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RESEARCH ARTICLE

The moisture regimes and herbicides efficacy in improving productivity and profitability of maize-wheat cropping system

Sandeep Rawal, A.S. Dhindwal, Ashok Yadav, Aradhna Bali and Pardeep Sagwal*

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ABSTRACT

Two factorial field experiments were conducted in Haryana in split plot arrangement during 2013-14 and 2014-15 to evaluate moisture regimes and weed control treatments efficacy to managing weeds and improve productivity and profitability in maize-wheat cropping system. Four moisture regimes in main plots were based on cumulative pan evaporation (CPE) at 80-, 120-, 160- and 200-mm CPE interval in maize and at 75, 100, 125 and 150 mm CPE interval in wheat. Weed management treatments included pre-emergence application (PE) of pendimethalin at 1000 g/ha, atrazine at 750 g/ha PE, post-emergence application (PoE) of tembotrione at 120 g/ha in maize and pendimethalin at 1500 g/ha PE, clodinafop + carfentrazone at 60 +20 g/ha PoE and pinoxaden + metsulfuron at 50 + 4 g/ha PoE in wheat, weed free and weedy check. Significantly higher system yield (10.02 and 10.21 Mg/ha) during both years (2013-14 and 2014-15) were recorded at 80 mm CPE interval in maize and CRI+75 mm CPE interval in wheat. The atrazine PE and tembotrione PoE in maize and herbicide mixture viz. clodinafop+ carfentrazone and pinoxaden + metsulfuron PoE in wheat were the most effective weed management treatments.

Keywords: Clodinafop + carfentrazone, maize-wheat cropping system, moisture-weed interaction, Pinoxaden + metsulfuron, Tembotrione, Weed management

INTRODUCTION

Rice-wheat cropping system (RWCS) is crucial for the country's food security, but to ensure sustainability of natural resources and crop production in dark zones (over-exploited groundwater zones), diversification of rice by crops requiring less water, crops such as maize, is essential (Jat *et al*. 2015). Maize (*Zea mays* L.) is one of the most versatile cereal crops having wider adaptability under diverse soil and climatic conditions (Kumar *et al*. 2015) fits best with wheat in cropping system. Weeds are a major biological constraint that limits the production of wheat by 10-60% and maize by 30-40% (Ramesh *et al.* 2017). In India, chemical weed control is the most viable and practical option due to labour scarcity and rising cost coupled with untimely and continuous rainfall that makes timely manual weed control operations difficult. Current rates of agricultural water use are unsustainable, creating an urgent need to identify improved irrigation strategies for water limited areas (Lopez *et al.* 2017). This is especially evident in areas that rely heavily on groundwater resources (Scanlon *et al.* 2012). Among different approaches for scheduling irrigation of field crops; moisture regimes and climatological approach are found to be reliable and dependable (Jaffar *et al.* 2017). The irrigation and weed management at the cropping system level can provide better insight into managing natural resources more efficiently. This will help in optimizing the moisture regimes and weed management practices in maize-wheat cropping sequence under furrow irrigated raised bed system (FIRBS). Thus, an experiment was conducted to identify the optimized moisture regimes and weed management practices in maize-wheat cropping sequence.

MATERIAL AND METHODS

The experiment was conducted in cropping system mode during Kharif and Rabi season of 2013-14 and 2014-15 at CCS Haryana Agricultural University, Hisar research farm situated at $29^0 10'$ North latitude and $75^0 46'$ East longitudes at an elevation of 215.2 m above mean sea level. The soil (0-30 cm) of the experimental field was a typic Torripsamments with pH 7.8, 0.51% organic carbon (Walkley and Black 1934), 141.6 kg/ha alkaline $KMnO_4$ oxidizable N (Subbiah and Asija 1956), 16.8 kg/ha Olsen-P (Olsen *et al*. 1954) and 268.4 kg/ha ammonium acetate extractable K. The texture of soil was sandy loam with 1.5 g/cm3 bulk density and

Department of Agronomy, CCS Haryana Agricultural University, Hisar, Haryana 125004, India

* Corresponding author email: pardeepsagwal@gmail.com

basic infiltration rate of 4.3 mm/h. High rainfall (564 mm) was received during 2013 maize crop season (June-September) while second year was comparatively dry with average rainfall daily deficit of 4.29 mm. During wheat season (November-April) rainfall deficit over ET_0 of 1.26 and 1.92 mm/day as observed during 2013-14 and 2014-15 respectively.

Experiment was laid down using split plot design with 20 treatment combinations comprising of four moisture regimes in main plots and five weed control treatments in sub plots, replicated thrice in both maize and wheat. Irrigation was applied at different intervals depending upon cumulative pan evaporation (CPE) as per treatments. In maize, irrigations were applied when value of CPE minus rainfall reached 80 mm, 120 mm, 160 mm and 200 mm. In wheat, after a common irrigation at crown root initiation, irrigations were scheduled at 75 mm, 100 mm, 125 mm and 150 mm CPE. The details of irrigations applied in different treatment is presented in Table A and B.

Five weed control treatments consisted of weed free, weedy check, pre-emergence application (PE) of pendimethalin at 1000 g/ha and atrazine at 750 g/ha and post-emergence application (PoE) of tembotrione at 120 g/ha in maize. While in wheat, treatments consisted of weed free, weedy check, pendimethalin at 1500 g /ha PE, clodinafop + carfentrazone at 60 +20 g /ha PoE and pinoxaden + metsulfuron at 50 + 4 g /ha PoE. Herbicides were sprayed with manually operated knapsack sprayer fitted with flat fan nozzle using 500 litres of water per hectare.

Maize hybrid (HQPM 1) and wheat (WH 1105) were sown on June 23 and November 29 during 2013 and on June 21 and 21 November 21 during 2014. Both crops were sown on top of bed of 45 cm width (one line of maize and three lines of wheat). All other management practices were as per package and practice of maize and wheat in Haryana.

System productivity: Productivity of maize-wheat cropping system was calculated in terms of wheat equivalent yield (WEY) which was calculated by using following expression:

$$\text{WEY of maize} = \frac{\text{Maize yield x maize price}}{\text{Wheat price}}$$

System productivity (Mg/ha) = Grain yield of wheat (Mg/ha) + WEY of maize (Mg/ha)

For water use monitoring soil samples were taken from 0-15, 15-30, 30-60 and 60-90 cm soil depth to monitor the profile moisture status of the active root zone before and after each irrigation. Irrigation water productivity (IWP) of different treatments was computed by dividing the economic yield (kg/ha) by irrigation water applied (cm) in respective treatments.

$$\text{IWP} = \frac{\text{Economic (grains) yield (kg/ha)}}{\text{Irrigation water applied (cm)}}$$

While total water productivity (TWP) was calculated by formula:

$$\text{TWP (kg/m}^3\text{)} = \frac{\text{Grain yield (kg/ha)}}{\text{Total water used (m}^3\text{)}}$$

Total water used = Effective rainfall (m^3) + Irrigation water applied (m^3) + Profile water use including depletion from soil (m^3)

Table A. Date and depth of irrigation water applied in maize

Crop Season	Moisture regimes in maize, irrigation at			
	80 mm CPE	120 mm CPE	160 mm CPE	200 mm CPE
Kharif 2013	02/07/2013			
Total depth	5.70 cm			
Kharif 2014	06/07/2014	11/07/2014	15/07/2014	23/07/2014
	15/07/2014	15/08/2014	27/08/2014	
	15/08/2014			
	27/08/2014			
Total depth	19.30 cm	10.30 cm	10.50 cm	5.90 cm

Table B. Date and depth of irrigation water applied in wheat

Crop Season	Moisture regimes in wheat, irrigation at			
	75 mm CPE	100 mm CPE	125 mm CPE	150 mm CPE
Rabi 2013-14	One common irrigation at CRI state on 21/12/2013			
	26/02/14	20/03/14	31/03/14	
Total depth	9.70 cm	9.90 cm	10.30 cm	4.90 cm
Rabi 2014-15	One common irrigation at CRI state on 12/12/2014			
	01/03/15			
Total depth	9.70 cm	4.80 cm	4.85 cm	4.85 cm

RESULTS AND DISCUSSION

Dry matter partitioning in maize: Leaves and stem dry weight didn't differ significantly owing to well distributed rainfall but cob and total dry weight with irrigation applied at 80 mm CPE interval over other moisture regimes, *viz*. 120 mm, 160 mm and 200 mm CPE observed marked differences during both the years (**Table 1**). During 2014, significant variation in leaf and stem dry weight was observed among various moisture. Highest leaf and stem dry weight (47.4 g and 53.3 g/plant, respectively) being under irrigation applied at an interval of 80 mm CPE. Under the water stressed conditions, there is low nutrient availability and high temperature stress (Chaves *et al.* 2002) which also affects the photosynthesis process adversely, leading to low DMA in lower moisture regimes. Similar pattern was observed in cob and total dry weight during 2014 season.

The weed control treatments effect on partitioning of biosynthates in different maize crop parts was similar during both the years. Atrazine at 750 g/ha PE and Tembotrione at 120 g/ha PoE were at par with weed free in producing significantly higher leaf, stem, cob and total dry weight of maize as compared to weedy check and pendimethalin at 1000 g/ha PE. This may be attributed to less competition from weeds, greater penetration of solar radiation for enhanced rate of photosynthesis and more accumulation of dry matter (Rajcan and Swanton 2001 Rathore *et al*. 2014).

Dry matter partitioning in wheat: The dry weight of leaves (248.4 g/m^2), stem (488.1 g/m^2) and spike (486.6 g/m^2) recorded at maturity during 2013-14 was significantly higher with irrigation at CRI+CPE=75 mm over CRI+CPE=125 mm and CRI+CPE=150 mm but was at par with irrigation at CRI+CPE= 100 mm (**Table 2**). During 2014-15, although leaf and stem dry weight did not vary significantly with varying moisture regimes, but significantly higher dry matter of spike was recorded in CRI+CPE= 75 mm CPE over all other moisture regimes which were at par with each other. In terms

Table 1. Dry matter partitioning of maize at maturity as influenced by different moisture regimes and weed control treatments during 2013 and 2014

Treatment	2013				2014			
	Dry matter (g/plant)			Total	Dry matter (g/plant)			Total
	Leaf	Stem	Cob		Leaf	Stem	Cob	
Moisture regime (Irrigation at an interval of)								
80 mm CPE	48.2	48.9	95.6	192.7	47.4	53.3	106.4	203.1
120 mm CPE	46.4	46.3	87.9	180.6	44.2	49.8	99.7	189.6
160 mm CPE	46.1	45.9	87.7	179.7	42.6	48.3	97.2	184.5
200 mm CPE	46.0	45.8	87.6	179.3	39.7	44.9	91.8	172.4
LSD (p=0.05)	NS	NS	6.1	6.2	2.6	2.7	5.4	5.2
Weed control								
Weed free	49.3	51.0	98.4	198.8	45.8	53.3	105.1	200.2
Weedy check	42.9	42.0	75.2	160.1	38.9	41.1	87.6	163.7
Pendimethalin 1000 g/ha PE	45.1	45.0	83.6	173.7	42.2	47.2	95.1	180.6
Atrazine 750 g/ha PE	48.0	48.0	97.8	193.8	45.7	52.6	104.5	198.7
Tembotrione 120 g/ha POE	47.9	47.6	93.6	191.2	44.7	51.1	101.6	193.6
LSD (p=0.05)	2.4	4.4	6.7	8.1	2.1	3.1	5.9	6.7

Table 2. Influence of different moisture regimes and weed control treatments on dry matter partitioning of wheat at maturity as during cropping season of 2013-14 and 2014-15

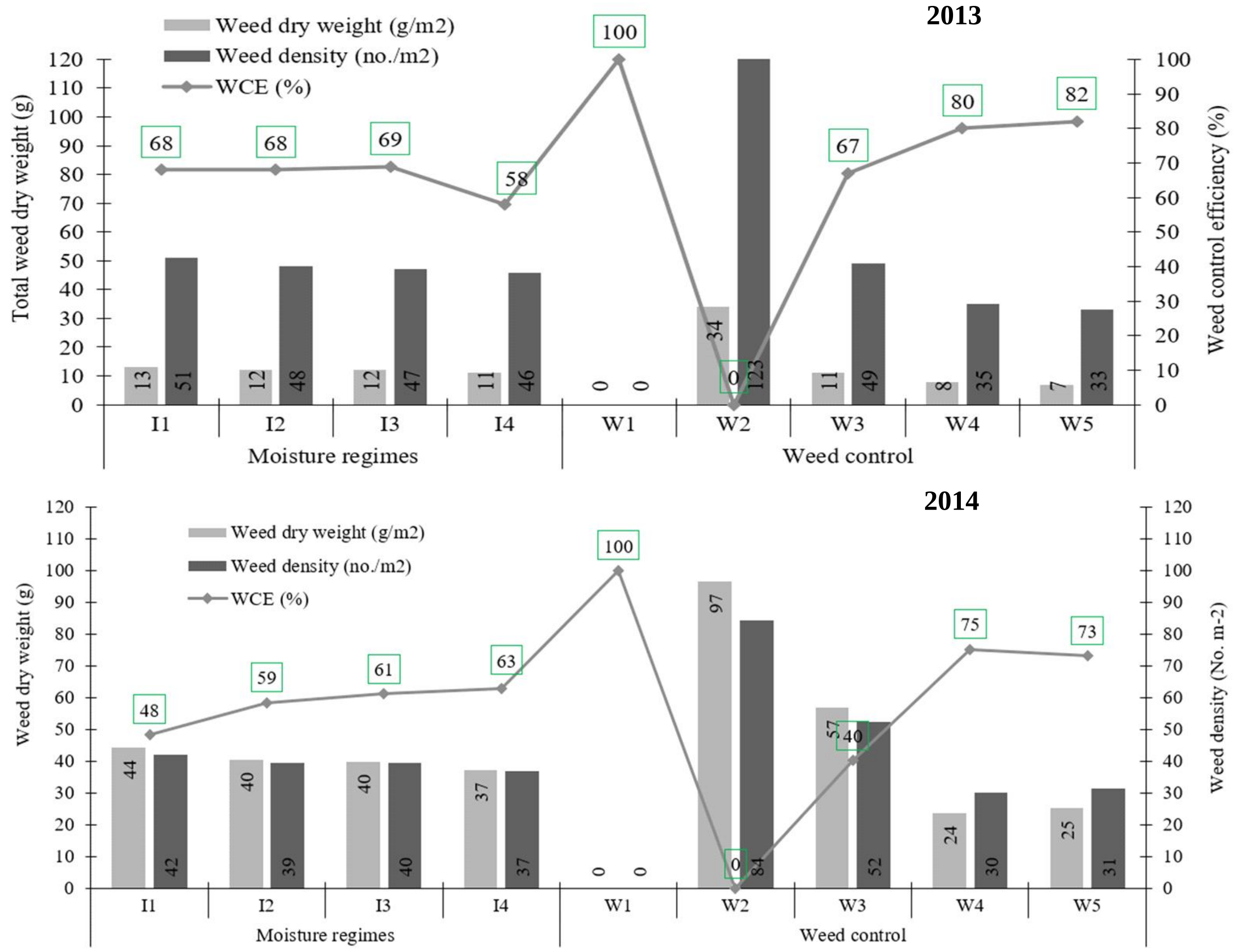
Treatment	2013-14				2014-15			
	Dry matter (g/m^2)			Total	Dry matter (g/m^2)			Total
	leaf	stem	spike		leaf	stem	spike	
*Moisture regime (Irrigation at an interval of) **								
75 mm CPE	248	488	487	1223	252	497	491	1242
100 mm CPE	243	469	478	1190	248	486	483	1220
125 mm CPE	239	457	474	1170	247	485	483	1217
150 mm CPE	228	431	462	1127	246	484	482	1215
LSD (p=0.05)	10.5	24.8	8.7	27	NS	NS	5.2	10
Weed control								
Weed free	246	482	490	1218	259	504	494	1257
Weedy check	230	430	448	1107	221	462	463	1153
Pendimethalin 1500 g/ha PE	238	456	467	1161	249	479	484	1212
Clodinafop+ carfentrazone (60+20 g/ha) PoE	242	468	484	1194	252	495	490	1246
Pinoxaden+ metsulfuron (50+4 g/ha) PoE	244	476	487	1207	254	499	492	1250
LSD (p=0.05)	5.6	25.3	16.3	31	7.6	10.1	5.8	13

of total dry weight, CRI+CPE= 75 mm CPE proved to be significantly superior in producing significantly higher dry matter accumulation during 2013-14, as compared to irrigation applied at CRI + 100-, 125- and 150-mm CPE. Both CRI+CPE 100- and 125-mm CPE irrigations being at par with each other with respect to total dry weight, were significantly superior over CRI+CPE= 150 mm treatment. During 2014-15, highest total dry weight was recorded under CRI+CPE=75 mm over other moisture regimes which were at par with each other, which might be due to better availability of soil water content from the root initiation stage up to the maturity (Fondo *et al*. 2010). This also might be due to enhanced moisture and nutrient, which resulted in higher photosynthetic activity per unit area and hence more dry matter production. (Borrill *et al*., 2015) reported that higher amount of dry matter accumulation in leaves helped the photosynthetic area to remain active for longer period and is responsible for overall better performance of plant under moisture stress condition.

During both the years of study, weed free treatment recorded maximum dry weight which was significantly higher than weedy check and pre-emergence application of pendimethalin at 1500 g/ha but was at par with clodinafop + carfentrazone at 60 + 20 g/ha PoE and pinoxaden + metsulfuron at 50 + 4 g/ha PoE due to less competition for light, space, nutrients and moisture from weeds which were effectively controlled (Mehmood *et al.* 2014).

Weed density, biomass and control efficiency

Maize: Different moisture regimes had not significantly influenced total weed density and dry matter (biomass) during 2013 maize crop season even then significant variation in weed control efficiency was noticed among moisture regimes (**Figure 1**). Maximum weed control efficiency (WCE) of 61.5 % was recorded under irrigation applied at an interval of 80 mm CPE which was significantly higher as compared to other moisture regimes, *viz.* 120 mm, 160 mm and 200 mm CPE treatments which



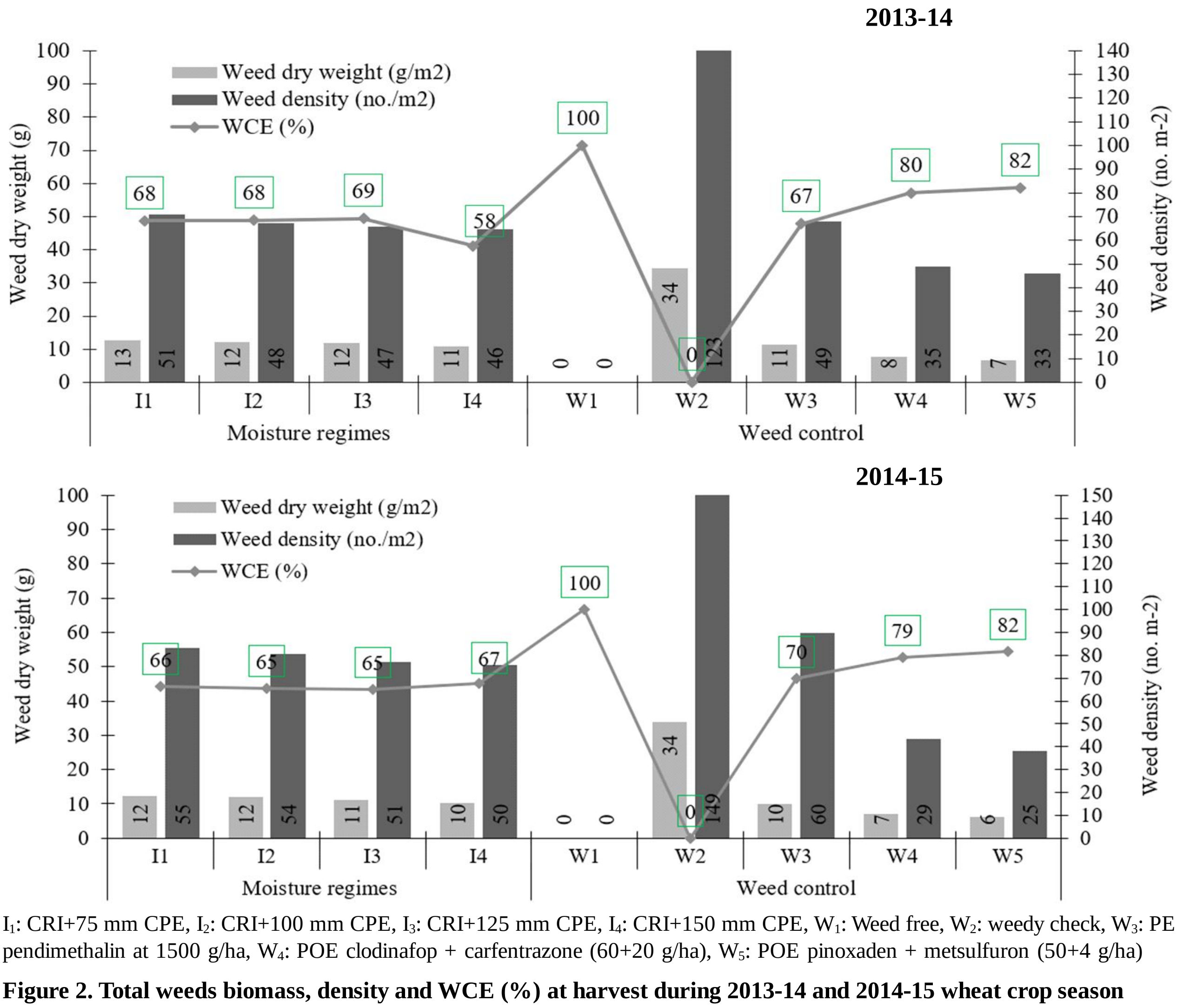
I_1: 80 mm CPE, I_2: 120 mm CPE, I_3: 160 mm CPE, I_4: 200 mm CPE, W_1: Weed free, W_2: weedy check, W_3: PE pendimethalin at 1000 g/ha, W_4: PE atrazine at 750 g/ha, W_5: POE tembotrione at 120 g/ha

Figure 1. Total weed dry weight (biomass), density and weed control efficiency at harvest during maize 2013 and 2014

remained at par with each other. One sole irrigation applied at 9 days after sowing (DAS) in 80 mm CPE treatment may have resulted in better efficacy of herbicides and hence better WCE as compared to other moisture regimes in which no irrigation was applied due to exceptionally high rainfall. During 2014, both weed biomass and density were significantly higher with irrigation application at interval of 80 mm CPE as compared to other moisture regimes, *viz.* 120 mm, 160 mm and 200 mm CPE treatments which remained at par with each other. Irrigation at 160- and 200-mm CPE interval resulted in statistically similar WCE of 61.2 and 62.8 % respectively which was significantly higher over irrigation at 120 (58.5%) and 80 mm CPE (48.4%) interval. Lower moisture availability under 200 mm CPE coupled with scanty rainfall may be reason for lower weed density and dry weight and hence higher WCE as compared to rest of moisture regimes.

Similar trend in total weed density and biomass with different weed control treatments was observed during both the years. Atrazine at 750 g/ha PE and Tembotrione at 120 g/ha PoE resulted in substantially higher WCE of 63.5 and 61.4% during 2013 and 75.3 and 73.1% during 2014 and were at par with each other but resulted in significantly lower weed density and biomass as compared to pendimethalin 1000 g/ha PE and weedy check.

Wheat: Different moisture regimes had not substantially effected total weed density and biomass during both years of study which may be due to almost equal contribution of ground water contribution and the fact that rabi weeds are able to germinate even at low moisture conditions (Steadman *et al.* 2004, Acosta *et al.* 2014) (**Figure 2**). Weed control efficiency (WCE) was statistically similar with irrigation applied at CRI+CPE=75 mm, CRI+CPE=100 mm, CRI+CPE=125 mm but was significantly higher than under CRI+CPE=150 mm. During 2014-15, significant variation in WCE among various moisture regimes was not observed.



I_1: CRI+75 mm CPE, I_2: CRI+100 mm CPE, I_3: CRI+125 mm CPE, I_4: CRI+150 mm CPE, W_1: Weed free, W_2: weedy check, W_3: PE pendimethalin at 1500 g/ha, W_4: POE clodinafop + carfentrazone (60+20 g/ha), W_5: POE pinoxaden + metsulfuron (50+4 g/ha)

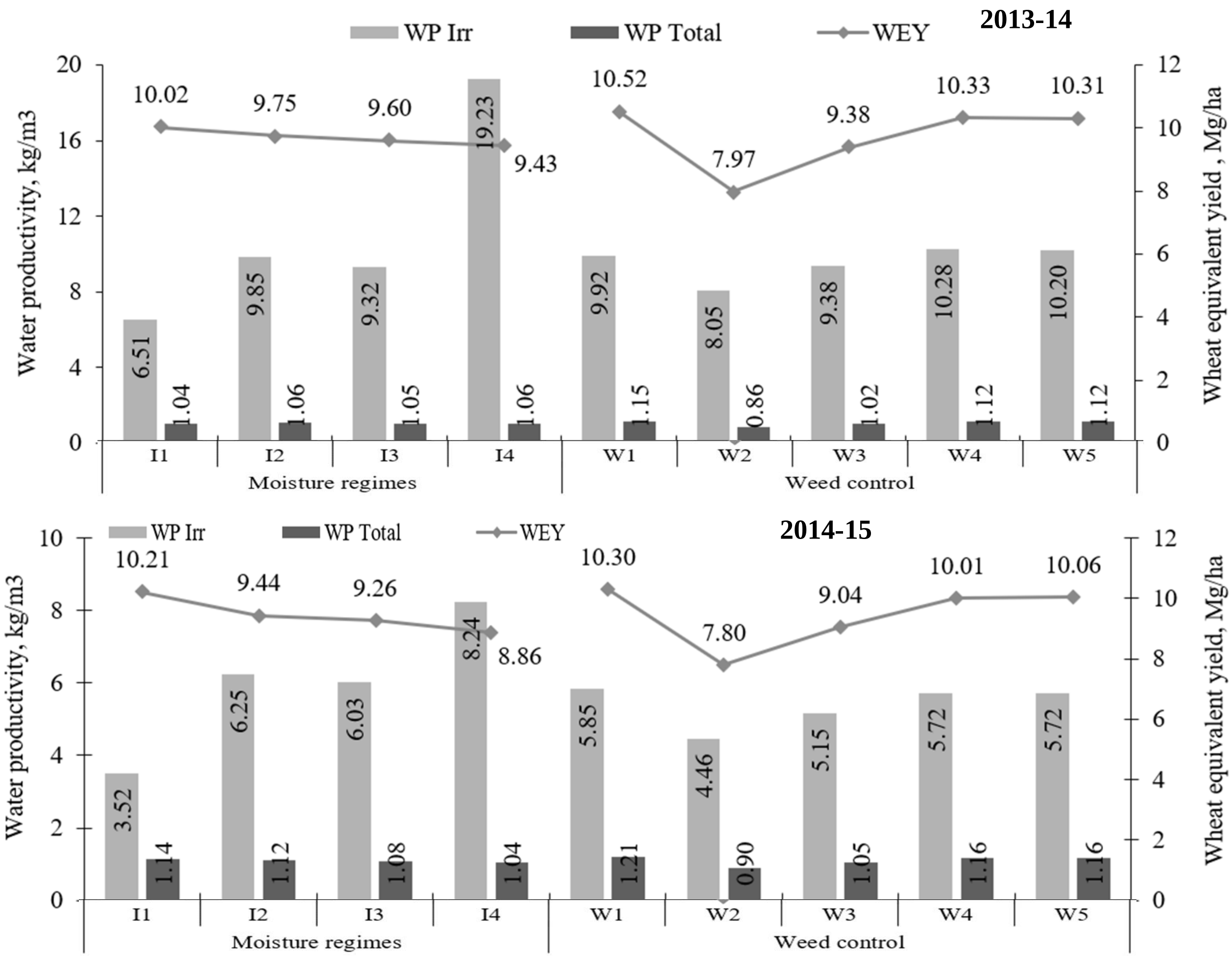
Figure 2. Total weeds biomass, density and WCE (%) at harvest during 2013-14 and 2014-15 wheat crop season

Clodinafop + carfentrazone 60 + 20 g/ha PoE and pinoxaden + metsulfuron 50 + 4 g/ha PoE proved significantly superior in reducing weed biomass and density resulting in significantly higher WCE. Among herbicides, pendimethalin at 1500 g/ha PE, was found to be less effective in reducing total weed biomass as compared to clodinafop + carfentrazone at 60 + 20 g/ha PoE and pinoxaden + metsulfuron at 50 + 4 g/ha PoE but was notably effective over weedy check in term of total weed biomass, density and WCE.

Maize-wheat cropping system: System productivity

Application of irrigation at CPE= 80 mm in maize and CRI+CPE=75 mm in wheat produced significantly highest system productivity of 10.02 and 10.21 Mg/ha during 2013-14 and 2014-15 (**Figure 3**). Difference in system yield between CPE=160 mm in maize and CRI+CPE=125 mm in wheat and at CPE= 200 mm in maize and CRI+CPE=150 mm in wheat, was not significant during 2013-14 while during 2014-15 it was significantly higher under previous as compared to latter. This may due to decreasing trend observed in individual maize and wheat crop yields with decreasing moisture regimes.

Weed free treatment resulted in highest system productivity during both years which was at par with atrazine at 750 g/ha PE in maize and clodinafop + carfentrazone at 60 + 20 g/ha PoE in wheat during 2013-14 and with tembotrione 120 g/ha PoE in maize and pinoxaden + metsulfuron 50 + 4 g/ha PoE in wheat during 2014-15. Among the herbicide treatment, the system yield did not differ between atrazine 750 g/ha PE in maize and clodinafop + carfentrazone 60 + 20 g/ha POE in wheat and with tembotrione at 120 g/ha POE in maize and pinoxaden



I_1: 80 and 75 mm CPE in maize and wheat respectively, I_2: 120 and 100 mm CPE in maize and wheat respectively, I_3: 160 and 125 mm CPE in maize and wheat respectively, I_4: 200 and 150 mm CPE in maize and wheat respectively, W_1: Weed free in maize and wheat, W_2: weedy check in maize and wheat, W_3: PE pendimethalin at 1000 and 1500 g/ha in maize and wheat respectively, W_4: PE atrazine at 750 g/ha in maize and PoE clodinafop + carfentrazone (60+20 g/ha) in wheat, W_5: PoE tembotrione at 120 g/ha in maize and pinoxaden + metsulfuron (50+4 g/ha) in wheat.

Figure 3. Water productivity (WP) and wheat equivalent yield (WEY) of maize-wheat system during 2013-14 and 2014-15

+ metsulfuron at 50 + 4 g/ha POE in wheat but was significantly higher than pendimethalin 1000 g/ha PE in maize and 1500 g/ha PE in wheat during both years.

Water productivity: During 2013-14, highest (19.23 kg/m^3) irrigation water productivity (IWP) of maize wheat system was recorded with irrigation at CPE= 200 mm in maize and CRI+CPE=150 mm in wheat (**Figure 3**). Total water productivity (TWP) of maize wheat system followed the same trend as that of IWP. Higher consumptive use of water was not able to bring the proportional increase in yield in higher moisture regimes as a result of which water productivity of irrigation water decreased although increase in yield was there in higher moisture regimes in comparison to lower moisture regimes. During 2014-15 also, irrigation at CPE= 200 mm in maize and CRI+CPE=150 mm in wheat resulted in highest IWP (8.24 kg/m^3), which decreased with increasing moisture regimes. Reverse trend was observed with respect to system TWP, with highest value (1.14 kg/m^3) in irrigation at CPE= 80 mm in maize and CRI+CPE=75 mm in wheat which decreased with decreasing moisture regimes.

Atrazine at 750 g/ha PE in maize and post emergence application of clodinafop + carfentrazone at 60 + 20 g/ha PoE in wheat and tembotrione at 120 g/ha PoE in maize and pinoxaden + metsulfuron at 50 + 4 g/ha PoE in wheat resulted in substantially higher IWP of maize wheat system than other treatments in maize and wheat during 2013-14. This may be due to lower use of water coupled with higher yield owing to higher weed control efficiency in atrazine 750 g/ha PE in maize and clodinafop + carfentrazone 60 + 20 g/ha POE in wheat and with tembotrione at 120 g/ha POE in maize and pinoxaden + metsulfuron at 50 + 4 g/ha POE in wheat. The TWP of maize wheat system was almost comparable (1.15, 1.12 and 1.12 kg/m^3) under weed free, atrazine at 750 g/ha PE in maize and clodinafop + carfentrazone at 60 + 20 g/ha POE in wheat and with tembotrione at 120 g/ha POE in maize and pinoxaden + metsulfuron at 50 + 4 g/ha POE in wheat, respectively but noticeably higher than weedy check and pendimethalin at 1000 g/ha PE in maize and 1500 g/ha PE in wheat. During 2014-15, highest system IWP (5.85 kg/m^3) was registered under weed free followed by atrazine at 750 g/ha PE in maize and clodinafop + carfentrazone at 60 + 20 g/ha POE in wheat and with tembotrione at 120 g/ha POE in maize and pinoxaden + metsulfuron at 50 + 4 g/ha POE in wheat (5.72 kg/m^3). Similar trend was observed with respect of TWP of maize wheat system.

Conclusion

Irrigation applied either at 80- or 120-mm CPE coupled with atrazine 750 g/ha PE or tembotrione 120 g/ha PoE in maize and CRI + 75 or 100 mm CPE in with of clodinafop + carfentrazone 60+20 g/ha PoE or pinoxaden + metsulfuron 50+4 g/ha PoE in wheat can be used to obtain higher grain yield, enhanced water productivity and profitability.

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