Research Articles

Indian Journal of Agricultural Sciences **88** (3): 354–60, March 2018/Article

Response of furrow irrigated raised bed planted maize (*Zea mays*) to different moisture regimes and herbicides treatments under semi-arid conditions

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Received:08 June 2017 ; Accepted: 19 November 2017

ABSTRACT

An experiment was conducted on furrow irrigated raise bed (FIRB) planted maize at Hisar, during *kharif* season of 2013 and 2014, in split plot design with three replications. Four moisture regimes, viz. irrigation applied at an interval of 80 mm, 120 mm, 160 mm and 200 mm cumulative pan evaporation (CPE) were evaluated in main plot and five weed control treatments, viz. weed free, weedy check (control), pre emergence application of pendimethalin at 1000 g/ha, pre emergence application of atrazine at 750 g/ha and post emergence application of tembotrione at 120 g/ha in sub plots. Above normal well distributed rainfall (564 mm) was received during 2013 maize crop season leading to comparatively higher consumptive use of water and less water productivity as compared to 2014 season, in which only 212 mm rainfall was received. Irrigation applied at 80 mm CPE resulted in significantly higher growth and yield parameters, grain, straw and biological yield while highest water productivity was achieved with 120 mm CPE interval irrigation. Among weed control treatments, growth and yield parameters, grain yield and the water productivity was highest in weed free which was statistically comparable with the application of atrazine, 750 g/ha (pre emergence) or tembotrione, 120 g/ha (post emergence) with lowest density and dry weight of weeds.

Key words: FIRBS**,** Irrigation scheduling, Pan evaporation, Water productivity (WP), Weed control

Maize (*Zea mays* L.) is one of the most versatile crops grown across wide range of agro climatic zones. In fact, its unmatchable suitability to diverse environment conditions coupled with highest genetic potential among cereals won it the name of "queen of cereals". It is the third most important food grain in India followed by wheat and rice and has registered highest growth rate during last one decade owing to newly emerging food habits as well enhanced industrial usage (Kumar *et al.* 2013). Its short duration, wider adaptability and climate change resiliency (being a C_4 crop) add towards its importance as the driving force for crop diversification, particularly in rice-wheat cropping areas which are already witnessing yield stagnation. In India, maize is cultivated on 8.80 m ha area with average production and productivity of 22.57 million tonnes and 2.56 tonnes/ha while, in Haryana its area is 6000 ha with 17000 tonnes production and 2.83 t/ha productivity (Indiastat 2016). In India, it is mostly grown during monsoon (*kharif*) season, characterised by erratic and untimely rains. Higher weed infestation owing to wide spacing (Fanadzo *et al.* 2007), higher sensitivity to both excess (Leyshon and Sheared 1974, Kanwar *et al.* 1988) and limited moisture (Meng *et al.* 2016) coupled with erratic rainfall during monsoon season pose a hindrance in achieving its potential yield. This may explain the yield gap between India's maize productivity (2.5 tonnes/ha) as compared to world's (5.2 tonnes/ha) (Anonymous 2014). CPE (cumulative pan evaporation) based scientific water management maintains balance between crop demand and water supply including net rainfall. This method is comparatively less expensive and time consuming (Ertek 2011). Therefore it can be easily adopted by Indian farmers to not only improve maize yields with less water, but also to improve weed management through improving herbicide use efficiency (Mohapatra *et al.* 2016). In addition to water management, weeds are among the dominant factor causing yield losses in maize production (Oerke 2006, de Mol *et al*. 2015). In India, the high cost and scarcity of labour during the peak season, necessitates use of herbicides for cost effective as well as timely control of weeds in almost all crops (Rao *et al.* 2014). Herbicides in variable herbicide groups, ranging from pre- to post-emergent, can be used in the efficient management of weeds, thus ensuring an all-season-round weed-free environment for crop production (Mathers and Parker 2013, Mhlanga *et al.* 2016). Coupled with irrigation scheduling, improved crop establishment practices, viz. raised bed planting not only offset high production costs and problems related with land preparation (Jat *et al.* 2015) but

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also saves precious water (Majeed *et al.* 2017) and results in better weed control. Therefore, present study was carried out to evaluate the optimum moisture regime for higher productivity along with effective control of weeds in *kharif* FIRB planted maize in semi-arid conditions.

MATERIALS AND METHODS

The experiment was conducted at research farm of Department of Agronomy, Chaudhary Charan Singh Haryana Agricultural University, Hisar, India ($29^0$10' N and $75^0$46' E) during the *kharif* seasons of 2013 and 2014. The soil (0-15 cm) of the experimental field was a typic Ustochrept 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/cm^3 bulk density and basic infiltration rate of 4.3 mm/h. The available moisture in the upper 30 cm soil layer was 14.3 per cent (20.3 at FC and 6 % at PWP). The experimental design used was split plot with 20 treatment combinations comprising four moisture regimes, viz. irrigation at 80 mm (I_1), 120 mm (I_2), 160 mm (I_3) and 200 mm (I_4) cumulative pan evaporation (CPE) interval in main plot and five weed control treatments, viz. weed free (W_1), weedy check (W_2), pre emergence application of pendimethalin at 1000 g/ha (W_3), pre emergence application of atrazine at 750 g/ha (W_4) and post emergence application of tembotrione at 120 g/ha (W_5) in sub plots, replicated thrice.

Daily pan evaporation and rainfall data was collected from the meteorological observatory located at the research farm of Chaudhary Charan Singh Haryana Agricultural University, Hisar to calculate the CPE values. A total of 564 mm during 2013, while only 212 mm rainfall during 2014 maize crop season was received with concomitant 504 and 594 mm pan evaporation during the respective years. Due to well distributed rainfall during *kharif* season of 2013, only one irrigation (5.7 cm) was applied on 2 July, 2013 under I_1 moisture regime. However, during the *kharif* season of 2014, four post sown irrigations (19.3 cm) were applied in I_1, while in I_2 and I_3 two irrigations (10.3 cm and 10.5 cm respectively), whereas one post sown irrigation (5.9 cm) was applied in I_4, at different dates period. Maize hybrid HQPM 1 was sown on June 23 and harvested on 28th September during 2013 while during 2014, it was sown on June 21 and harvested on 25 September. Two seeds per hill were hand dibbled at a spacing of 20 cm on top center of bed having 70 cm row to row spacing. Grain yield of maize is reported at 14% moisture content. Herbicides were applied as per the treatments. Pre emergence herbicides were sprayed 2 days after sowing (DAS) of experimental crop, whereas post emergence herbicides were sprayed 15-20 DAS during both the experimental years. Herbicides were sprayed with manually operated knapsack sprayer fitted with flat fan nozzle using 500 l of water per ha. Weed free plots were kept free from weeds manually throughout the cropping season. Statistical analysis of the data was done using OPSTAT software (Sheoran *et al*. 1998). Least significant difference (95% confidence) were used to compare treatment means. Graphs and figures were prepared using Microsoft excel.

RESULTS AND DISCUSSION

Growth parameters

The growth parameters, viz. plant height, leaf area index (LAI) at harvest did not vary statistically with different moisture regimes during 2013 as crop demand was met equally due to continuous and well distributed rainfall. During 2014, significantly higher plant height, leaf area index and dry matter accumulation (DMA) were observed with irrigation applied at an interval of 80 mm CPE, which decreased with decreasing moisture regimes. On pooled basis, plant height among growth parameters did not vary significantly with different moisture regimes which may be due to non-significant influence of moisture regimes on plant height during 2013 (Table 1). However higher moisture regimes, i.e. 80 mm CPE resulted in significantly higher LAI (2.39) and dry matter (197.9 g/plant), over other moisture regimes, viz. 120, 160 and 200 mm CPE on two year pooled basis. Decrease in growth parameters with decreasing moisture regimes can be attributed to closure of stomatal aperture due to water deficit, leading to less gaseous exchange and lower assimilation of CO_2 ultimately leading to less photosynthesis and less plant height, leaf expansion and dry matter production as well as accumulation (Anjum *et al.* 2011). Water stressed conditions decrease plant growth by stressing several physiological and biochemical processes such as leaf respiration, leaf chlorophyll content, gas exchange, leaf water content, plant relative growth rate, among others (Okunlola *et al*. 2017).

Among weed control treatments, significantly taller plants (227.2 cm) and higher dry matter accumulation (199.5 g/plant) on pooled basis for two *kharif* seasons was recorded in weed free treatment over weedy check, pre emergence application of pendimethalin, 1000 g/ha and post emergence application of tembotrione, 120 g/ha but was at par with pre emergence application of atrazine, 750 g/ha. However, LAI was found to be statistically similar among weed free, pre emergence application of atrazine, 750 g/ha and post emergence application of tembotrione, 120 g/ha but significantly higher than the rest two treatments. Among herbicide options both pre emergence atrazine and post emergence atrazine at 750 and 120 g/ha respectively, proved to be equally effective statistically with respect to all recorded growth parameters, viz. plant height, LAI and dry matter accumulation (DMA) but significantly superior than pre emergence application of pendimethalin at 1000 g/ha and control (Table 1). It may be ascribed to better growth of maize crop under weed free treatment, pre emergence application of atrazine, 750 g/ha and post emergence application of tembotrione, 120 g/ha treatments, owing to less competition from weeds, greater penetration of solar radiation leading to enhanced

Table 1 Growth and yield parameters of maize at maturity as influenced by various moisture regimes and weed control treatments

Treatment	Pooled			Pooled		
	Growth parameters			Yield parameters		
	Plant height (cm)	Leaf area index	DMA* (g/plant)	No. of cobs/mrl	Number of grains/cob	100 grains weight (g)
Moisture regimes: Irrigation at						
80 mm CPE	223.4	2.39	197.9	6.12	316.9	24.5
120 mm CPE	218.2	2.26	185.1	6.00	306.8	24.2
160 mm CPE	216.3	2.21	181.9	5.94	302.9	24.1
200 mm CPE	213.3	2.13	175.8	5.85	296.3	23.8
SEm±	2.2	0.02	1.0	0.03	1.4	0.1
CD (P=0.05)	NS	0.09	3.6	0.09	4.9	0.3
Weed control						
Weed free	227.2	2.38	199.5	6.31	318.6	25.0
Weedy check	202.0	2.03	161.9	5.28	277.2	22.7
Pendimethalin, 1000 g/ha	216.1	2.18	177.1	5.79	304.5	23.7
Atrazine, 750 g/ha	223.0	2.35	196.3	6.28	316.6	24.8
Tembotrione, 120 g/ha	220.7	2.32	191.3	6.21	311.8	24.5
SEm±	1.7	0.03	1.8	0.03	2.0	0.1
CD (P=0.05)	4.8	0.09	5.1	0.10	5.8	0.4

*DMA= Dry matter accumulation

rate of photosynthesis and more accumulation of dry matter (Shekhar *et al.* 2014). Mahadi (2014) and Owla *et al.* (2015) also observed corroborative results under similar set, i.e. atrazine + alachlor (0.4 + 2.0 kg/ha) of weed control treatments.

Yield attributes

Two year pooled data analysis revealed that frequent irrigations under 80 mm CPE interval treatment produced significantly higher number of cobs (6.12/mrl) and number of grains/cob (316.9) over other moisture regimes (Table 1). However, 100 grains weight was statistically similar among 80 mm (25.5 g) and 120 mm CPE (24.2 g) interval applied irrigation treatments but significantly higher than 160 and 200 mm CPE moisture regimes. Well-watered conditions with frequent irrigation at 80 mm CPE interval helped the plants to develop good size of photosynthetic source and capacity by keeping the plant cells fully turgid resulting in significantly better growth (plant height), statistically more LAI, significantly higher accumulation of dry matter which lead to higher translocation of photosynthates towards reproductive parts and hence higher yield attributes. Increased yield attributes under higher moisture regimes have also been reported by Soleimanifard *et al.* (2011) and Reddy *et al*. (2012).

Among weed control treatments, number of cobs/mrl during the two respective *kharif* seasons was significantly higher under weed free (6.31 cobs/mrl) treatment over pre emergence application of pendimethalin, 1000 g/ha and weedy check but it was at par with pre emergence application of atrazine, 750 g/ha (6.28 cobs/mrl) and post emergence application of tembotrione, 120 g/ha (6.21 cobs/mrl) (Table 1). Number of grains/cob and 100 grain weight was highest in weed free treatment which was statistically at par with pre emergence application of atrazine, 750 g/ha but significantly higher than other weed treatments. Among the treatments where herbicides were applied, the yield parameter were registered lowest with the application of pendimethalin, 1000 g/ha which was significantly lower as compared to pre emergence application of atrazine, 750 g/ha and post emergence application of tembotrione, 120 g/ha. Higher yield attributes under weed free treatment, pre emergence application of atrazine, 750 g/ha and post emergence application of tembotrione, 120 g/ha during both the seasons may be ascribed to efficient weed control by the two herbicides which helped in reducing the competition of crop plants with weeds and efficiently utilization of resources like light, space, moisture and nutrients which was reflected in higher growth parameters, viz. plant height, dry matter accumulation and LAI under these treatments. Khan *et al.* (2012) also reported higher cob length; Hatti *et al.* (2014) increased cob length, grains/cob, with the use of herbicides as compared to control.

Yield

Significantly higher maize grain yield (5331 kg/ha) was harvested with 80 mm CPE interval applied irrigations over other moisture regimes. Further, 120 mm CPE and 160 mm CPE resulted in significantly higher grain yield over 200 mm CPE although the former moisture regimes were at par with each other (Table 2). Similar trend in straw yield was observed with respect to different moisture regimes on two

Table 2 Effect of various moisture regimes and weed control treatments on grain yield, straw yield, water productivity (WP), weed density, dry weight and weed index of maize

Treatment	Pooled			Pooled		
	Grain yield (kg/ha)	Straw yield (kg/ha)	WP (kg/m)	Weed density (No./m)	Weed dry weight (g/m)	Weed index (%)
Moisture regimes: Irrigation at						
80 mm CPE	5331	7329	0.98	6.09 (44.9)	6.26 (49.0)	9.7
120 mm CPE	5048	7136	0.99	5.92 (42.8)	6.18 (47.0)	11.3
160 mm CPE	4938	7047	0.95	5.87 (42.0)	6.11 (46.3)	7.7
200 mm CPE	4726	6909	0.91	5.77 (40.0)	6.02 (44.9)	9.4
SEm±	32	40		0.04	0.04	1.2
CD (P=0.05)	110	137		0.15	0.14	NS
Weed control						
Weed free	5548	7463	1.05	1.00 (0)	1.00 (0)	0.0
Weedy check	3855	6324	0.74	9.76 (94.6)	10.30 (105.5)	30.2
Pendimethalin, 1000 g/ha	4819	6977	0.92	7.47 (55.0)	7.93 (62.4)	12.9
Atrazine, 750 g/ha	5452	7408	1.04	5.59 (30.4)	5.66 (32.1)	1.6
Tembotrione, 120 g/ha	5380	7355	1.03	5.74 (32.1)	5.82 (34.0)	3.0
SEm±	48	50		0.05	0.06	0.9
CD (P=0.05)	139	144		0.13	0.18	2.5

year pooled basis data, where significantly highest straw yield (7329 kg/ha) was recorded with irrigation applied at 80 mm CPE interval over other moisture regimes which decreased 2.63 % (7136 kg/ha), 3.84 % (7047 kg/ha) and 5.73 % (6909 kg/ha) with decreasing moisture regimes, viz. 120, 160 and 200 mm CPE moisture regimes . At lower moisture regimes, size of photosynthetic apparatus was restricted which could support comparatively smaller sinks, which is quite clear from comparatively lower values of yield parameters, viz. number of cobs per meter row length, number of grains/cob, and 100 grains weight. Singh (2010) and Aulakh *et al.* (2013) also harvested significantly higher grain yield of maize at higher moisture regimes.

Grain yield was found to be statistically at par with weed free and pre emergence application of atrazine, 750 g/ha while straw yield among weed free, pre emergence application of atrazine, 750 g/ha and post emergence application of tembotrione, 120 g/ha treatments but was significantly higher over weedy check and pre emergence application of pendimethalin, 1000 g/ha on pooled basis (Table 2). Both grain and straw yield obtained under post emergence application of tembotrione, 120 g/ha and pre emergence application of atrazine, 750 g/ha were at par, but significantly higher than control and pre emergence application of pendimethalin, 1000 g/ha. This may be due to less crop-weed competition for light, space, nutrients and moisture ultimately resulting in better uptake and assimilation of nutrients and more vigour under former two herbicide treatments. Khan *et al*. (2012) also recorded highest grain yield of maize in the atrazine treated plots. Similarly, Arvadiya *et al*. (2013) reported higher green cob yield with pre emergence application of atrazine @ 1 kg/ha and hand weeding at 40 DAS.

Interaction effect

Irrigation at 80 mm CPE either under weed free or pre emergence application of atrazine at 750 g/ha or post emergence application of tembotrione at 120 g/ha was statistically at par with irrigation at 120 mm CPE under weed free but significantly higher than rest of treatment combinations (Table 3). Highest stover yield of maize was obtained under weed free when irrigation was applied at 80 mm CPE, which was statistically at par with post emergence application of tembotrione at 120 g/ha at same moisture level but significantly higher than rest of the treatments.

Total water productivity

In general, water productivity was slightly less during 2013 as compared to 2014 maize crop season which may be due to higher consumptive use of water during 2013 season owing to ample rainfall. Water productivity (WP) was highest (0.99 kg/m^3) with irrigation applied at 120 mm CPE, closely followed by 0.98 kg/m^3 in 80 mm, while, 4.04% (0.95 kg/m^3) and 8.08 % (0.91 kg/m^3) less in 160 mm CPE and 200 mm CPE respectively over 120 mm CPE (Table 2). This may be due to relatively less amount of irrigation water used with irrigation applied at 120 mm CPE interval and good grain yield in 80 mm CPE interval applied irrigation over other treatments. Chigign *et al*. (2014) and Neelakanth *et al.* (2015) also observed higher WP in lower moisture regimes but in different conditions.

Among different weed control treatments WP was

Table 3 Interaction effect of moisture regimes and weed control on two seasons' pooled grain and stover yield of maize

Treatment	Pooled grain yield (kg/ha)					Pooled stover yield				
	W_1	W_2	W_3	W_4	W_5	W_1	W_2	W_3	W_4	W_5
I_1	5950	3958	5092	5742	5914	8139	6275	7365	7777	7851
I_2	5702	3773	4781	5495	5488	7361	6656	6691	7436	7506
I_3	5357	3849	4754	5460	5271	7048	6055	6594	7518	7349
I_4	5218	3840	4647	5112	4811	7305	6311	7256	6900	6716
SEm±			92					98		
CD (P=0.05)			271					290		

highest in weed free treatment and lowest in weedy check on two year pooled basis (Table 2). Pre emergence application of atrazine, 750 g/ha resulted in highest WP (1.04 kg/m^3) among herbicidal treatments, which was almost similar to that obtained in post emergence application of tembotrione, 120 g/ha (1.03 kg/m^3) but 11.53 % and 28.84 % higher than pre emergence application of pendimethalin, 1000 g/ha and control respectively. This could be attributed to relatively higher economic yield and lower consumptive use of water because of lower weed density under atrazine treated plots. Kour *et al*. (2014) and Owla *et al.* (2015) also reported reduced weed density and higher yields of maize with the use of atrazine and tembotrione herbicide which ultimately explains higher water productivity.

Weed density

At maturity significantly higher weed density was observed with irrigation application at interval of 80 mm CPE as compared to other moisture regimes, viz. 120 mm, 160 mm and 200 mm CPE which remained at par with each other (Table 2). Higher moisture availability may have favored weed growth.

Similar trend in total weed density with different weed control treatments was observed during both the years. At maturity, pre emergence application of atrazine at 750 g/ha (W_4) and post emergence application of tembotrione at 120 g/ha (W_5) being at par with each other resulted in significantly lower weed density as compared to pre emergence application of pendimethalin at 1000 g/ha (W_3) and weedy check (Table 4). Among the herbicidal application, weed density was significantly higher under W_3 as compared to W_4 and W_5 but it was substantially lower than weedy check.

Weed dry matter

Significantly higher dry matter of weeds was observed under irrigation application at interval of 80 mm CPE and 120 mm CPE interval irrigation treatments as compared to other moisture regimes 160 mm and 200 mm CPE which remained at par with each other (Table 2). Higher moisture availability favored more weed growth and hence higher weed dry matter.

Highest weed dry matter under weedy check and lowest under weed free treatment was observed at harvest during both years (Pooled basis). Among the herbicides, pre emergence application of atrazine at 750 g/ha (W_4) and post emergence application of tembotrione at 120 g/ha (W_5) being at par with each other resulted in significantly lower weed dry matter as compared to pre emergence application of pendimethalin at 1000 g/ha (W_3) and weedy check (W_2) at harvest.

Weed index

Weed index did not differ due to various moisture regimes during both the years (Table 2). Among weed control treatment greater loss of yield due to weeds was observed under weedy check as evident from significantly higher values of weed index (30.2 %) during two maize seasons. Pre emergence application of atrazine at 750 g/ha (W_4) and post emergence application of tembotrione at 120 g/ha (W_5) being statistically similar with each other resulted in substantially lower yield loss due to weeds (-1.6 % and -3.0 % respectively) during both years over pre emergence application of pendimethalin at 1000 g/ha (12.9 %) and weedy check (-30.2 %).

Conclusion

Under semi-arid, shallow water table conditions and sandy loam soil, higher grain yield and enhanced water productivity in maize could be achieved by applying either pre emergence application of atrazine, 750 g/ha or post emergence tembotrione, 120 g/ha with irrigation at either 80 or 120 mm CPE. The crop water requirement of maize variety HQPM 1 is around 520 mm in semi-arid conditions of Hisar and depending upon weather conditions, it has to be applied in 3-4 irrigations. If proper account of rainfall events and water amount received from rainfall as well as from ground water contribution is maintained and irrigation is applied on the basis of cumulative pan evaporation minus the rainfall, almost three irrigations (136 mm) in maize can be saved without any significant yield penalty.

ACKNOWLEDGEMENTS

The authors gratefully acknowledges the support and necessary facilities received from CCS Haryana Agricultural University, Hisar. Gratitude is also due to Department of Agrometerology for providing meteorological data for the crop duration during 2013 and 2014.

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