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Alleviating moisture stress under irrigation scheduling and crop establishment techniques on productivity and profitability of wheat (*Triticum aestivum*) under semi-arid conditions of western India

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ABSTRACT

A field experiment was carried out in semi-arid condition of Hisar during two consecutive years (2012-13 and 2013-14) to assess the performance of wheat under varied irrigation schedules with crop establishment techniques. In present study, wheat planted on beds (FIRBS) resulted in 15-19% increase in grain yield than minimum and conventional tillage systems but the margin was slightly lower and it was statistically at par with zero tillage (ZT). Inclusions of beds in wheat cultivation have led to improved growth indices, growth and yield parameters over conventional and reduced tillage practices. Adoption of ZT under semi-arid conditions led to 12-48% (2012-13) and 27-68 % (2013-14) higher net returns to farmers by reducing the cost incurred on the primary tillage operations. Consumptive water use was reduced by 9-12% besides improved water use efficiency (WUE) and irrigation water productivity (WP_I) under beds than conventional tillage. Improved soil health concerning bulk density, soil organic carbon and total NPK status were perceived under ZT wheat. Growth indices, growth and yield parameters, grain and biological yields of wheat showed improvement under application of irrigation at higher moisture regime of CRI+IW:CPE=0.90 over lower moisture regimes.

Key words: Bulk density, Economics, FIRBS, Irrigation schedule, Soil organic carbon, ZT

Under semi-arid condition, water is the scarcest input which has considerable effects on productivity factor of any crop and also on the efficiency of other natural and applied inputs (Sarkar 2015). Evapotranspiration (ET) becoming key factor determining the effectiveness of applied inputs or technologies under resource starved situations with variable rainfall conditions. Abating this non-beneficial ET through proficient technologies and strategies will be greatly enhancing the water productivity under semi-arid situations. In north-western part of India, gradual decrease in the water table associated with faulty irrigation practices led to reduced individual factor productivity. Conventional practices based wheat cultivation is predominant in major wheat growing areas of western India. Conventional planting of wheat requires repeated tillage (5-6 times) coupled with improper irrigation schedules led to dwindling natural resources greatly besides static or declined wheat productivity. Climatic variability and vulnerabilities are the major factors governing enhanced input use efficiency. Concurrently, higher cost of production and deteriorated soil productivity urge for a sound crop management strategies are need of the hour under semi-arid conditions.

Potential resource conservation techniques (RCTs) like zero tillage, minimum tillage and FIRBS planting gaining importance in the IGP and are found to retrieve the scarce natural resources like water (Hari *et al.* 2010). Zero tillage (ZT) technique is an ecological approach for soil surface management and seed bed preparation resulting in less energy requirement, less weed problem, better crop residue management and higher or equal yield (Karunakaran and Behera 2013). The FIRBS planting wheat is an innovative and novel method to save irrigation water from 18 to 35% in wheat (Hobbs and Gupta 2003, Rajanna *et al.* 2017) further enhancing the input use efficiency and factor productivity. Several criteria have been used by investigators for scheduling irrigation in wheat to improve the water productivity. Irrigation scheduling is highly location specific and proper scheduling will largely improve the water productivity at field level.At the field level water productivity can be improved by minimizing the losses (15-40%) during water application and distribution and proper irrigation scheduling for a particular crop is important to achieve higher application efficiency. Production technologies such as scheduling irrigation and planting techniques lead

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to higher productivity per unit of water use need to be developed. Since the information on behaviour and water distribution is meagre, thus the present study was conducted to assessing the different crop establishment techniques and irrigation regimes on the performance of wheat in terms of growth, yield parameter, yield and economics under semi-arid condition of Haryana.

MATERIALS AND METHODS

The two year field investigation was carried out at Research Farm of CCS Haryana Agricultural University, Hisar (29^0 10' North latitude and 75^0 46' East longitude at an altitude of 215.2 m AMSL) during winter (*rabi*) seasons of 2012-13 and 2013-14. The pan evaporation and rainfall were 357.2, 341.1 mm, 113.8 and 78.6 mm, respectively received during the crop seasons. At sowing, the water table in the experimental field was 148 and 152 cm deep; fluctuated around 141 and 155 cm during the active growth period of the crop and was 155 and 168 cm at harvest, during the respective two crop seasons.

The experiment was designed with four crop establishment methods, viz. FIRBS, CT, MT and ZT in main plots and three irrigation regimes, viz. irrigation at CRI and thereafter at IW:CPE=0.90, 0.75 0.60 in subplots using strip plot design with three replications. Under FIRBS, 75 cm beds were made with bed planter (three rows of wheat at 15 cm distance on top of the beds). Under CT, two harrowing + two ploughing, under MT, the tillage practices were reduced to two, while under ZT no tillage operations were adopted. Same layout has been utilized for the second year experimentation having sandy loam texture soils with 0.58% organic carbon. After a pre-sown irrigation, wheat variety WH 711 was sown in the respective treatments. Recommended agronomic management practices were adopted for cultivation of crop, irrespective of treatments. Current meter based application of irrigations had been adopted in individual plots and the depth was measured. Based on depth of irrigation water and the cumulative pan evaporation during the particular period, the IW: CPE ratios were calculated.

Observations were measured at different growth stages and at harvest by following the standard procedure from net plot area. Growth indices, viz. leaf area index was recorded with laser leaf area meter, crop growth rate (CGR) and net assimilation rate (NAR) were calculated as per the standard procedures. The total water use (depletion from soil, rainfall, contribution from shallow ground water, rainfall and post sown irrigations) was calculated in both the crop seasons. Soil profile moisture depletion was calculated by using gravimetric method. Contribution from shallow ground water table to root zone was measured as proposed by Giesel *et al*. (1972). Irrigation water productivity (WP_I) and water use efficiency (WUE) were computed by using the economic yield and irrigation water/total amount of water. After harvesting of wheat, the composite soil samples from plough layer (0–15 cm) were collected and analyzed for physicochemical properties following standard procedures. Economic analysis was done as per the prevailing cost of inputs/operations and price of the marketable produce. The data recorded for different parameters were analyzed through analysis of variance (ANOVA) technique for a strip plot design and the result are presented at 5% level of significance (P=0.05).

RESULTS AND DISCUSSION

Crop establishment techniques

The results of the experiment shows that, number of tillers, total dry matter production and leaf area index (LAI) were markedly increased under bed (FIRBS) planted wheat at maturity in comparison with other tillage or crop establishment methods however the difference with ZT was not distinct during 2012-13 and 2013-14 crop seasons (Table 1). The increase in numbers of tillers under FIRBS and zero-tillage may be attributed to better growth conditions provided through higher light interception at all the growth stages and increased moisture and nutrient supply compared to conventional tillage. This also could be due to earlier emergence rate with improved vigour and establishment of plants which induces better root development and growth (Kumar *et al*. 2013) by reducing soil compaction by localized deposition of more fertile top soil on beds (Naresh *et al*. 2014). While, CGR (17.3 and 18.2 g/m^2/day) and NAR (1.61 and 1.68 g/m^2/day) were significantly higher under FIRBS in comparison to CT and MT but was at par with ZT during 2012-13 and 2013-14 seasons for 61-90 days period, respectively (Fig 1). Higher LAI in wheat under FIRBS as well as under ZT may be assigned to increased number of tillers due to better growth conditions as has also been explained earlier for plant height and tillers. Numbers of spikes, grains/spike and 1000-grain weight were also significantly higher under FIRBS during the respective two crop seasons compared to CT and MT but was at par with ZT (Table 1).

Appreciably higher grain yield (5.17 t/ha) of wheat was recorded under FIRBS during 2012-13 in comparison with other crop establishment techniques. However, in the 2nd crop season, although, FIRBS had noticeable edge over CT and MT but the difference with ZT was not significant (Table 2). The pooled grain yield (5.34 t/ha) and biological yield (11.99 t/ha) of wheat were considerably higher with FIRBS in comparison to other crop establishment techniques but the difference between FIRBS and ZT was not well evident. The increase in grain yield of wheat under FIRBS could be attributed to higher yield attributes. Improved yield attributing parameters under FIRBS may be ascribed to higher dry matter and translocation and the conversion of photosynthetic into reproductive parts by producing higher yield attributes (Zhang *et al*. 2007, Rajanna *et al.* 2017), to some extent it could also due to longer grain filling duration (Tanwar *et al.* 2014). Contrary to this, Kumar *et al*. (2013) obtained lowest yields under raised bed method due to less plant population in bed planting than under ZT and CT.

The total consumptive water use by the wheat crop

Table 1 Growth and yield attributes of wheat under different crop establishment techniques and irrigation regimes during 2012-13 and 2013-14

Treatment	Tillers (m^2)		Dry matter (g/m^2)		LAI		Spikes/m^2			Grains/spike			1000-grain weight (g)		
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	Pooled	2012-13	2013-14	Pooled	2012-13	2013-14	Pooled
Crop establishment technique															
FIRBS	321	340	1211	1251	1.79	1.67	283	306	295	43.0	43.0	43.0	44.0	45.4	44.7
CT	312	303	1123	1071	1.72	1.44	280	292	286	42.5	39.2	40.9	42.2	41.8	42.0
MT	290	321	1075	1115	1.70	1.42	267	294	281	38.7	40.8	39.7	42.0	43.2	42.6
ZT	319	328	1152	1196	1.77	1.60	281	303	292	41.7	42.7	42.2	43.1	44.4	43.8
SEm±	1.7	3.6	8.6	5.8	0.01	0.02	3.2	2.4	2.6	0.9	0.3	0.4	0.4	0.3	0.3
CD (P=0.05)	6	13	30	20	0.03	0.07	11	8	9	3.0	1.1	1.4	1.4	1.1	0.9
Irrigation schedule															
I_1	314	334	1175	1202	1.81	1.59	281	302	292	42.1	42.6	42.3	43.5	44.5	44.0
I_2	313	324	1143	1154	1.74	1.55	280	300	290	41.7	41.3	41.5	43.0	43.9	43.5
I_3	304	311	1103	1118	1.69	1.46	273	294	284	40.7	40.4	40.5	41.9	42.7	42.3
SEm±	2.0	2.3	2.1	2.3	0.02	0.02	1.4	0.8	0.7	0.3	0.4	0.2	0.2	0.3	0.2
CD (P=0.05)	8	9	8	8.0	0.07	0.06	6	3	3	1.0	1.4	0.8	0.7	1.1	0.7

*I_1, CRI+IW:CPE=0.90;I_2, CRI+IW:CPE=0.75; I_3, CRI+IW:CPE=0.60. ** Number of tillers and dry matter production were recorded at physiological maturity; LAI was recorded from 61-90 days period.

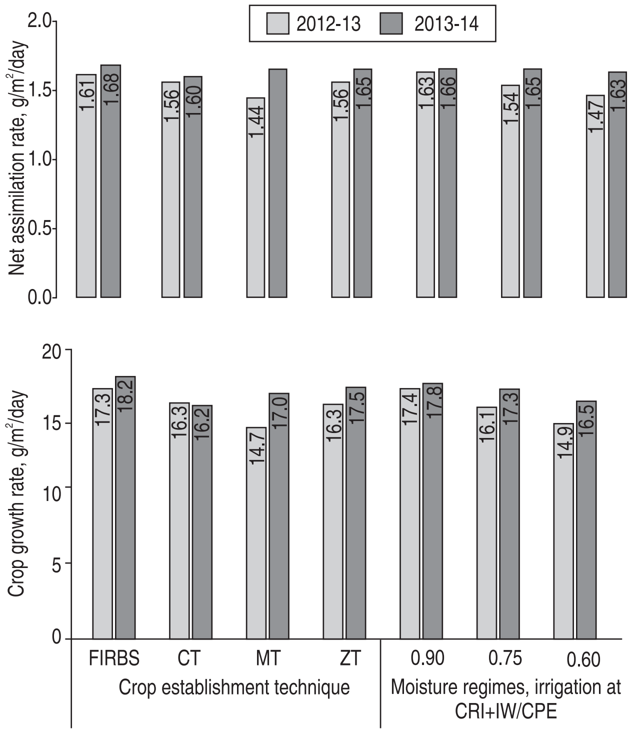

Fig 1 Net assimilation and crop growth rate of wheat at 61-90 days period under crop establishment techniques and irrigation regimes.

during 2012-13 was relatively more (40.75>39.75>38.50 cm) under CT followed by MT and ZT, respectively. However, it was the lowest under FIRBS (35.71 cm) than other three tillage techniques. The saving of water under FIRBS, ZT and MT was around 12, 6 and 2% higher than CT (Fig 2). During 2013-14 crop season the percentage water saving was little less than the first year (9, 5 and 2% under FIRBS, ZT and MT, respectively) in comparison with CT. Total water use was more under CT could be due to higher amount of irrigation water use than FIRBS where spread of water on wider space covering more land area owing to increased soil moisture depletion and use of ground water. Tanwar *et al*. (2014) reported an average of 22% irrigation water saved under bed planting of wheat over conventional system. Bed planted wheat achieved highest WUE (14.5 and 15.5 kg/ha-mm) and WP_I (4.3 and 4.5 kg/m^3) during respective crop seasons as compared to other crop establishment techniques (Fig 2). WUE and WP_I was highest with bed planted wheat followed by ZT wheat during both the crop seasons (Fig 2) could be attributed to relatively higher economic yield and lower consumptive use of water by wheat crop during the respective seasons.

The net returns (₹ 40.45 and 49.67 $\times 10^3$ /ha) and benefit cost ratio (1.92 and 2.06) were significantly higher with ZT during 2012-13 and 2013-14, respectively as compared with CT and MT but were at par with FIRBS. The input cost in zero tilled wheat in both the seasons was marginally lower than FIRBS, CT and MT. This was primarily due to saving in cost of preparatory tillage and irrigation water under no-tillage system's wheat seeding technology can play an important role in saving inputs, turnaround time, reducing

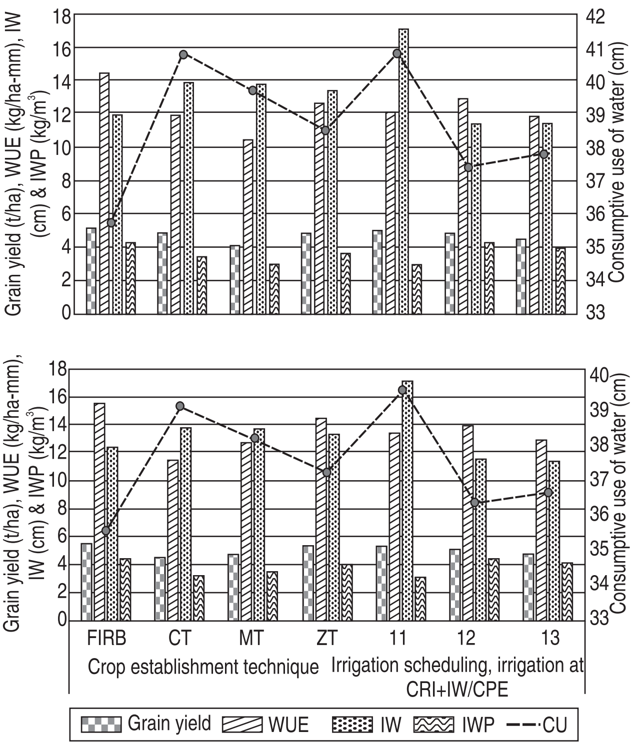

Fig 2 Effect of crop establishment techniques and irrigation schedules on grain yield, consumptive use of water, irrigation water application, water use efficiency and irrigation water productivity of wheat during 2012-13 and 2013-14.

energy usage, and environmental pollution, and improving farmer's income (Vivak *et al.* 2013).

Soil properties

Bulk density (BD) in different treatment follows the order: ZT>MT>CT>FIRBS. Higher value of BD was found in ZT. This could be ascribed due to absence of tillage which results in increase in BD. Similarly, MT has also higher BD in surface layer due to less tillage. CT and FIRBS recorded less amount of BD in surface layer due to intensive tillage. No significant difference was found in consecutive year due to very less time difference. The highest value of soil BD was noticed under ZT-flat in surface and sub-surface layer which may be due to non-disturbance of the soil matrix, which resulted in less total porosity compared to CT and bed systems (Bhattacharyya *et al*. 2008, Dey *et al*. 2016). Ram *et al.* (2010) reported that higher BD values under continuous ZT practices than CT practice, but lower values of soil BD under residue applied treatments compared to without residue ZT practices in maize-wheat cropping system.

The initial soil (0-15 cm profile depth) was neutral to slightly alkaline in reaction with pH ranged between 7.93 to 8.04 during 2012 year and 7.88 to 8.04 during 2013 year. Whereas EC was non-saline in reaction ranged between 0.21 to 0.28 and 0.20 to 0.32 dS/m during 2012 and 2013. Both pH and EC of soil recorded with the lowest value in CT and the highest value in ZT (Table 4). Busari and Salako (2013) observed that ZT soil had a significantly higher pH at the end of the first year after tillage but the pH became significantly lower compared with the CT soil at the end of the second year after tillage. The study also revealed that MT resulted in significantly higher pH and EC than CT at the end of each of the two years of the study suggesting that

Table 2 Grain and biological yield (t/ha) of wheat under different crop establishment techniques and irrigation regimes (2012-13, 2013-14 and pooled)

Crop establishment technique (P)	Grain yield (t/ha)							
	Irrigation schedule (I), irrigation at IW:CPE							
	0.90	0.75	0.60	Mean	0.90	0.75	0.60	Mean
	2012-13				*2013-14*			
FIRBS	5.32	5.18	5.00	5.17	5.64	5.59	5.30	5.51
CT	5.21	4.89	4.39	4.83	4.85	4.44	4.09	4.46
MT	4.41	4.16	3.85	4.14	5.33	4.74	4.43	4.83
ZT	4.84	5.06	4.68	4.86	5.38	5.51	5.15	5.35
Mean	4.94	4.82	4.48		5.30	5.07	4.74	0.00
SEm±	P = 0.08, I = 0.04, P × I = 0.07				P = 0.06, I = 0.03, P × I = 0.09			
CD (P=0.05)	P = 0.27, I = 0.15, P × I = 0.22;				P = 0.21, I = 0.12, P × I = 0.28			
	Pooled grain yield				*Pooled biological yield*			
FIRBS	5.48	5.39	5.15	5.34	12.27	12.02	11.66	11.99
CT	5.03	4.67	4.24	4.64	11.87	11.21	10.38	11.15
MT	4.87	4.45	4.14	4.49	11.27	10.86	10.34	10.82
ZT	5.11	5.29	4.92	5.10	11.70	11.75	11.32	11.59
Mean	5.12	4.95	4.61		11.78	11.46	10.93	
SEm±	P = 0.05, I = 0.03, P × I = 0.06				P = 0.15, I = 0.05 P × I = 0.07			
CD (P=0.05)	P = 0.17, I = 0.13, P × I = 0.19;				P = 0.45, I = 0.19, P × I = 0.22			

FIRBS: Furrow irrigated raised bed, CT: Conventional tillage, MT: Minimum tillage and ZT: Zero tillage, CRI+IW:CPE: Crown root initiation + Irrigation water: Cumulative pan evaporation.

Table 3 Net returns (₹ $\times 10^3$/ha) and benefit cost ratio (B:C) of wheat under different crop establishment techniques and irrigation regimes

Crop establishment technique (P)	Irrigation schedule (I), irrigation at IW:CPE							
	0.90	0.75	0.60	Mean	0.90	0.75	0.60	Mean
	2012-13				2013-14			
				Net returns				
FIRBS	40.98	41.17	38.47	40.20	47.91	48.20	43.57	46.56
CT	41.31	37.67	29.52	36.17	34.85	30.60	24.57	30.01
MT	30.38	28.61	22.92	27.30	44.39	38.65	34.49	39.18
ZT	38.85	43.96	38.54	40.45	49.48	52.33	47.19	49.67
Mean	37.88	37.85	32.37		44.16	42.44	37.46	
SEm±	P = 1.16, I = 0.61, P × I = 0.98				P = 0.92, I = 0.43, P × I = 0.43			
CD (P=0.05)	P = 4.02, I = 2.41, P × I = 3.04				P = 3.17, I = 1.69, P × I = 1.69			
				B:C				
FIRBS	1.81	1.84	1.79	1.82	1.89	1.93	1.84	1.89
CT	1.83	1.78	1.61	1.74	1.66	1.60	1.48	1.58
MT	1.63	1.62	1.50	1.58	1.86	1.79	1.70	1.78
ZT	1.86	2.01	1.89	1.92	2.02	2.13	2.02	2.06
Mean	1.78	1.81	1.70		1.86	1.86	1.76	
SEm±	P = 0.02, I = 0.01, P × I = 0.02				P = 0.02, I = 0.01, P × I = 0.02			
CD (P=0.05)	P = 0.08, I = 0.05, P × I = 0.07				P = 0.07, I = 0.03, P × I = 0.07			

Table 4 Influence of crop establishment techniques and irrigation scheduling on physico-chemical properties of wheat after harvest

Treatment	BD (g/cm^3)		pH		EC (dS/m)		OC (%)		Available N (kg/ha)		Available P_2O_5 (kg/ha)		Available K_2O (kg/ha)	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Crop establishment techniques														
FIRBS	1.32	1.35	7.97	7.95	0.25	0.28	0.62	0.63	131.6	133.1	22.5	23.6	271.0	268.3
CT	1.39	1.39	8.01	8.04	0.21	0.20	0.57	0.57	127.9	128.0	20.0	19.7	268.3	263.9
MT	1.41	1.43	7.95	7.94	0.24	0.27	0.60	0.65	130.6	132.9	20.3	21.2	269.1	264.4
ZT	1.46	1.52	7.93	7.88	0.28	0.32	0.66	0.70	136.9	141.0	25.4	27.0	277.9	274.9
SEm±	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01	1.29	1.31	0.40	1.29	0.78	0.96
CD (P=0.05)	0.05	0.04	0.03	0.07	0.03	0.03	0.03	0.04	4.46	4.52	1.40	4.47	2.71	3.31
Irrigation scheduling														
I_1	1.41	1.43	7.95	7.96	0.22	0.23	0.61	0.64	131.3	133.4	22.0	22.8	271.9	267.3
I_2	1.40	1.40	7.97	7.96	0.25	0.26	0.62	0.64	131.4	133.0	21.9	23.2	271.6	267.6
I_3	1.38	1.40	7.97	7.94	0.27	0.31	0.61	0.63	132.6	132.7	22.3	22.6	271.2	268.7
SEm±	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	1.08	1.43	0.28	0.25	0.45	2.09
CD (P=0.05)	NS	NS	NS	NS	0.03	0.03	NS	NS	NS	NS	NS	NS	NS	NS

less soil disturbance is beneficial to soil chemical quality improvement.

Soil OC content after wheat harvest during 2012-13 and 2013-14 ranged between 0.57-0.66 % and 0.57-0.70% in different crop establishment techniques, with the lowest values in CT and the highest in ZT (Table 4). ZT also increased soil OC significantly over FIRBS, MT and CT. Govaerts *et al*. (2007) reported that permanent raised beds with full residue retention increased soil organic matter content 1.4 times in the 0-5 cm layer compared to conventionally tilled raised beds with straw incorporated and it increased significantly with increasing amounts of residue retained on the soil surface in the permanent raised beds.

After two years of experimentation, available NPK status increased remarkably under various crop establishment techniques (Table 4).Wheat planted under ZT improved available NPK status in the soil after harvest of the wheat crop as compared to CT, FIRBS and MT. The improved soil NPK status due to absence of tillage which results in increase in available N, i.e. 136.9 and 141.0 kg/ha during

2012 and 2013 crop seasons, respectively. But the N trend in 2013 showed a slightly increase in all treatments compared with 2012. In fact, available N content of soil under all the treatments receiving N fertilizer at recommended rates showed an increase with the passage of time. However, there was no depletion of available N in CT. Astier *et al*. (2006) also observed a significantly higher total N under NT compared to CT in the highlands of Central Mexico. Similarly trend was recorded in available P content of soil under all the treatments (Table 4) and follow the order ZT>FIRBS>MT>CT. It was recorded the highest with the ZT techniques and the lowest with CT techniques during both the years. Numerous studies have reported higher extractable P levels in no tillage (NT) than in CT largely due to reduced mixing of the fertilizer P with the soil, leading to lower P-fixation (Du-Preez *et al*. 2001, Duiker and Beegle 2006). Available K content follows the same trend as that of N and P (Table 4). It was recorded the highest with ZT techniques over other treatments. But the trend in 2013 showed a smaller depletion in all the treatments compared with 2012 crop season.

Irrigation regimes

Irrigation applied at higher moisture regime where moisture stress level is comparatively low at CRI+IW:CPE=0.90 produced significantly more number of tillers, total dry matter production and leaf area index as compared to higher stress level of CRI+IW:CPE=0.60 however, substantial difference was not observed with CRI+IW:CPE= 0.75 during the two crop seasons (Table 1).The rate of crop growth and NAR at 61-90 days period enhanced in irrigation regime of CRI+IW:CPE=0.90 over that of irrigation at lower moisture regimes. Growth parameters and growth indices were decreased significantly with each cut in moisture regimes during wheat crop seasons might be due to improved moisture and nutrient availability resulting in taller plants and enhanced crop growth. Higher CGR and NAR was recorded due to higher leaf area index (LAI) resulted in higher dry matter accumulation at a faster rate per unit leaf area per unit time by reducing mortality of tillers and senescence of leaves under moisture stress management practices (Patil *et al*. 2014).

Yield parameters, viz. number of spikes, number of grains/spike and 1000-grain weight were significantly higher with irrigation regime of CRI+IW:CPE=0.90 over CRI+IW:CPE=0.60 but was at par with CRI+IW:CPE=0.75 during 2012-13 and 2013-14 crop seasons (Table 1). Similarly grain yield of wheat (4.94, 5.30 and 5.12 t/ha, during 2012-13, 2013-14 and pooled yield, respectively) was also significantly higher with CRI+IW:CPE=0.90 than other irrigation regimes and decreased significantly with decrease in each moisture regime, except in 2012-13 where the difference between irrigation at CRI+IW:CPE=0.90 and 0.75 was not marked (Table 2). Likewise, irrigation at CRI+IW:CPE=0.90 produced significantly higher pooled biological yield of wheat (11.78 t/ha) as compared to other irrigation regimes. Higher grain and straw yield of wheat with irrigation at CRI+IW:CPE=0.90 was due to collective effect of more spikes, grains/spike and 1000-grain weight. There exists a positive correlation between grain yield and better yield components like number of effective tillers, fertile spikelets and grains/spike under higher irrigation frequencies (Pal *et al*. 1996).

Around 8 and 7% higher amount of water was consumed by wheat crop under CRI+IW:CPE=0.90 (40.83 and 39.34 cm) plots than other two lower moisture regimes where stress was more during 2012-13 and 2013-14, respectively (Fig 2). The main reason for this variation in water use was the different amount of irrigation water applied under varying moisture regimes. The increased consumptive use of water with increase in number of irrigations might be due to the fact that surface layers under higher frequency of irrigations remained wet for a longer duration thereby creating the condition for higher rate of evaporation as compared to lower frequency of irrigations.

Application of irrigation at CRI+IW:CPE=0.75 resulted in highest WUE of 12.9 and 14.0 kg/ha-mm during 2012-13 and 2013-14, respectively compared to other two moisture regimes (Fig 2). Likewise, the WP_I was also highest (4.2 and 4.4 kg/m^3) with irrigation at CRI+IW:CPE=0.75, followed by CRI+IW:CPE=0.60 and lowest, i.e. 2.9 and 3.1 kg/$m^3$with CRI+IW:CPE=0.90 during 2012-13 and 2013-14, respectively. The highest WUE and WP_I as obtained with irrigation at CRI + IW:CPE=0.75 was mainly because of relatively better grain yield coupled with lesser amount of irrigation water applied. This is also due to higher consumptive use of water under higher irrigation levels compared to lower moisture regimes which resulted in lower WUE and WP_I.

Considerably higher net returns (₹ 37.88 and 44.16 $\times 10^3$/ha in 1^{st} and 2^{nd} season, respectively) was also obtained with lower moisture stress level of CRI+IW:CPE=0.90 in comparison with higher moisture stress levels (Table 3). Significantly higher B:C were achieved by applying irrigation at CRI+IW:CPE=0.75 (1.81 and 1.86) which were significantly more than CRI+IW:CPE=0.60 but the difference with CRI+IW:CPE=0.90 was not distinct during both the crop seasons, respectively. This was attributed to better economic yield with higher moisture regimes than lower moisture regimes.

Interaction effect of crop establishment techniques and irrigation regimes

Interaction effect of irrigation regimes under various crop establishment techniques on grain yield of wheat (Table 2) revealed that irrigation applied at CRI+IW:CPE= 0.90 under FIRBS produced considerably higher grain yield of 5.32 and 5.64 t/ha in the respective two crop seasons as compared to other combinations, with the exception of irrigation at CRI+IW:CPE= 0.90 in CT during 2012-13 and irrigation at CRI+IW:CPE=0.75 in FIRBS and ZT during 2013-14. The pooled grain yield and biological of wheat were also improved markedly with FIRBS under CRI+IW:CPE= 0.90 (5.48 and 12.27 t/ha, respectively) as compared to other combinations. This might be due to the favorable soil physical conditions and improved water availability enhances deeper root growth and thereby the yield. Linear positive relationship exists between different root growth parameters, irrigation depth and grain yield under raised bed (Singh *et al*. 2006). Higher moisture regime of CRI+IW:CPE= 0.75 under ZT wheat produced significantly higher net profit of ₹ 43.96 and 52.33 × 10^3 /ha and significantly higher B:C of 2.01 and 2.13 during the respective two crop seasons over other combinations (Table 3). However, in 2012-13 crop season, the difference with irrigation at CRI+IW:CPE= 0.90 or 0.75 in FIRBS, and CRI+IW:CPE= 0.90 in CT was not significant. The higher net profit and B: C of wheat owing to higher grain and straw yields in the respective treatments.

Conclusions

Thus, it can be concluded that planting of wheat under beds (FIRBS) is better for interaction of plants to moisture and tillage practices with respect to growth, yield, WUE and WP_I. While, ZT is better in relation to economics and soil health improvement. However, scarce resource like water could be saved around 12% by adopting beds. Bed planting of wheat with CRI+IW:CPE= 0.90 irrigation schedule had positive influence on improved growth and yield of wheat by conserving moisture in the soil. Hence, FIRBS and ZT could be a better option for sustainable wheat production under conservation agriculture in the regions where higher level of stress was observed due to moisture.

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