukamma produced higher grain yield, straw yield and water productivity as compare to KunaramSannalu, Sheethal and Telangana Sona. Based on the results, it can be concluded that among four rice varieties, Bathukamma recorded higher yield with recommended submergence and water productivity was higher with irrigation of 5 cm at one DADSW. There was no significant interaction effect between different rice varieties and irrigation regimes on yield and water use efficiency.

Keywords: AWD- alternate wetting and drying, Rice varieties, Yield, WUE-Water use efficiency

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Introduction

Rice (*Oryza sativa* L.) is a major staple food for the world's population dominantly produced and consumed in the Asia with about two-thirds of the total rice production grown under irrigation [1]. While rice is essential for ensuring global food security, traditional rice cultivation, practiced in flooded paddy soils, demands higher water inputs than other cereal crops [2]. With the increasing threat of water scarcity currently affecting 4 billion people around the globe [3], it is crucial to develop agronomic practices with the potential to reduce water use while maintaining or increasing yields to support a growing population. The need for "more rice with less water" is crucial for food security, and irrigation plays a key role in meeting future food needs than it has in the past [4]. Moreover, rice cultivation is threatened by climate change which represents the major challenge that irrigated agriculture all over the world will have to face. It is foreseen that by 2025, 15–20 million ha of rice lands will suffer from water scarcity [5]. Therefore, the effects of climate change necessitate an optimization of water use in irrigated rice. Continuous flooding (CF) provides a favourable water and nutrient supply under anaerobic conditions. However, the conventional system consumes a large amount of water [6].To tackle this problem, a number of water-saving irrigation (WSI) technologies to reduce water use, to increase water use efficiency, and to maintain or increase production for rice-based systems have been developed [7]. Among the different methods of water-saving irrigation, one practice that has been shown to reduce water use in rice systems is an irrigation management practice referred to as Alternate Wetting and Drying (AWD) [8].

The purpose of this current study was to evaluate the response of popular rice varieties in terms of yield and water productivity under different water management regimes in low land rice (Oryza sativa L.).

Materials and Method

Location

The field experiment was conducted during *kharif* 2016 season at College Farm, College of Agriculture, Rajendranagar, Hyderabad. The farm is geographically situated in the southern part of Telangana at 17°32' N latitude and 78°40'E longitude at an altitude of 542.6 m above mean sea level.

Treatments and design

The experiment was laid out in a split plot design with three irrigation regimes as main plots and four different rice varieties as sub plots and replicated thrice. The treatment combination includes three irrigation regimes (I_1-irrigation of 5 cm when water level falls below 5 cm from soil surface in field water tube,I_2- irrigation of 5 cm, at one day after disappearance of water on the surface of the soil and I_3- recommended submergence of 2-5 cm water level as per crop stage) as main treatments and four popular rice varieties in the Telangana region(V_1- Telangana sona, V_2-Kunaramsannalu,V_3- Bathukamma and V_4- Sheethal) as sub plots treatments respectively. The experimental plot size was 6 × 4.2 m. The 21days old seedlings of different rice varieties were transplanted by adopting a spacing of 15 × 15 cm. The experimental field was provided with proper irrigation channels, buffer channels and the individual plots were demarcated by bunds(**Figure 1**).

Figure 1 General view of experimental site

Soil properties and Fertilizer application

The experimental soil was sandy clay in texture, moderately alkaline in reaction, non-saline, low in organic carbon content (0.62 %), low in available nitrogen (N- 244.8 kg ha^{-1}), medium in available phosphorous (P_2O_5- 56.3 kg ha^{-1}) and potassium (K_2O- 230.7 kg ha^{-1}). A uniform dose of 120 kg N, 60 kg P_2O_5 and 40 kg K_2O ha^{-1} was applied. The N, P and K were applied in the form of urea, single super phosphate and muriate of potash respectively. The entire P fertilizer was applied as basal dose. The K fertilizer was applied in two equal splits as basal and at panicle initiation stage. The fertilizer N was applied in the form of prilled urea (46 % N) in three equal splits at basal, active tillering and panicle initiation stage.

AWDI Practice and Water measurements

AWDI practice is to measure the depth of standing water and water tables in the field, either above the surface or below the surface. Three different irrigation regimes based on water levels below the surface was practiced using the tube (**Figure 2**). Irrigation was given when water depth falls 5 cm from the surface. Water level depth in this tube was measured by simple measuring scale. The subsequent irrigation will be given to re-flood the field to a depth of 5 cm as per respective treatments. Irrigation was with held 15 days prior to harvest.

Figure 2 Water measurements in field water tube

In this experiment, PVC pipes were used to measure the water level below the ground level in the field. The diameter and the length of the PVC pipe were 15 cm and 40 cm, respectively, having perforations 2 cm away from each other. The pipe was installed in the field keeping 20 cm above the soil and the remaining portion (20 cm) below the soil. After irrigation, water entered in the pipe through small perforations and the water level inside the pipe was the same as that of outside. When the water level falls below the ground level, water level was measured by scale. Thus, the irrigation water was applied when the water level inside the pipe reached a predetermined position as per the treatments.

Imposition of treatments

In the conventional method of irrigation (I_3), the field was kept flooded up to 2 cm depth from 15 DAT to panicle initiation and up to 5 cm depth of irrigation from panicle initiation to physiological maturity. The irrigation treatments I_1 and I_2 were imposed from 10 days after transplanting to grain filling stage of the crop, and 5 cm irrigation to a depth of 5 cm submergence was given AWDI of 5 cm, when water level falls below 5 cm from soil surface (I_1) and irrigation of 5 cm submergence was given at one day after disappearance of water on the surface of the soil (I_2). The irrigation water was applied through plastic pipe from the source and a water meter was used for measuring irrigation water.

Field water tubes were placed in each main plot to measure the depth of standing water and water tables in the field, either above or below the surface. The irrigation was given when water depth goes below the surface to 5 cm. Water levels in the tube were measured by simple ruler. In all the irrigation regimes irrigation was withheld 15 days ahead of harvest.

Calculations and statistical analysis

The data collected from the experiment were analyzed statistically by analysis of variance (ANOVA) method for split plot design with irrigation regimes and rice varieties as main and sub factor, respectively. Whenever the treatment differences were found significant (F test), critical differences were worked out at five per cent probability level. Treatment differences that were non-significant were denoted by NS. The water studies were analyzed through water balance sheet and yield, water productivity data recorded and tabulated after statistical test.

Result and Discussion

Grain yield, straw yield and harvest index of rice was significantly influenced by different rice varieties and irrigation regimes (**Table 1** and **Figure 3a, 3b**). However, there was no significant effect of interaction between different rice varieties and irrigation regimes.

Grain yield (kg ha^{-1})

Among the different irrigation regimes, recommended submergence of 2-5 cm water level as per crop stage (I_3) recorded significantly higher grain yield of 6289 kg ha^{-1} than AWDI of 5 cm irrigation when water level falls below 5 cm in the field water tube (I_1) and was at par with AWDI of 5 cm at one day after disappearance of ponded water (I_2). Significantly lower yield (5928 kg ha^{-1}) was obtained with AWDI of 5 cm irrigation when water level falls below 5 cm in the field water tube (I_1) and was at par with the AWDI of 5 cm, one day after disappearance (I_2) of ponded water (6049 kg ha^{-1}) (Figure 3a).

Table 1 Grain yield, Straw yield (kg ha^{-1}) and harvest index (%) of rice varieties as influenced by irrigation regimes

Treatment	**Yield (kg ha^{-1})**		**Harvest index (%)**
	Grain	**Straw**	
Main plot- (Irrigation regimes)			
I_1: AWDI of 5 cm, when water level falls below 5 cm from soil surface in perforated pipe.	5928	5839	50.4
I_2: AWDI of 5 cm, one day after disappearance of ponded water on the surface of the soil.	6049	7408	45.2
I_3: Recommended submergence of 2-5 cm water level as per crop stage.	6289	8703	41.9
SEm±	63	220	0.8
C.D (P=0.05)	249	864	3.3
Sub plot- (Varieties)			
V_1 – RNR 15048(Telangana Sona)	5820	6858	46.5
V_2– KNM 118 (KunaramSannalu)	6319	7158	47.3
V_3– JGL 18047(Bathukamma)	6468	7755	45.8
V_4– WGL 283 (Sheethal)	5748	7496	43.7
SEm±	85	187	0.8
C.D (P=0.05)	253	555	2.5
Interaction			
Rice varieties at same level of Irrigation regimes			
SEm±	148	323	1.5
C.D (P=0.05)	NS	NS	NS
Irrigation regimes at same or different rice varieties			
SEm±	143	356	1.5
C.D (P=0.05)	NS	NS	NS

AWDI: Alternate wetting and drying irrigation, NS: Non Significant

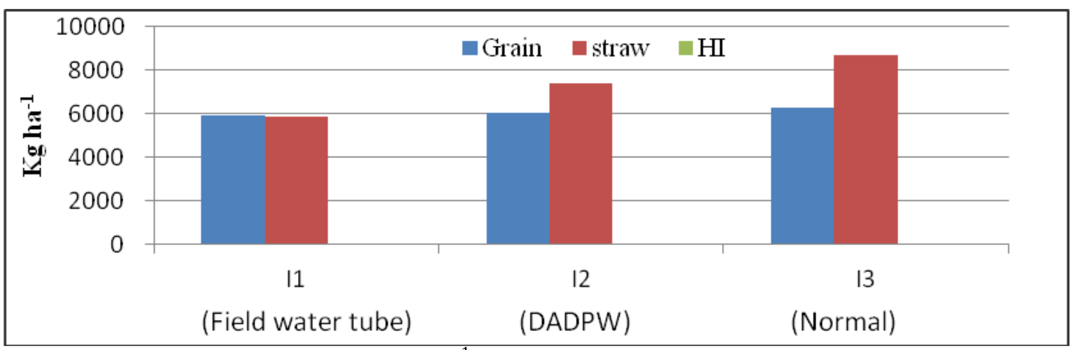

Figure 3a Grain yield, straw yield (kg ha^{-1}) and harvest index (%) of different irrigation regimes

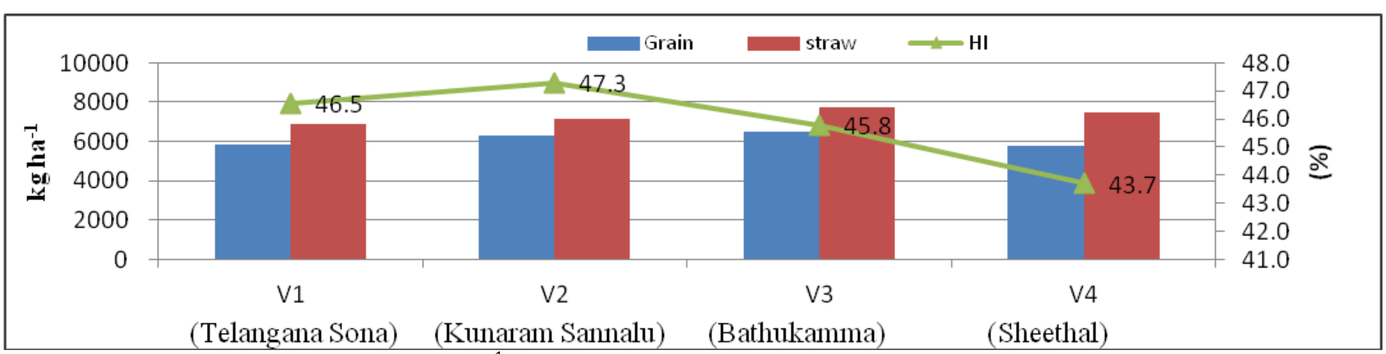

Figure 3b Grain yield, straw yield (kg ha^{-1}) and harvest index (%) of rice varieties as influenced by irrigation regimes

There was saving of water of 10.8 (1118.1mm) and 11.2 (1113.1mm) per cent of total water and 28.5 and 34.6 per cent of applied irrigation water over recommended submergence (1253.8 mm) with AWDI of 5 cm at one DADSW and AWDI of 5 cm at 5 cm water level fall in field water tube from surface. The effective rainfall was 64.6 and 71.9

percentage of total rainfall in AWDI of 5 cm at one day after disappearance of ponded water (I_2) and AWDI of 5 cm irrigation when water level falls below 5 cm in the field water tube (I_1) against 58.5 per cent under normal irrigation (**Table 2**). The saving in water was 8.5 per cent (37.2 mm) in AWDI of 5 cm at 5 cm water level fall in field water tube from surface over AWDI of 5 cm at one day after disappearance of surface water (I_2), though there was reduction in yield of 2.0 per cent (121 kg ha^{-1}).

Table 2 Calculated percentages of effective rainfall, saving of irrigation water and total water among different irrigation treatments by water balance sheet

Percentages	**I_1 (Field water tube)**	**I_2 (DADPW)**	**I_3 (Normal)**
% Effective Rainfall	71.9	64.6	58.5
% saving of irrigation water compare to normal (I_3)	34.6	28.5	
%saving of total water compare to normal (I_3)	10.8	11.2	
%saving of total water (I_1) compare to normal (I_2)	8.5		

Among varieties, Bathukamma recorded significantly higher grain yield (6468 kg ha^{-1}) as compare to Telangana Sona(5820 kg ha^{-1}) and Sheethal(5748 kg ha^{-1}) and was at par with KunaramSannalu (6318 kg ha^{-1}). Significantly lower yield was recorded with Sheethal than KunaramSannalu and Bathukamma and was on par with Telangana Sona (Figure 3b). The grain yield with Bathukamma was 2.4, 11.1 and 12.5 per cent higher than KunaramSannalu, Telangana Sona and Sheethal respectively. The yield with Telangana Sona was 10.0 per cent lower than the yield of Bathukamma and was 1.25 per cent higher than Sheethal. Similarly Sheethal recorded lower yield of 1.2, 9.0 and 11.1 per cent of Telangana Sona, KunaramSannalu and Bathukamma respectively.The lower yield of Telangana Sona might be due to low test weight and less panicle length as compared to the Bathukamma.

The increased yields under recommended submergence might be due to favourable growth and nutrition supply which resulted in higher dry matter and increased uptake of nutrients which lead the plants with superior growth enhancing the yield attributing characters with higher source to sink conversion, which in turn resulted in higher grain yields. On the other hand, AWDI irrigation practice at 5cm when water level falls 5 cm below in the field water tube and at one day after disappearance of ponded water (DADPW) also attained same level of yield. These results are in line with findings of Thiyagarajan *et al*.(2002) [9] and Geethalakshmi *et al*.(2009) [10]. On the other hand, AWDI irrigation practice at 5cm drop of water level in the field water tube and one day after disappearance of ponded water (DADPW) also attained on par yield. Similar results were found by Ashouri (2014) [11].

Straw yield (kg ha^{-1})

Mean straw yield of 8703 kg $ha^{-1}$was observed under recommended submergence of 2-5 cm water level as per crop stage (I_3) which was significantly higher than AWDI of 5 cm at one day after disappearance of surface water (I_2) with 7408 kg ha^{-1} and AWDI of 5 cm irrigation when water level falls 5 cm below in the field water tube (I_1). Significantly lower straw yield was obtained with AWDI of 5 cm submergence when water level falls 5 cm below in the field water tube (I_1) with 5839 kg ha^{-1}. Highest straw yield of rice under the conventional method of irrigation practice might be due to adequate moisture availability which contributed to increased dry matter accumulation. Similar results were reported by Ashouri.(2014) [11] Sariam and Anuar (2010) [12] and Kumar *et al*. (2014) [13].

Among the varieties, Bathukamma recorded significantly higher mean straw yield (7755 kg ha^{-1}) than KunaramSannalu (7158 kg ha^{-1}) and Telangana Sona (6858 kg ha^{-1}) and was on par with Sheethal (7496 kg ha^{-1}). Significantly lower straw yield was recorded with Telangana Sona than rest of the varieties except KunaramSannalu which was at par with Telangana Sona. Similarly, straw yield of KunaramSannalu and Sheethal were also found at par. The lower straw yield of Telangana Sona might be due to lower plant height and low dry matter as compared to Bathukamma.

Harvest index

The harvest index ranged from 43.7 to 47.3 per cent among different varieties. Among the different irrigation regimes, it ranged from 41.9 to 50.4 per cent and recommended submergence of 2-5 cm water level as per crop stage (I_3) recorded significantly lower harvest index (41.9%) than AWDI of 5 cm irrigation when water level falls 5 cm below in the field water tube (I_1) with 50.4 per cent and was on par with AWDI of 5 cm at one day after disappearance of ponded water (I_2) with 45.2 per cent. Significantly higher harvest index in I_1 might be due to lower grain yield and straw yield and also lower dry matter production at harvest (Table 1).

Among the varieties, KunaramSannalu recorded significantly higher harvest index (47.3%) than Sheethal (43.7%) and was on par with Telangana Sona (46.5%) and, Bathukamma (45.8%). Significantly lower harvest index was recorded in Sheethal than KunaramSannalu and Telangana Sona and was on par with Bathukamma. However rice varieties of KunaramSannalu, Telangana Sona and Bathukamma were at par in harvest index. The lower harvest index of Sheethal might be due to lower grain yield and higher straw yield and also higher dry matter production at harvest compared to other varieties.

Water Use Studies

Field water use

The Field water use mostly depends on irrigation frequency and the quantity of water used by the crop. Water input (irrigation plus effective rainfall) in different treatments varied between 1113.4 mm to 1253.8 mm (**Table 3**). The recommended submergence of 2-5 cm water level as per crop stage consumed more water (1253.8 mm) among different irrigation regimes. This was followed by irrigation of 5 cm, when water level falls below 5 cm from soil surface in field water tube (1118.0 mm) and irrigation of 5 cm at one day after disappearance of surface water (1113.4 mm). Increased consumptive use of water registered under recommended submergence of 2-5 cm water level as per crop was mainly due to more frequent irrigations and increased daily evapotranspiration and also deep percolation losses. Where the number of irrigations was 31 compared with 22 in irrigation of 5 cm at one day after disappearance of surface water and 17 in irrigation of 5 cm, when water level falls below 5 cm from soil surface in field water tube. On the contrary, lesser consumptive use of water was observed under AWDI at 5 cm drop of water level in the field tube was due to lesser number of irrigations (17) and practicing irrigation of 5 cm,at one day after disappearance of surface water treatments recorded least water consumption(1113.4 mm) among different irrigation regimes, which may be due to less evaporation losses compared to daily irrigation as per crop stage. Similar results of less water required were reported by Sathish. (2015) [14].

Table 3 Applied water, effective rainfall, total water and water productivity of rice varieties as influenced by irrigation regimes

Treatment	Water applied (mm)	Effective Rainfall (mm)	Total water (mm)	Water use efficiency (kg mm^{-1})
Main plot-(Irrigation regimes)				
I_1: AWDI of 5 cm, when water level falls below 5 cm from soil surface in perforated pipe.	702.8	415.2	1118.0	5.30
I_2: AWDI of 5 cm, one day after disappearance of ponded water on the surface of the soil.	740.1	373.3	1113.4	5.43
I_3: Recommended submergence of 2-5 cm water level as per crop stage	916.0	337.8	1253.8	5.02
SEm±				0.04
C.D (P=0.05)				0.17
Sub plot- (Varieties)				
V_1 – RNR 15048(Telangana Sona)	786.3	375.4	1161.7	5.02
V_2– KNM 118 (KunaramSannalu)	786.3	375.4	1161.7	5.45
V_3– JGL 18047(Bathukamma)	786.3	375.4	1161.7	5.57
V_4– WGL 283 (Sheethal)	786.3	375.4	1161.7	4.96
SEm±				0.07
C.D (P=0.05)				0.21
Interaction				
Rice varieties at same level of Irrigation regimes				
SEm±				0.12
C.D (P=0.05)				NS
Irrigation regimes at same or different rice varieties				
SEm±				0.11
C.D (P=0.05)				NS

AWDI: Alternate wetting and drying irrigation, NS: Non Significant

Water use efficiency

Water use efficiency (WUE) determination in irrigation commands will indicate the unit quantity of grain yield obtained per unit quantity of water used. Water use efficiency of the treatments assessed are furnished in Table 3 and **Figure 4**.

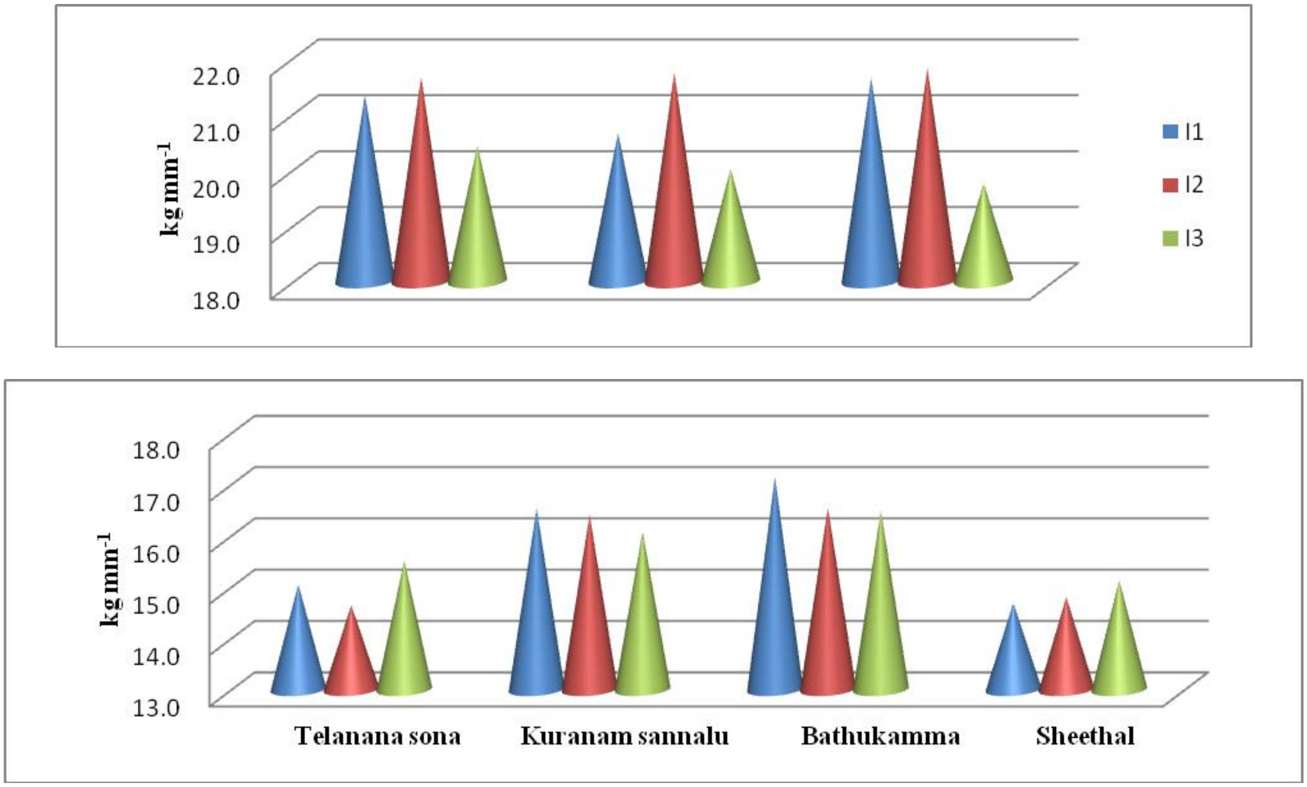

Figure4 Water use efficiency of four different rice varieties as influenced by different irrigation regimes

The different irrigation practices significantly influenced the WUE of the rice crop. The WUE was higher with irrigation of 5 cm at one day after disappearance of ponded water(I_2), which registered 5.43 kg mm^{-1} and was on par with irrigation of 5cm when water level falls below 5 cm from soil surface in field water tube with (5.30 kg mm^{-1}).The lowest WUE was accounted with recommended submergence of 2-5 cm water level as per crop stage (I_3), which recorded 5.02 kg mm^{-1} due to excessive irrigation with large depths of standing water in paddy fields with high water losses by evaporation, percolation, seepage, and surface runoff, critical in the efficient water use in rice production. The water use efficiency (WUE) can be increased in AWD rice crop either by increasing yield or by maintaining the same yield level with reduced quantity of water input and with small seepage and percolation losses. Therefore, greater water use efficiency was consistently observed in AWD irrigation regimes than continuous flooding irrigated crop (Yao *et al.*, 2012) [15].In the present study also, reduction in consumptive water use under irrigation of 5 cm when water level falls below 5cm from soil surface in field water tube and irrigation of 5 cm at one day after disappearance of surface water coupled with the maintenance of yield at an optimum level increased the WUE. WUE under AWDI of 5 cm submergence depth when water level falls below 5 cm from soil surface in field water tube treatment was 5.7 per cent higher compared to the recommended submergence of 2-5 cm water level as per crop stage and irrigation of 5 cm at one day after disappearance of surface water recorded higher WUE of 8.2 per cent over recommended practice due to reduction in consumptive use. Similar results was found by Sathish. (2015) [14] and Kishore. (2016) [16].

Significantly higher water use efficiency (5.57 kg mm^{-1}) was recorded with Bathukamma than Telangana Sona (5.02 kg mm^{-1}) and Sheethal (4.96 kg mm^{-1}) and was at par with KunaramSannalu (5.45 kg mm^{-1}) due to higher grain yield. Significantly lower water use efficiency was recorded with Sheethal and was on par with Telangana Sona. The water use efficiency with Bathukamma was 2.4, 11.0 and 12.5 per cent higher than KunaramSannalu, Telangana Sona and Sheethal, respectively. The water use efficiency with Telangana Sona was 9.8 per cent lower than that of Bathukamma and was 12.2 per cent higher than Sheethal. The lower water use efficiency of Telangana Sona might be due to lower grain yield as compared to Bathukamma.The variation in water use efficiency may be due to inherent genetical character of the varieties.

Conclusion

It can be concluded that recommended submergence of 2-5 cm water level recorded significantly higher grain and straw yield over AWDI of 5 cm when water falls below 5 cm from soil surface in field water tube and was on par with AWDI of 5 cm at one DADSW. Water productivity was higher with irrigation of 5 cm at one DADSW and was on par with irrigation of 5cm when water level falls below 5 cm from soil surface in field water tube. Bathukamma produced higher grain yield, straw yield and water productivity compared to KunaramSannalu, Sheethal and Telangana Sona.

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