Vol. 17, No. 1, pp. 87-95 (2017)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in

Research Article

Comparative Performance of Wheat Roots under Micro-irrigation and Check Basin Method

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ABSTRACT

A field study was conducted during winter seasons of 2013-14 and 2014-15 in Ludhiana, Punjab to investigate the effect of three irrigation methods (check basin, drip and sprinkler irrigation) and four irrigation regimes (Cumulative pan evaporation: irrigation water) CPE/IW ratio of 0.6, 0.8, 1.0 and 1.2 with inclusion of recommended surface irrigation (7.5 cm depth) as standard check on plant growth parameters and yield of wheat. The experiment was laid out in randomised block design with three replications. Results revealed that there was significant improvement in root length density, root mass density and grain yield in drip irrigation as compared to sprinkler irrigation, being at par with check basin method. Among the irrigation schedules, yield increased markedly with increase in irrigation frequency from CPE:IW ratio of 0.6 to 1.2.

Key words: Root growth, Irrigation schedule, Micro-irrigation, Wheat, Yield

Introduction

Wheat is an essential commodity for human civilization and is planted annually in an area of around 220 million hectares (m ha) across the world. Wheat provides 21% of the food calories and 20% of the protein for more than 4.5 billion people in 94 countries. In India, wheat is the second most important cereal crop and plays a key role in food and nutritional security. India is a privileged country to attain and retain the status of second largest producer of wheat in the world and register a historic production of 95.85 million tonnes during 2013-14 with a growth of around 3% over the previous year and productivity of 3.15 t ha^{-1}. The target for wheat in India is projected around 140 million tonnes by 2050 considering its growing demand for consumption and trade due to burgeoning population. The ever increasing population of the Indian sub-continent has necessitated the well-thought and planned efforts to face the challenges of increased food demand with diminishing resources.

Climate change scenarios paint a somber picture, particularly for the Indo-Gangetic plains. The favourable wheat acreage of the country comprising most parts of NWPZ which represent irrigated, high yielding environments may shrink upto 51% and acquire constraints akin to the less favourable Central and Peninsular zones on account of rising temperature and falling water availability. The Intergovernmental Panel on Climate Change predicted a 20% reduction in annual wheat production by 2030. The gist of most studies on climate change lies in a 20-30% yield loss, assuming a temperature increase of 2-3°C in various wheat growing regions of the country by 2050. The unmitigated effects of even

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a partial realization of these projections can be devastating.

Investigations on irrigation scheduling to crops are usually aimed at eliminating over- or under-irrigation and ensuring optimum yields with high water productivity. For wheat, a simple concept that takes into account the effects of evaporative demand and rainfall for timing irrigation to crop was put forward in 1970s (Parihar *et al*. 1974). This approach of scheduling irrigation to wheat based on irrigation water (IW) to cumulative open pan evaporation (PAN-E) ratio of 0.75 to 0.90 saved two irrigations compared to 5-6 irrigations applied at fixed growth stages without any significant loss in crop yields (Prihar *et al*. 1976). Heavy pre-sowing irrigation followed by irrigation at IW/PAN-E ratio of 0.75 (Jalota *et al*. 1980) and last irrigation during mid March further improved water productivity.

In case of micro-irrigation, where lower amount of irrigation water is applied frequently, there is a need to work out optimum irrigation schedule for obtaining higher water use efficiency and yield of wheat crop under micro-irrigation system. Since water application is targeted to the root zone rather than entire field and both unproductive losses like evaporation and deep drainage are considerably reduced, irrigation efficiencies as high as 90 and 80% are achieved with drip and sprinkler systems, respectively. The overall water savings with drip system ranged between 50-60% in vegetables. However, the common obstacle for shifting from check basin to localized drip irrigation system is high investment cost of farm investment, which has to be worked out through extensive field research. At present, scientific information with respect to drip and sprinkler irrigation on crop productivity and profitability of wheat under varying irrigation regimes is lacking. Hence, the present investigation was carried out to explore the possibility of micro-irrigation in Central Punjab.

Materials and Methods

Experimental site and weather

Wheat (*Triticum aestivum* L) variety HD-2967 was sown in field experiment carried out during winter (*rabi*) season (November-April) of 2013-14 and 2014-15, at the research farm of Punjab Agricultural University, Ludhiana, India, situated at 30°56 N latitude, 75°52 E longitude and 247 m above mean sea level. The climate of the area is characterized as sub-tropical and semi-arid with hot and dry spring summer from April to June, hot and humid summer from July to September and cold autumn winter from November to March. The average annual rainfall of the area is 705 mm, most of which is received during the monsoon period from July to September, while few showers are received during the winter season also. The total amount of rainfall received during the crop seasons from November to April was 177 mm and 221 mm during 2013–14 and 2014–15, respectively. The amount of rainfall received during February and March (reproductive phase) was 36.7 and 35.0 mm during 2013-14 and 38.6 and 84.6 mm in 2014-15. Mean monthly minimum air temperatures recorded in February were 8.2°C and 12.5°C during the year 2013-14 and 2014-15, respectively. The corresponding values for the month of March were 12.5°C and 13.3°C, respectively. The values for the 30 year long term average monthly minimum air temperatures and rainfall recorded were 7.2°C, and 29.9 mm during February and 11.3°C and 26.1 mm during March. These values clearly indicated that there was an increase of 1°C and 1.2°C in average monthly minimum air temperatures during February and March over 30 years long-term average in 2013-14. The corresponding increase during these two months were 3.2°C and 2°C in 2014-15. Hence, it could be understood that due to this increase in monthly minimum air temperatures, the experimental crop faced the problem of terminal heat stress severely during both the years, but more prominently during 2014-15.

The soil of the experimental field is loamy sand in texture with pH of 7.8. The soil is low in both available N (189.4 kg ha^{-1}) and Walkley and Black organic carbon (0.16–0.30%) in 0–15 cm soil layer. The 0.5 mol L^{-1} $NaHCO_3$-extratable Olsen-P is medium (9.7 mg/kg) and the soil is sufficient (81–83 mg kg^{-1}) in 1 mol L^{-1} NH_4OAC-extractable K. The nine treatments of osmoprotectants included thiourea @ 20, 40 and 60 mM, potassium nitrate @1.0, 2.0 and 2.0%) and sodium nitroprusside @ 400, 800 and 1200 µg/ml. Two additional treatments of water spray and untreated control was also included in the study. The treatments were replicated three times in a completely randomized block design.

A half dose of N and full dose of P and K were drilled at sowing through urea, diammonium phosphate (DAP) and muriate of potash and the remaining half dose of N was top-dressed in two equal splits at the first and second irrigations. Wheat variety 'HD-2967' was sown in rows, 23 cm apart, using a seed rate of 100 kg ha^{-1} on 8^{th} November during both the years. Four irrigations (each of 7.5 cm) were applied uniformly at critical growth stages and weeds were controlled through spraying of 2,4-Dichlorophenoxyacetic acid (2,4-D) at 0.50 kg ha^{-1} applied 35 days after sowing (DAS). The foliar sprays of each osmoprotectants were made two times after anthesis at weekly interval using spray volume of 600 L ha^{-1}. In order to make sprays more effective, teepol was mixed at 0.50 ml L^{-1} with spray solution as a sticking agent. The crop was harvested in the third week of April.

The drip unit consisted of pump, filters, main and sub-main pipes, control valves and laterals. A drip tape was placed at a distance of 30 cm in the midway between two adjacent rows of wheat. Offline drippers were used in the study with a discharge rate of 4 L hr^{-1}. For a plot size of 6m × 2.6m, 5 laterals were used with 20 drippers on each lateral. The distance between two dripper was 30 cm. The micro-sprinkler head was operated at 2.5 kg cm^{-2} pressure. Ssprinkler irrigation system for each plot comprised of three impact sprinklers, mounted on 120 cm high risers. The spraying angle was maintained to 90^0 and sufficient overlapping was maintained. The spraying range of each micro-sprinkler was about 2 m. The pressurized irrigation systems were operated through a shallow tube well with 5 HP motor. Control valve was fixed next to the filter on the main pipe to regulate water supply as per the treatment requirement.These heads were installed to cover the field in an overlapping manner. The uniformity co-efficient of the entire micro-irrigation system was above 85%, to ensure even water application in the field.

One common irrigation was given to all the treatments in both experiments during both the years for the crop establishment before starting the irrigation as per treatments. After that, irrigation was applied as per treatments. In check basin, common irrigation of 75 mm and in micro-irrigation 30 mm irrigation was given. In case of drip irrigation, treatments and sprinkler irrigation treatments, 30 mm (IW) was fixed and for check basin treatments, IW was fixed as 75 mm. CPE was kept as variable in each treatment and kept out as 18, 24 and 30 and 36 mm in micro-irrigation and 45, 60, 75 and 90 mm in case of check-basin irrigation for the treatments of CPE:IW 0.6, 0.8, 1.0 and 1.2, respectively. In case of surface irrigation (Recommended by Punjab Agricultural University, Ludhiana), 7.5 cm deep irrigation was given as per recommended schedule.

Root studies

Representative wheat plants from three replications were selected for root sampling and root length and weight density were recorded at maximum tillering and physiological maturity. Metallic cores (0.126 m length and 0.104 diameter) were used for root sampling. The cores were kept in water over night and roots were made free from soil by washing with fine spray of water. Roots were collected on fine sieve (1 mm) for final washing with micro jet tap and observations for following parameters were made.

Root length density

Root length was measured in a glass bottomed shallow dish of 0.4 m x 0.2 m dimensions using Newman (1966) technique. Graph ruled in millimeter was placed under the dish. The wet roots were cut from the root shoot joint and poured into the dish containing some water. The roots were positioned randomly over the graph paper lines (representing a grid) with the help of forceps and needle so that they did not over lap one another. The counts for intersections of roots (N) with vertical and horizontal lines of 1 cm grid were recorded care was taken to avoid more then 400 counts at one instance. Root length was computed using the modified version of Newman (1966) formula as proposed by Tenant (1975).

Root length (R) = 11/14 × no. of intersections (N) × grid unit (cm)

The grid unit was combined with 11/14 factor which gave a factor of 0.76 for one grid square.

The root length density was calculated as root length per unit soil core volume.

RLD = Total root length (m)/ volume of core (m^3).

Root mass density

Soil samples were collected with the help of core from each treatment in all three replications. The roots were washed on 70 mesh sieve with water jet and dried in an oven at 70°C for three days to determine the root mass. The root mass density (RMD) was calculated as root mass per unit soil core volume.

RMD = oven dry weight of roots (kg) / vol of core (m^3)

Grain and straw yield

The total produce was weighed in bundles after harvesting and threshed thereafter. The weight of grains was recorded. The straw weight was obtained after deducting the weight of grains from total bundle weight. Grain and straw yield were computed and expressed as t ha^{-1}.

Data were subjected to analysis of variance (ANOVA) using the SPSS program: Version 8 (SPSS, 1998). The ANOVA was performed by using a Randomized Block Design with nine treatments replicated three times. Treatment mean differences were separated and tested by Fisher's protected least significant difference (LSD) at P = 0.05 significance level.

Results and Discussion

Root length density

Table 1 shows the distribution of roots at maximum tillering stage in 2013-14 and 2014-15.

Table 1. Effect of irrigation methods and their scheduling on root length density (mm m^{-3}) of wheat at maximum tillering stage

Treatment	RLD (0.0-0.1 m)	
	2013-14	2014-15
Irrigation methods		
Check basin	0.110	0.163
Drip	0.153	0.209
Sprinkler	0.109	0.160
LSD (p=0.05)	0.064	0.074
Irrigation schedules (CPE:IW)		
0.6	0.131	0.183
0.8	0.126	0.179
1.0	0.124	0.177
1.2	0.114	0.168
LSD (p=0.05)	0.067	0.077
Irrigation methods × Irrigation schedules (CPE:IW)		
Check basin 0.6	0.122	0.174
Check basin 0.8	0.109	0.160
Check basin 1.0	0.114	0.166
Check basin 1.2	0.097	0.147
Drip 0.6	0.154	0.210
Drip 0.8	0.156	0.212
Drip 1.0	0.155	0.210
Drip 1.0	0.149	0.204
Sprinkler 0.6	0.114	0.165
Sprinkler 0.8	0.114	0.165
Sprinkler 1.0	0.107	0.158
Sprinkler 1.2	0.101	0.151
LSD (p=0.05)	NS	NS
Recommended surface irrigation	0.120	0.172
Recommended vs Treatment LSD (p=0.05)	NS	NS

Among the three irrigation methods, the highest RLD in 0-10 cm depth was observed in drip irrigation, while the lowest was recorded in check basin. These results resulted from the frequent application of water in drip and sprinkler irrigation which encourages root growth in top layer but is not conducive for root growth in the deeper layers.

During 2013-14, at physiological maturity stage, maximum root length density was recorded in 0-10 cm depth (Table 2). There was decline in root length density (RLD) with depth. For 0-10

Table 2. Effect of irrigation methods and their scheduling on root length density (mm m^{-3}) of wheat at physiological maturity stage

Treatment	RLD (0.0-0.1 m)		RLD (0.1-0.2 m)		RLD (0.2-0.3 m)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Irrigation methods						
Check basin	1.28	1.53	0.267	0.330	0.097	0.106
Drip	1.99	2.31	0.193	0.192	0.043	0.048
Sprinkler	1.11	1.34	0.377	0.429	0.062	0.074
LSD (p=0.05)	0.83	0.094	0.016	0.015	0.034	0.0039
Irrigation schedules (CPE:IW)						
0.6	1.56	1.84	0.301	0.332	0.767	0.084
0.8	1.51	1.78	0.287	0.313	0.700	0.789
1.0	1.43	1.69	0.270	0.291	0.678	0.722
1.2	1.35	1.60	0.257	0.276	0.633	0.689
LSD (p=0.05)	0.96	0.011	0.013	0.017	0.039	0.0045
Irrigation methods x Irrigation schedules (CPE:IW)						
Check basin 0.6	1.40	1.59	0.299	0.329	0.106	0.116
Check basin 0.8	1.34	1.51	0.272	0.294	0.098	0.108
Check basin 1.0	1.26	1.35	0.260	0.278	0.093	0.102
Check basin 1.2	1.12	2.39	0.238	0.249	0.092	0.101
Drip 0.6	2.05	2.36	0.211	0.214	0.047	0.051
Drip 0.8	2.03	2.26	0.207	0.209	0.046	0.050
Drip 1.0	1.94	2.24	0.186	0.182	0.041	0.046
Drip 1.0	1.92	1.45	0.169	0.160	0.038	0.042
Sprinkler 0.6	1.22	1.38	0.395	0.454	0.077	0.084
Sprinkler 0.8	1.15	1.30	0.382	0.437	0.070	0.077
Sprinkler 1.0	1.08	1.22	0.362	0.411	0.067	0.074
Sprinkler 1.2	1.01	1.60	0.368	0.418	0.061	0.068
LSD (p=0.05)	NS	NS	NS	NS	NS	NS
Recommended surface irrigation	1.35	1.66	0.317	0.352	0.097	0.107
Recommended Vs Treatment LSD (p=0.05)	NS	NS	NS	NS	NS	NS

cm depth, root length density (RLD) of wheat increased from 1.28 mm m^{-3} in check basin irrigation to 1.99 mm m^{-3} in drip irrigated plots and only 1.11 mm m^{-3} with sprinkler irrigated wheat plots. For 10-20 cm, the maximum values were obtained in sprinkler (0.267 mm m^{-3}) to a minimum in drip irrigation (0.193 mm m^{-3}). For 20-30 cm depth, maximum RLD was found in check basin irrigation (0.097 mm m^{-3}) and minimum RLD (0.043 mm m^{-3}) with drip irrigated wheat plots.

Crop receiving frequent irrigation also registered higher root length density at all the soil layers. It was highest with most frequent irrigation level, i.e., 0.6 CPE: IW ratio. Thus, it revealed that RLD of wheat increased with increasing irrigation levels. The higher rooting densities seem to be associated with higher soil moisture storage in the profile and particularly in the surface layers. The rapid drying of the surface layers containing most of the roots caused water stress in the crop, which could also have reduced root development in less frequent irrigation levels of 1 and 1.2 CPE:IW. Irrigation at 0.6 and 0.8 CPE:IW eliminated water stress and decreased soil mechanical impedance, thus removing the constraints for root growth and extension beyond plough layer. Moreover, optimum supply of water throughout growth stages induced the crop to distribute roots into greater volume of soil. Thus, in higher frequency irrigation level i.e., optimum supply of irrigation water influenced the crop to enhance root proliferation and distribution, that in turn helped the crop to uptake soil moisture and nutrients from greater volume of soil. Similar trend was followed in 2014-15 for both irrigation methods and their schedules.

Root mass density (kg m^{-3})

In 2013-14, at maximum tillering stage, root mass density of wheat increased from 0.174 kg m^{-3} in check basin irrigation to 0.451 kg m^{-3} in drip irrigated plots and only 0.157 kg m^{-3} with sprinkler irrigated wheat plots (Table 3). In 2014 also, similar trend was noticed with significant differences between different methods of irrigation. At physiological maturity stage, in 0-10 cm soil depth, the values were 2.29 kg m^{-3} in check basin irrigation and 1.49 kg m^{-3} in drip irrigated plots, and only 1.41 kg m^{-3} with sprinkler irrigated wheat plots (Table 4). There was reverse trend for 10-20 and 20-30 cm soil layer. Sprinkler method gave the maximum root mass density in 10-20 and check basin in 20-30 cm soil depth. In 2013-14, in 20-30 cm soil layer, the values varied from 0.197 kg m^{-3} in check basin irrigation to 0.147 kg m^{-3} in sprinkler irrigated plots and only 0.075 kg m^{-3} with drip irrigated wheat plots. During 2014-15 also, similar trend was followed.

Crop receiving higher irrigation levels also registered higher root dry weight it all the soil layers. The higher rooting densities seem to be associated with higher soil moisture storage in the profile and particularly in the surface layers.

Table 3. Effect of different irrigation methods and schedules on root mass density of wheat (kg m^{-3}) at maximum tillering stage

Treatment	RDW (0.0-0.1 m)	
	2013-14	2014-15
Irrigation methods		
Check basin	0.174	0.182
Drip	0.451	0.488
Sprinkler	0.157	0.163
LSD (p=0.05)	0.049	0.054
Irrigation schedules (CPE:IW)		
0.6	0.288	0.309
0.8	0.282	0.300
1.0	0.258	0.276
1.2	0.214	0.227
LSD (p=0.05)	0.056	NS
Irrigation methods × Irrigation schedules (CPE:IW)		
Check basin 0.6	0.200	0.211
Check basin 0.8	0.192	0.202
Check basin 1.0	0.184	0.193
Check basin 1.2	0.121	0.124
Drip 0.6	0.499	0.540
Drip 0.8	0.489	0.529
Drip 1.0	0.441	0.476
Drip 1.0	0.377	0.405
Sprinkler 0.6	0.168	0.175
Sprinkler 0.8	0.162	0.169
Sprinkler 1.0	0.150	0.156
Sprinkler 1.2	0.147	0.152
LSD (p=0.05)	NS	NS
Recommended surface irrigation	0.178	0.187
Recommended Vs treatment LSD (p=0.05)	NS	NS

Grain yield

Data showed that grain yield was influenced by irrigation methods during both the year (Table 5). Significantly higher grain yield was recorded in drip irrigation (5.29 and 5.10 t ha^{-1}) than sprinkler irrigation (4.78 and 4.74 t ha^{-1}). However, it was at par with check basin method. During 2014-15, non significant differences were observed among various methods of irrigation. Grain yield recorded was the highest in drip irrigation (5.10 t ha^{-1}) followed by check basin (4.90 t ha^{-1}) and the lowest in sprinkler irrigation method (4.74 t ha^{-1}). During 2013-14, significantly higher grain yield was obtained when irrigation was applied at CPE:IW 0.6 (5.37 t ha^{-1}) than that at 1.0 (4.89 t ha^{-1}) and 1.2 (4.70 t ha^{-1}). Grain yield obtained from irrigation scheduled at CPE:IW 0.6 and 0.8 were at par. Similar trend was observed in 2014-15.

Further investigation of data indicated that among the interaction values, the highest grain yield was obtained in drip irrigation applied at

Table 4. Effect of different irrigation methods and schedules on Root mass density (kg m^{-3}) of wheat at physiological maturity stage

Treatment	(0.0-0.1 m)		(0.1-0.2 m)		(0.2-0.3 cm)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Irrigation methods						
Check basin	1.49	1.64	0.358	0.547	0.197	0.240
Drip	2.29	2.58	0.256	0.433	0.075	0.107
Sprinkler	1.41	1.55	0.384	0.582	0.147	0.184
LSD (p=0.05)	0.29	0.335	0.055	0.064	0.226	0.024
Irrigation schedules (CPE:IW)						
0.6	1.86	2.08	0.365	0.559	0.150	0.190
0.8	1.80	2.01	0.345	0.536	0.146	1.183
1.0	1.72	1.91	0.322	0.509	0.141	1.177
1.2	1.53	1.69	0.297	0.480	0.121	0.157
LSD (p=0.05)	NS	NS	NS	NS	NS	NS
Check basin 0.6	1.63	1.81	0.40	0.60	0.21	0.26
Check basin 0.8	1.56	1.72	0.37	0.56	0.21	0.25
Check basin 1.0	1.49	1.64	0.34	0.53	0.20	0.25
Check basin 1.2	1.27	1.39	0.32	0.51	0.17	0.21
Drip 0.6	2.47	2.79	0.30	0.48	0.08	0.11
Drip 0.8	2.40	2.71	0.27	0.45	0.08	0.11
Drip 1.0	2.31	2.60	0.24	0.42	0.07	0.10
Drip 1.0	1.97	2.21	0.21	0.38	0.06	0.09
Sprinkler 0.6	1.48	1.64	0.40	0.60	0.15	0.19
Sprinkler 0.8	1.45	1.59	0.40	0.59	0.15	0.19
Sprinkler 1.0	1.37	1.50	0.38	0.58	0.15	0.18
Sprinkler 1.2	1.34	1.47	0.36	0.56	0.14	0.18
LSD (p=0.05)	NS	NS	NS	NS	NS	NS
Recommended surface irrigation	1.47	1.62	0.36	0.55	0.19	0.23
Recommended Vs Treatment LSD (p=0.05)	NS	NS	NS	NS	NS	NS

CPE:IW 0.6 (5.66 t ha^{-1}) followed by drip irrigation applied at CPE:IW 0.8 (5.42 t ha^{-1}) and check basin irrigation 0.6 (5.35 t ha^{-1}). During 2014-15, similar trend was observed. The highest grain yield in drip irrigation system could be due to the fact that frequent watering resulted into higher water potential and thus minimizing fluctuations in soil moisture in the effective root zone. The uniform moisture distribution might have helped in better growth, higher nutrient uptake and less deep perculation losses which ultimately improves the grain yield. Further, sufficient moisture in root zone was maintained during critical stages of crop growth, and ultimately resulted in higher yield. The reduction in yield in check basin method might be due to lower moisture content in the surface layer due to seepage and deep percolation losses leading to unfavourable soil physical environment for root development. During sprinkler irrigation, some amount of water is lost due to wind drift and evaporation. This might have resulted in lower yield in sprinkler irrigation treatments.

Frequent irrigation levels had played a key role in enhancing crop performance through higher photosynthesis, which consequently increased the dry matter production as well as quick development of extensive root system. In general, wheat grain yield in 2013-14 was higher than 2014-15.

Table 5. Effect of different irrigation methods and schedules on biological, grain, straw yield and harvest index of wheat

Treatment	Biological yield ($t\ ha^{-1}$)		Grain yield ($t\ ha^{-1}$)		Straw yield ($t\ ha^{-1}$)		Harvest index (%)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Irrigation methods								
Check basin	11.98	11.65	5.03	4.90	6.95	6.75	42.18	42.15
Drip	12.24	12.02	5.29	5.10	6.95	6.92	43.28	42.50
Sprinkler	11.10	11.29	4.78	4.74	6.33	6.55	43.09	42.03
LSD (p=0.05)	0.74	NS	0.31	NS	NS	NS	NS	NS
Irrigation schedules (CPE:IW)								
0.6	12.52	12.44	5.37	5.27	7.15	7.17	43.15	42.59
0.8	12.08	12.08	5.26	5.08	6.92	7.00	42.77	42.04
1.0	11.44	11.23	4.89	4.76	6.54	6.47	42.88	42.48
1.2	11.06	10.88	4.70	4.53	6.36	6.33	42.59	41.81
LSD (p=0.05)	0.86	0.98	0.36	0.39	NS	NS	NS	NS
Irrigation methods × Irrigation schedules (CPE:IW)								
Check basin 0.6	12.68	12.52	5.35	5.28	7.33	7.24	42.54	42.40
Check basin 0.8	12.21	12.16	5.16	5.15	7.06	7.01	42.38	42.30
Check basin 1.0	11.75	11.23	4.92	4.78	6.83	6.45	41.99	42.67
Check basin 1.2	11.28	10.71	4.51	4.39	6.58	6.32	41.81	41.22
Drip 0.6	13.07	12.77	5.66	5.37	7.41	7.39	43.44	42.26
Drip 0.8	12.57	12.41	5.42	5.23	7.15	7.18	43.13	42.05
Drip 1.0	11.84	11.54	5.14	4.92	6.70	6.62	43.47	42.68
Drip 1.0	11.51	11.38	4.96	4.82	6.56	6.49	43.07	43.01
Sprinkler 0.6	11.83	12.04	5.11	5.16	6.71	6.88	43.48	43.10
Sprinkler 0.8	11.46	11.67	4.91	4.88	6.55	6.79	42.80	41.76
Sprinkler 1.0	10.74	10.92	4.63	4.59	6.11	6.33	43.18	42.08
Sprinkler 1.2	10.37	10.52	4.45	4.34	5.93	6.19	42.89	41.19
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Recommended surface irrigation	12.38	12.30	5.21	5.10	7.20	7.21	42.04	41.44
Recommended vs Treatment LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Biological yield

A reference to data revealed that different irrigation methods and schedules affected biological yield in both the years (Table 5). Results revealed that drip irrigation had favorable effect on biological yield of wheat over the other two methods of irrigation. Highest biological yield was obtained with drip irrigation (12.24 and 12.02 $t\ ha^{-1}$) followed by check basin (11.98 and 11.65 $t\ ha^{-1}$) and sprinkler irrigation (11.10 and 11.29 $t\ ha^{-1}$) in 2013-14 and 2014-15, respectively. In 2013, biological yield in both drip and check basin irrigation methods was statistically at par whereas, sprinkler irrigation method resulted in significantly lower biological yield than the two other methods. However in 2014, methods of irrigation did not influence biological yield significantly.

Further examination of data indicated that different irrigation schedules had marked effect on biological yield of wheat in both the years, which increased with increasing irrigation frequency i.e., from 120% to 60% of pan evaporation replenishment. Significantly higher biological yield (12.52 and 12.44 t ha^{-1}) was obtained when irrigation during crop growing season was applied at 0.6 CPE:IW than 1.0 (11.44 and 11.23 t ha^{-1}) and 1.2 CPE:IW (11.06 and 10.88 t ha^{-1}) in 2013-14 and 2014-15, respectively. It was evident from the data that grain yield obtained from irrigation scheduled at 0.6 to 1.2 CPE:IW were at par. The increase in biological yield of wheat with increasing frequency of irrigation could be attributed to potential role of water in modifying soil and water environment conductive to better plant growth. Adequate supply of moisture might have ensured adequate supply of nutrients, which helped plants to produce better growth and yield, resulting in higher biological yield.

Conclusions

Based on two year study, it was concluded that drip irrigation method improved plant growth, yield attributes and yield as compared to check basin and sprinkler irrigation methods. Beside higher yield and water use efficiency, profitability in terms of net return and B:C ratio was improved under drip irrigation method. Performance of wheat crop with respect to growth parameters was significantly superior when irrigation was scheduled at CPE:IW ratio 0.6 than both 1.0 and 1.2 CPE:IW ratio.

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Received: March 14, 2017; Accepted: June 10, 2017