



## Maximizing blue water use efficiency of wheat (*Triticum aestivum*) through irrigation and mulching

M MADHU<sup>1</sup>, PARTHA PRATIM ADHIKARY<sup>2</sup>, PRAVEEN JAKHAR<sup>3</sup>, N K DAS<sup>4</sup> and G W BARLA<sup>5</sup>

ICAR-Indian Institute of Soil and Water Conservation, Koraput, Odisha 763 002 India

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### ABSTRACT

A field study was conducted in sub-humid Eastern Ghats region of India to investigate the effect of different soil moisture conservation practices, viz. no-mulch (NM) as a control, ridge and furrow (RF), *Gliricidia* mulch (GM) and *Lantana* mulch (LM) on water productivity, and yield of wheat (*Triticum aestivum* L.) under three levels of irrigation ( $CPE_{100} = 100\%$ ,  $CPE_{80} = 80\%$  and  $CPE_{60} = 60\%$ ). Total water use by wheat was 270.1–365.6 mm during 2016–17 and 210.4–302.5 mm during 2015–16. Averaging both years, wheat used was 88.35 mm (26.8%) and 44.9 mm (13.6%) more water at  $CPE_{100}$  over  $CPE_{60}$  and  $CPE_{80}$ , respectively. Among the irrigation levels, higher water productivity (WP) was observed in  $CPE_{60}$  (13.6, 9.8 kg/m<sup>3</sup>) compared to  $CPE_{80}$  (12.8, 9.3 kg/m<sup>3</sup>) and  $CPE_{100}$  (11.3, 8.9 kg/m<sup>3</sup>) for both years, respectively.  $CPE_{60}$  resulted in 5.9 and 15.8% greater WP over  $CPE_{80}$  and  $CPE_{100}$ , respectively. Mulching increased WP by 27.8% in GM and 23.3% in LM treatments compared to NM. Irrigation with mulching treatments,  $CPE_{60} + GM$  exhibited WP of 15.9 and 14.7 kg/m<sup>3</sup>, and  $CPE_{60} + LM$  WP of 11.0 and 10.6 kg/m<sup>3</sup> during 2015–16 and 2016–17, respectively. On an average, mulching treatment produced additional total WP of 2.2–2.6 kg/m<sup>3</sup>, green WP of 0.5–0.7 kg/m<sup>3</sup> and blue WP of 1.7–2.0 kg/m<sup>3</sup> over NM. Thus  $CPE_{80} + GM$  could be successfully applied during post-monsoon (*Rabi*) season in wheat production allowing a water savings of 20% without any yield loss.

**Key words:** Eastern Ghats, Mulch, Rainwater harvesting, Water productivity, Wheat

In rainfed areas, harvested rainwater is the main source of water for raising successful *rabi* crops because of insufficient residual soil profile moisture and scanty rainfall. Utilization efficiency of harvested rainwater is very low due to uncontrolled irrigation and evapotranspiration losses. Modern irrigation methods are highly efficient but their adoption by resource poor community is very limited due to socio-economic constraints. Wheat (*Triticum aestivum* L.) in Eastern Ghats of Odisha is cultivated under residual moisture with very limited irrigation, resulting in low yields of 1.77 t/ha (Agricultural statistics at a glance 2018). Under this situation, efficient use of harvested rainwater along with profile soil moisture conservation measures is essential for improving wheat yield. Adhikary *et al.* (2015) reported that successful management of rainwater for agriculture depends on techniques of increasing water use efficiency (WUE). A combine notion of deficit irrigation and mulching appears to be promising for increasing WUE (Jakhar *et al.* 2017).

Mulching increases crop yield by improving soil physical conditions by maintaining optimum moisture

and thermal environment in soil (Chakraborty *et al.* 2008, Dass and Bhattacharyya 2017). Straw mulch increases soil moisture storage by serving as a vapour barrier against moisture losses from the soil and conservation of soil moisture (Mulumba and Lal 2008), which moderates plant water status, soil temperature, leading to better root growth and higher grain yields (Jakhar *et al.* 2015). Irrigation along with mulching is advocated for better uptake of water by the spring wheat (Li *et al.* 2004) with reduced quantity of water and number of irrigations. There are different types of mulching materials available and their efficiency to conserve soil moisture is widely reported (Chakraborty *et al.* 2008). The information on effectiveness of locally available materials with irrigation levels is scanty. The present study aims to optimize the irrigation at critical stage of wheat crop growth with low cost mulching based conservation methods. The specific objective of the study was to evaluate the effect of harvested rainwater irrigation levels with soil moisture conservation practices on WUE of wheat.

### MATERIALS AND METHODS

The study was conducted during *rabi* 2015–16 and 2016–17 at research farm of ICAR-Indian Institute of Soil and Water Conservation (IISWC), (18°45' N latitude, and 82°42' E longitude, 900 m amsl), Odisha, in the Eastern Ghats region of Odisha. Climate of the study area was sub-humid type. The annual mean maximum and minimum

Present address: <sup>1</sup>Principal Scientist (madhupmd@gmail.com), <sup>2,3</sup>Senior Scientist (partha.adhikary@icar.gov.in, icarpraveen@gmail.com), <sup>4,5</sup>Technical Officer (nabindas@rediffmail.com, gwbarla2014@gmail.com), ICAR-Indian Institute of Soil and Water Conservation, Research Centre, Koraput, Odisha, India.

temperature were 30.4°C and 17.5°C, respectively (Jakhar *et al.* 2011). Mean annual rainfall was 1540 mm, 80.6%. Soil of the study site was red lateritic and slightly acidic, taxonomically classified as a fine loamy, mixed, hypothermic type *Rhodustalfs*. Soil organic carbon (OC) was low to medium, cation exchange capacity (CEC) 7.2 Cmol (P+)/kg at 0–15 cm soil depth with base saturation (BS) 63%. The soil moisture content at field capacity and wilting point was 35.6 m<sup>3</sup>/m<sup>3</sup> and 14.9 m<sup>3</sup>/m<sup>3</sup> respectively, with maximum available water 20.7 m<sup>3</sup>/m<sup>3</sup>. Available nitrogen (N), phosphorus (P) and potassium (K) content of the soils were 308, 12.8 and 27.4 kg/ha, respectively. The experiment was laid-out in a split-plot design where three irrigation levels (CPE based irrigation) were in main-plot and mulching (soil moisture conservation) treatments were in sub-plots with three replications in a plot size of 16 m<sup>2</sup>. Treatment means were compared using least significant difference (LSD, P=0.05) procedure (Gomez and Gomez 2010). This study included five irrigations at five critical growth stages of wheat crop with pre-sowing irrigation of 50 mm. The quantity of irrigation water depth for each irrigation levels was calculated as:

$$IW_{di} = R * CPE_i - P$$

Where  $IW_{di}$ , Irrigation water depth in mm at  $i^{th}$  growth stage; R, IW/CPE ratio (in this study it was 0.6, 0.8, and 1.0);  $CPE_i$ , Cumulative pan evaporation data at  $i^{th}$  growth stage in mm calculated from the  $(i-1)^{th}$  growth stage; P, Precipitation in mm occurred in between  $(i-1)^{th}$  and  $i^{th}$  growth stage.

Irrigation was applied to each plot/treatment at 20 days interval exactly, matching with the different critical growth stages of wheat. The four treatments were un-mulched field as a control (NM), ridges and furrow (RF), *Gliricidia* mulch (GM) @10 t/ha and *lantana* mulch (LM) @10 t/ha. Immediately after sowing, uniform irrigation of 50 mm was applied to all the plots to facilitate germination and uniform soil moisture distribution in the soil profile.

In agriculture, blue water refers to the volume of surface and groundwater consumed (mainly from irrigation) as a result of the production of a goods; the green water refers to the rainwater consumed (Hoekstra *et al.* 2009). Carryover soil moisture from the previous growth stage (final soil moisture before irrigation or end of growth stage) was segregated into green and blue water with the assumption that proportionately contributed to the soil profile moisture from the total green and blue water. The total water used at each growth stage of wheat crop, viz. sowing to CRI, CRI to tillering, tillering to jointing, jointing to flowering and flowering to maturity was calculated as:

$$TW_i \text{ (mm)} = GW_i + BW_i$$

Where  $TW_i$ , Total water used at  $i^{th}$  growth stage (mm);  $GW_i$ , Green Water used at  $i^{th}$  growth stage (mm);  $BW_i$ , Blue Water used at  $i^{th}$  growth stage (mm).

$$GW_i = R_i + GW_{sp}$$

Where  $R_i$ , Rainfall occurred at  $i^{th}$  growth stage (mm);

$GW_{sp}$ , Green Water from soil profile at end of each growth stage upto 40 cm soil depth.

$$GW_{sp} = (R_i + TM_{sp}) / ATW_i$$

Where  $TM_{sp}$ , Total moisture in soil profile at end of each growth stage (upto 40cm depth);  $ATW_i$ , Available Total Water at  $i^{th}$  growth stage (Irrigation + Rainfall +  $TM_{sp}$ ).

$$BW_i = IR_i + (TM_{sp} - GW_{sp})$$

Where  $IR_i$ , Irrigation water applied upto  $i^{th}$  growth stage  
Green or blue water productivity is the product of total WP and percent share of green or blue water out of the total water used which is calculated as.

$$WP = (TWP * \% \text{ of green or blue water used})$$

## RESULTS AND DISCUSSION

*Water budgeting:* Component-wise water budgeting reveals that the average soil moisture content at the time of sowing of wheat crop was 40.9 and 47.1 mm during 2015–16 and 2016–17, respectively (Table 1). Contribution of moisture from Rainfall during the cropping season was only 16.5 mm during both the years. Irrigation of 186, 231 and 277 mm was applied at  $CPE_{60}$ ,  $CPE_{80}$  and  $CPE_{100}$ , respectively. The average soil moisture at harvest was 32.8 mm in 2015–16 and 34.9 mm in 2016–17. The higher value of soil moisture in second year is due to higher rainfall received during 2016–17 compared to 2015–16. The total water used during the crop period increased with greater water availability from soil. Total water used by the wheat crop was higher in 2016–17 (270.1 - 365.6 mm) compared to 2015–16 (210.4–302.5 mm). On average wheat crop used 88.35 mm (26.8%) and 44.9 mm (13.6%) more water at  $CPE_{100}$  over  $CPE_{60}$  and  $CPE_{80}$ , respectively. Total water used among the mulching treatments was not significant during 2016–17 where rainfall contributed 72.1 mm against 16.5 mm in 2015–16. However, total water use was slightly higher in mulching treatments (LM and GM) compared to NM plot and RF at all the irrigation levels. In mulch treatments, the rate of soil drying was low which resulted in the availability of water to the crops for longer duration (Zhang *et al.* 2013).

Green water (GW) contribution accounted in the limits of 16.9–24.08% and 29.3–39.1% of the total water use, respectively, under different treatments during both the years. Green water contribution through rainfall was 16.5 mm and 72.1 mm in 2015-16 and 2016-17, respectively. Percent GW contribution to total water was higher by 8–9% at  $CPE_{60}$  and decreased with increased irrigation level ( $CPE_{80}$  and  $CPE_{100}$ ) in both the years (Fig 1). Average green water contribution was 50.9 mm and 107.0 mm in 2015–16 and 2016–17, respectively. Similarly average blue water contribution during the cropping season was 196 mm and 204.6 mm in 2015–16 and 2016–17, respectively. Total blue water used varied from 151.0–240.6 mm (71.6–80.3%) in 2015–16 and 161.4–251.0 mm in 2016–17 (59.7–69.0%) among the treatments and it increased with irrigation levels

Table 1 Component of water budgeting under irrigation and conservation treatments during 2015–16 and 2016–17 wheat cropping season

Treatment	Initial Soil Moisture (mm)		Rainfall (mm)		Irrigation (mm)		Final Soil Moisture (mm)		Total Water Used (mm)	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
CPE60+NM	41	47	17	72	219	187	33	30	243	276
CPE60+RF	39	48	17	72	219	187	30	29	244	278
CPE60+GM	42	47	17	72	219	187	31	28	246	278
CPE60+LM	42	46	17	72	219	187	32	29	245	276
CPE80+NM	41	47	17	72	281	236	35	32	305	322
CPE80+RF	42	44	17	72	281	236	35	31	303	320
CPE80+GM	41	49	17	72	281	236	31	31	308	325
CPE80+LM	42	48	17	72	281	236	32	30	307	325
CPE100+NM	39	45	17	72	343	292	35	32	364	377
CPE100+RF	40	43	17	72	343	292	34	31	366	376
CPE100+GM	42	50	17	72	343	292	33	33	369	381
CPE100+LM	40	51	17	72	343	292	33	32	367	383

CPE, Cumulative Pan Evaporation; NM, No Mulch; RF, Ridges and Furrows; GM, Gliricidia Mulch; LM, Lantana Mulch

(Fig 1). More blue water was used at CPE<sub>100</sub> (250.4 mm, 76.4%) compared to 206.1 mm (68.7%) at CPE<sub>80</sub> and 163.8 mm (73%) at CPE<sub>60</sub>. Blue water contribution due to moisture conservation practices (mulching) does not showed noticeable differences in water used among the treatments (72.4–73%). Percent contribution of blue water to the total water use was greater in 2015–16 due to low green water contribution (low rainfall) in comparison to 2016–17, where rainfall was higher.

*Yield attributes:* Deficit irrigation treatment (CPE<sub>60</sub>) gave significantly lower values of yield attributes during both years of study whereas irrigation at CPE<sub>80</sub> and CPE<sub>100</sub> gave statistically non-significant values for most yield attributes. However, irrigation at CPE<sub>80</sub> gave maximum value of effective tillers (269 and 276 per m<sup>2</sup>) and grains/spike (39.42 and 35.33) in 2015–16 and 2016–17, respectively. Irrigation regime at CPE<sub>100</sub> gave maximum values of

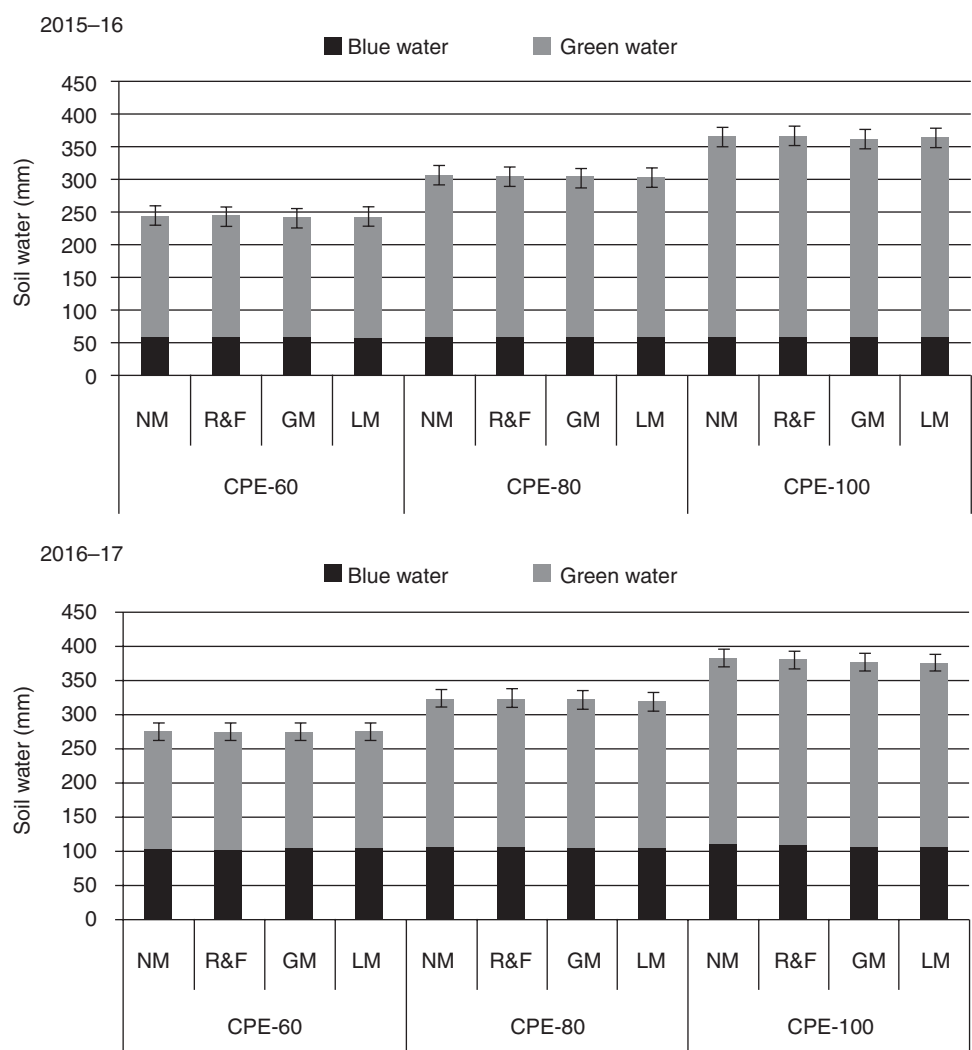


Fig 1 Green and blue water used by wheat crop under different irrigation levels with various soil moisture conservation practices.

Table 2 Irrigation levels and soil moisture conservation practices on wheat grain yield, straw yield, biological yield and harvest index

Treatment	Grain yield (q/ha)		Straw yield (q/ha)		Biomass yield (q/ha)		Harvest Index (%)	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
<i>Irrigation</i>								
CPE75	26.44	28.85	47.52	49.57	73.95	78.42	35.67	36.88
CPE100	29.13	32.73	50.12	52.81	79.26	85.54	36.84	38.41
CPE125	31.99	34.00	49.43	51.75	81.42	85.76	39.30	39.69
SEm+	0.76	0.77	0.49	0.50	0.88	0.86	0.65	0.58
LSD(P<0.05)	3.00	3.01	1.91	1.96	3.44	3.36	NS	NS
CV (%)	9.07	8.34	3.43	3.37	3.89	3.57	6.04	5.25
<i>Soil moisture conservation practices</i>								
NM	25.51	27.87	46.18	47.39	71.69	75.26	35.56	37.13
RF	28.44	31.48	47.40	50.32	75.84	81.80	37.46	38.57
GM	31.54	34.96	50.41	52.49	81.96	87.44	38.55	40.00
LM	31.26	33.12	52.10	55.32	83.36	88.44	37.50	37.62
SEm+	0.69	0.80	1.51	2.18	1.61	2.59	0.96	0.93
LSD (P<0.05)	2.04	2.37	4.47	6.47	4.79	7.70	NS	NS
CV (%)	7.07	7.50	9.21	12.71	6.18	9.34	7.77	7.26

CPE, Cumulative pan evaporation; SE.m, Standard error of mean; LSD, Least significant difference; CV, Coefficient of variation; NM, No mulch; RF, Ridges and furrows; GM, *Gliricidia* mulch; LM, *Lantana* mulch

spike length (7.13 cm and 7.65 cm) as well as test weight (44.92 g and 44.43 g) in 2015-16 and 2016-17, respectively. Varied moisture conservation treatments in the form of mulch registered significant effect on yield attributes. In comparison to the NM; RF and mulching treatments yielded significantly superior values. Maximum values of effective tillers (262.7 and 286.2), grains/ spike (39.11 and 37.11), and spike length (7.29 cm and 7.92 cm) were recorded in 2015-16 and 2016-17, respectively. The findings are in agreement with Hari Ram *et al.* (2013).

*Yield:* Two years statistically analyzed data pertaining to yields and harvest index (Table 2) signifies that CPE<sub>100</sub> manifested maximum grain yield (32.0 and 34.0 q/ha) for both years. Numerically, it was at par with CPE<sub>80</sub> (29.13 and 32.73 q/ha) in first and second year, respectively. In comparison to CPE<sub>100</sub> irrigation level decrease in the yield with CPE<sub>60</sub> was of 17.3% and 15%, respectively. Similar trend was observed for straw and biological yield, and under CPE<sub>60</sub> irrigation yielded significantly less values for both the parameters. For biological yield the decrease in the yield was 6.5 and 9.1, and 8.5 and 8.7 in comparison to CPE<sub>80</sub> and CPE<sub>100</sub> in 2015-16 and 2016-17, respectively. Quanqi *et al.* (2010) attributed the increase in grain yield with increased irrigation to the increased radiation use efficiency and increase in spike number. In the present study there was an increase in grain yield of 17.8% and 20.9% for the years 2015-16 and 2016-17, respectively when the irrigation regime was changed from CPE<sub>60</sub> to CPE<sub>100</sub>. Different mulching treatments showed significant effect on wheat grain and straw yield (Table 2). In comparison to NM; RF, GM and LM gave significantly superior grain yield values of 10.3, 19.1, 18.4 and 11.4, 20.3, 15.9% for 2015-16 and 2016-17, respectively. In case of straw yield

the results were inconspicuous and statistically at par thus showing no significant impact. For biological yield, GM and LM were significantly superior to control treatment with 12.5% and 13.9% during 2015-16 and 13.9% and 15.0% during 2016-17. In comparison to RF treatment, LM gave higher biological yield values of 9.0% and 15.6% in 2015-16 and 2016-17, respectively. The increase in grain yield due to GM and LM was possibly due to better hydrothermal regime and root growth, which increased nutrient uptake and crop growth. Decomposition of leguminous mulch also added organic matter to the soil and helped increase the crop yield. Similar findings were also reported by Dar and Ram *et al.* (2017).

*Water productivity:* Water productivity (WP) under different treatments was greater in 2015-16 (10.5 to 15 kg/m<sup>3</sup>) compared to 7.7-10.6 kg/m<sup>3</sup> in 2016-17 which can be attributed to low total water use in 2015-16 (Table 3). Among the irrigation levels, greater WP was in CPE<sub>60</sub> (13.6, 9.8 kg/m<sup>3</sup>) compared to CPE<sub>80</sub> (12.8, 9.3 kg/m<sup>3</sup>) and CPE<sub>100</sub> (11.3, 8.9 kg/m<sup>3</sup>) for both the years, respectively. Irrigation at CPE<sub>60</sub> produced 5.9 and 15.8% greater WP over CPE<sub>80</sub> and CPE<sub>100</sub>, respectively. Higher WP under DI system was mainly because of more partitioning of biomass to the grains. WP was greater by 27.8% in GM and 23.3% in LM mulch treatments compared to NM. Irrigation with mulching treatments of CPE<sub>60</sub> + GM (15.9 and 14.7 kg m<sup>3</sup>) and CPE<sub>60</sub> + LM (11.0 and 10.6 kg/m<sup>3</sup>) produced greater WP in 2015-16 and 2016-17, respectively. Green WP was greater in CPE<sub>60</sub> + GM (3.8 and 4.3 kg/m<sup>3</sup>) and CPE<sub>80</sub> + LM (3.4 and 4.1 kg/m<sup>3</sup>) in 2015-16 and 2016-17, respectively. Green WP was lower in 2015-16 (1.8-3.8 kg/m<sup>3</sup>) due to low contribution of green water to the total water attributed to low rainfall compared to 2016-17. At lower irrigation

Table 3 Green, blue and total water productivity ( $\text{kg}/\text{m}^3$ ) of wheat under irrigation and conservation treatments during 2015–16 and 2016–17 wheat cropping season

Treatment	Total WP		Green WP		Blue WP	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
CPE60+NM	10.7	7.9	2.6	3.1	8.1	4.8
CPE60+RF	13.2	9.5	3.2	3.7	10.1	5.8
CPE60+GM	15.9	11.0	3.8	4.3	12.1	6.7
CPE60+LM	14.7	10.6	3.4	4.1	11.3	6.5
CPE80+NM	11.3	8.4	2.3	2.9	9.0	5.5
CPE80+RF	12.6	8.9	2.5	3.1	10.0	5.9
CPE80+GM	13.3	10.0	2.7	3.4	10.6	6.6
CPE80+LM	14.1	9.7	2.9	3.2	11.3	6.4
CPE100+NM	10.5	7.7	1.8	2.4	8.7	5.3
CPE100+RF	11.3	8.6	2.0	2.7	9.3	6.0
CPE100+GM	12.7	9.3	2.1	2.8	10.6	6.6
CPE100+LM	10.8	9.8	1.8	2.9	9.0	7.0

CPE, Cumulative pan evaporation; NM, No mulch; RF, Ridges and furrows; GM, *Gliricidia* mulch; LM, *Lantana* mulch

level ( $\text{CPE}_{60}$ ) green water productivity was 22.6–52.4% higher than at  $\text{CPE}_{80}$  and  $\text{CPE}_{100}$ . However, mulching of GM and LM produced greater WP during both the years and greater by 21.2–26.5% over NM. Blue WP was greater by 64% in 2015–16 ( $10.0 \text{ kg}/\text{m}^3$ ) compared to 2016–17 ( $6.1 \text{ kg}/\text{m}^3$ ). Irrigation treatment  $\text{CPE}_{60}$  with mulching (GM and LM) produced greater blue WP ( $12.1$  and  $11.3 \text{ kg}/\text{m}^3$ ) in 2015–16. Mulching of GM and LM produced greater blue WP of 24.4–28.5% then the NM. On an average mulching treatment produced additional TWP of 2.2–2.6  $\text{kg}/\text{m}^3$ , green WP of 0.5–0.7  $\text{kg}/\text{m}^3$  and blue WP of 1.7–2.0  $\text{kg}/\text{m}^3$  over NM, respectively. The translocation of photosynthates became rapid under this condition and improved WP. Better hydrothermal condition will improve the WP by decreasing the evapotranspiration (Quanqi *et al.* 2010) and increasing the grain yield (Chakraborty *et al.* 2008).

From this study it was observed that maximum water productivity was observed under the treatment combination  $\text{CPE}_{60}$  with *Gliricidia* mulch. Although highest yield was observed in the treatment  $\text{CPE}_{100}$  + *Gliricidia* mulch but the treatment  $\text{CPE}_{80}$  + *Gliricidia* mulch can be recommended for the farmers for commercial cultivation of wheat in this region as this treatment saves 20% of water input while producing statistically same yield of treatment  $\text{CPE}_{100}$  + *Gliricidia* mulch.

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