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Water use pattern and productivity in bed planted wheat (*Triticum aestivum*) under varying moisture regimes in shallow water table conditions

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ABSTRACT

Field experiment was conducted during winter (*rabi*) seasons of 2010-11 and 2011-12 at Chaudhary Charan Singh Haryana Agricultural University, Hisar having shallow water table (85 to135 cm) to evaluate the water use and its components in bed planted (FIRBS) wheat (*Triticum aestivum* L.) under three levels of moisture regimes, viz. irrigation at IW/CPE = 0.5, 0.7 and 0.9. Depletion of soil moisture (SMD) and contribution from shallow water table (GWC) increased with stage of the crop, maximum during 86 DAS to maturity period. Soil water, in the respective two crop seasons, contributed 8.63 cm and 9.27 cm under FIRBS, and 8.10 cm and 8.77 cm with conventional method of sowing towards crop ET. Total water use was 38.24 and 40.83 cm in conventional sowing which decreased to 37.43 and 36.84 cm under FIRBS in the respective two crop seasons. The water productivity of the applied irrigation water under FIRBS was higher by 25.2 and 21.5% (630 and 305 kg/ha-cm) than conventional sowing (503 and 251 kg/ha-cm) in the respective two crop seasons. The share of soil water to crop ET was highest (37.8%) with IW/CPE=0.5 and decreased to 30.8% with IW/CPE=0.9. GWC was not influenced by varying moisture regimes in the 1st crop season, but in the 2nd season it was higher under IW/CPE=0.5 and decreased with increase in moisture regimes. The total water use in the two crop seasons was highest (40.44 and 43.71 cm with irrigation at IW/CPE of 0.9 and decreased with decrease in moisture regimes. Irrigations applied at IW/CPE=0.9 resulted in significantly higher grain yields closely followed by IW/CPE=0.7. The WUE of irrigation water applied was highest (733 kg/ha-cm) with irrigation at IW/CPE of 0.7 in 2010-11, but in 2011-12, it was highest (378 kg/ha-cm) with lowest moisture regimes of irrigation at IW/CPE of 0.5.

Key words: Bed planting, Moisture, Shallow water table, Water productivity, Wheat yield

Wheat (*Triticum aestivum* L.) is the first important and strategic *rabi* cereal crop for food security of India, planted over an area of 29.86 mha mainly in the north-western and central zone with a productivity of 3 117 kg/ha during 2011-12. Although, there has been increase in overall productivity of wheat, i.e. 3 117 kg/ha during 2011-12, but the individual factor productivity has declined. Under semi-arid conditions water is the scarcest input which has considerable effects on the efficiency of other natural and applied inputs. The share of water to agriculture will further reduce to about 72 to 75% by 2050. About 75 to 85% water requirement of wheat in the north-western plain zone is met through irrigation. Minimizing non-beneficial ET through efficient technologies and strategies, will greatly enhance the water productivity.

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Planting wheat on beds (FIRBS) is a novel technique to save water and enhancing the productivity of other input applied. Typical irrigation savings under FIRBS ranged from 18 to 35% in wheat (Hobbs and Gupta 2003) with higher yield. Other advantages of FIRBS of wheat planting are less lodging, more efficient utilization of applied nutrients, and temperature moderation (Sayre *et al*. 1997), less weed competition (Kumar *et al*. 2014) and higher N, P and K uptake. Water table in many areas had risen to near the soil surface which contributes substantially towards crop ET and so the irrigation requirements can be considerably reduced. Wheat crop met its entire water requirement from the shallow (0.5 m) ground water table (Kahlown *et al*. 2005). Earlier Jhorar *et al*. (1991) observed that shallow water table (~ 1 m) can supply as much as 50 to 60 percent of water requirement of the crops. Thus, there is potential for improvements in irrigation water use efficiency in areas where shallow water tables are a low salinity risk. Under such situations the irrigation schedule is likely to be different than the normal conditions.

Proper scheduling of irrigation to crops is an important component of water saving technologies. Therefore, it becomes imperative to find out appropriate irrigation schedule for exploiting yield potential. This study was done to estimate the irrigation requirements, components of temporal water use and water productivity of bed planted wheat under shallow water table condition.

MATERIALS AND METHODS

Field experiment was conducted during winter (*rabi*) seasons of 2010-11 and 2011-12 at Chaudhary Charan Singh Haryana Agricultural University, Hisar (29º 10' N, 75º 46' E) having shallow water table. The soil was sandy loam in texture and has a basic infiltration rate of 5.3 mm/h. It contained 20.9 and 6.5% moisture on weight basis at -0.03 and -1.5 MPa, respectively. Two methods of planting, *viz*. bed (FIRBS) and conventional in main plots and three irrigation regimes, viz. irrigation at IW/CPE = 0.5, 0.7 and 0.9 in sub plots were studied on the same field during both the years. After applying pre-sown irrigation, wheat cv. WH 502 was planted on 10 and 13 December in the respective years. Under FIRBS, three rows of wheat at a row spacing of 15 cm on the bed were sown with bed planter. The furrows were about 20 cm deep. The conventional plots were sown by drill keeping 20 cm row spacing. All other practices were followed as per recommendations.

Meteorological observatory data located at the Research Farm of Chaudhary Charan Singh Haryana Agricultural University, Hisar was used to calculate the CPE. During 2010-11 crop season, 90.9 mm well distributed rainfall was received with a total pan evaporation of 261.5 mm. Whereas, 2011-12 was a dry season with only 14.4 mm rainfall and 304.1 mm pan evaporation. The water table of the field during the crop periods fluctuated between 95 to 120 cm during 2010-11 and 95 to 135 cm during 2011-12. The period wise pan evaporation and water table depth in the two crop seasons are given in Table 1, and rainfall and the amount of irrigation water applied are presented in Fig 1.

The soil moisture depletion was estimated as per standard procedure (Dastane 1972).

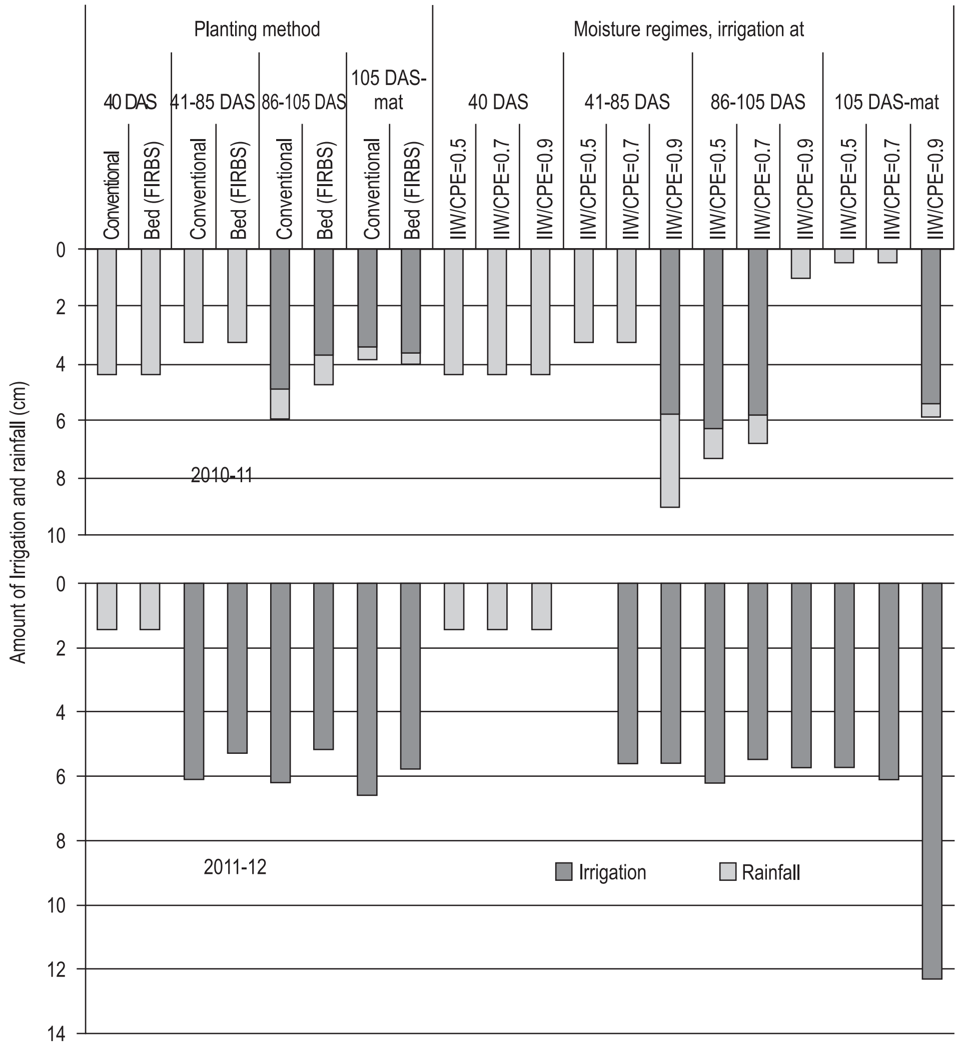
The ground water contribution (GWC) was calculated by estimating the flux density of the soil water from ground water table to root zone was estimated using Darcy's law for steady state conditions as proposed by Giesel *et al*. (1972) as under:

$$q = K\theta\ (dh/dz-1)$$

Table 1 Pan evaporation and water table depth during 2010-11 and 2011-12 crop seasons

Crop period	Pan evaporation (mm)		Water table depth (cm)	
	2010-11	2011-12	2010-11	2011-12
Sowing to 40 DAS	47.6	50.8	95	105
From 41 to 85 DAS	79.7	101.4	85	95
From 86 to 105 DAS	59.8	77.3	95	100
From 105 DAS to maturity	74.4	74.6	120	135
Average/total	261.5	304.1		

DAS, Days after sowing



IW = Depth of irrigation water; CPE= cumulative open pan evaporation; DAS= days after sowing

Fig 1 Rainfall and the amount of irrigation water applied in 2010-11 and 2011-12 during different periods of wheat crop where, q = water flux density, Kθ = capillary conductivity, h = soil water suction at the bottom of the crop root zone, z = depth of water table from the bottom of the root zone.

The capillary conductivity (Kθ) at the moisture content (θ) was estimated from saturated hydraulic conductivity (Ks), using Campbell (1974) equation. The ground water contribution was, thus, estimated from the flux density assuming that the flux entering the lower layer of the root zone is the potential contribution. The saturated hydraulic conductivity of the different soil layers, i.e. 0-30, 30-60, 60-90 and 90-120 cm was taken as 20.2, 18.5, 14.0 and 12.0, respectively.

Seasonal consumptive use of water between all the irrigation events

$$U = \sum_{i=1}^{n} ui$$

where, U = Total seasonal consumptive use (mm) = (E_0×0.85) + (M_1-M_2) + GWC + ER, n = number of intervals, ui = consumptive use (mm) during a given interval i, E_0 = evaporation (mm) from pan evaporimeter during the interval of 2 days after application of irrigation and before recording the moisture, 0.85=evaporimeter constant, M_1 = soil moisture in mm in root profile 2 days after irrigation, M_2 = soil moisture in mm in root zone before next irrigation, ER = effective rainfall during interval, and GWC = ground water contribution during the interval.

The total water use was estimated using the following water balance equation:

Water use (ET) = S + I + P + C – D – R

where, S = change in soil moisture in root zone; I=irrigation water applied; P = effective rainfall; C = ground-water contribution from shallow water-table; D = downward drainage from crop-root zone; and R = surface water run-off.

The total and irrigation water productivity was calculated as the production of grain yield per unit of total or irrigation water used.

RESULTS AND DISCUSSION

Soil moisture depletion (SMD)

The depletion of soil moisture from the 0-90 cm layer increased with the stage of the crop under both the planting methods in both the years (Table 2). It was maximum being during grain development stage, i.e. from 106 DAS to maturity. Higher ET requirement due to enhanced growth, more plant roots (density and depth) during this period which eventually caused more uptake of water from soil (Musick *et al*. 1994). In bed (FIRBS) planted crop the share of soil water depleted in seasonal crop ET was higher, i.e. 8.63 cm (21.7%) and 9.27 cm (32.3%) than in the conventional method of sowing, i.e. 8.10 cm (19.9%) and 8.77 cm (29.8%) in the respective two crop seasons. This was mainly due to fact that the soil surface exposure area was more under FIRBS and eventually higher evaporation from this exposed area. Well distributed higher amount of rainfall during the 1st crop season has resulted in lower soil moisture depletion as compared to 2nd crop season.

In general and irrespective of moisture regimes, depletion of soil moisture was lowest during initial stage and increased with the stage of the crop during both the seasons (Table 2). In 2010-11, lowest moisture regime of irrigation at IW/CPE=0.5 resulted in higher SMD, i.e. 8.95

Table 2 Cumulative soil moisture depletion and ground water contribution during different periods of wheat crop in 2010-11 and 2011-12

Treatment	Up to 40 DAS		Up to 85 DAS		Up to 105 DAS		Up to maturity	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Soil moisture depletion								
Planting methods								
Conventional	1.20	1.83	2.70	3.91	5.00	6.13	8.10	8.77
Bed (FIRBS)	1.28	1.90	2.93	4.07	5.43	6.41	8.63	9.27
Moisture regimes, irrigation at								
IW/CPE=0.5	1.20	1.80	2.80	4.00	5.00	6.00	8.95	8.85
IW/CPE=0.7	1.30	1.90	2.87	4.20	5.57	6.45	8.50	9.10
IW/CPE=0.9	1.22	1.90	2.78	3.80	5.08	6.40	7.64	9.15
Ground water contribution								
Planting methods								
Conventional	0.80	0.72	2.23	2.61	8.12	6.58	13.00	11.00
Bed (FIRBS)	0.80	0.73	2.19	2.49	7.69	6.31	12.49	10.53
Moisture regime, irrigation at								
IW/CPE=0.5	0.84	0.73	2.31	2.76	8.36	7.55	12.61	11.79
IW/CPE=0.7	0.82	0.72	2.29	2.58	7.93	6.59	13.01	11.00
IW/CPE=0.9	0.74	0.74	2.04	2.32	7.43	5.20	12.61	9.52

DAS, Days after sowing

cm and decreased with increase in moisture regime. Although, substantial differences in the SMD was not observed under varying moisture regimes in 2011-12, but the share of soil moisture depletion to crop ET was highest (37.8%) with IW/CPE=0.5 and decreased to 30.8% with IW/CPE=0.9. In the second crop season only 14 mm of rainfall was received during initial crop period (up to 40 DAS) and irrigations were applied more frequently under all the moisture regimes. In low moisture regimes of irrigation at IW/CPE=0.5 relatively less amount of irrigation water was applied and the plants extracted more water from the soil profile to meet their metabolic requirement. Kumar and Dhindwal, 2009 also observed similar results in wheat on a sandy loam soil under semi-arid conditions. While, Bandyopadhyay and Mallick (2003) observed maximum profile water depletion and ETa of wheat in the wetter moisture regime of IW:CPE of 1.2 than the lower ones.

Ground water contribution (GWC)

In general, the contribution from shallow water table was low during initial crop periods and increased to the maximum during development stage (86-105 DAS) in 2010-11 and during 106 DAS to maturity in 2011-12 (Table 2). The largest groundwater contribution occurred at the end of the growing season when roots of safflower were fully developed (Soppe and Ayars 2003). Babajimopoulos *et al*. (2007) also observed increase in groundwater contribution as root length increases in maize. The GWC in wheat crop was less by 0.5 cm under FIRBS than conventional planting during both the seasons. The contribution of GWC in crop ET did not differ between the two methods of planting and varied between 23.2 to 23.5% in 1st and 22.2 to 22.8% in 2nd crop season.

Higher amount of irrigations (16.3-18.9 cm), applied more frequently in 2011-12 has resulted in lower GWC by 2.0 cm than 2010-11. The GWC towards crop ET increased with the stage of the crop, particularly during reproductive development and 86 to 105 DAS. The GWC was not influenced by varying moisture regimes in the 1st crop season, but in the 2nd season it was higher under IW/CPE=0.5 and decreased with increase in moisture regimes. Earlier, Kumar and Dhindwal (2009) also found lower ground water use under higher moisture regimes of irrigation at CRI+IW/CPE=0.9 than CRI+IW/CPE=0.5 in wheat crop under shallow water table conditions.

Total water use

The total water use from different sources was higher in conventional (38.24 and 40.83 cm) over FIRBS of planting (37.43 and 36.84 cm) in the two crop seasons, respectively (Table 3). This was primarily due to the higher amount of irrigation water applied in the conventional planting. The difference in water use between the two methods of planting and irrigation was observed after 85 DAS. In 2010-11 crop season, the total water use was highest (40.44 cm) with irrigation at IW/CPE of 0.9 where two irrigations, 1st during 40-85 DAS and the 2nd after 105 days of sowing, with a total depth of 11.2 cm water. In other two moisture regimes, only one irrigation during 86-105 DAS could be applied and the total water use did not differ between them.

Among the varying moisture regimes, the total water use in 2011-12 crop season was highest (43.71 cm) with irrigation at IW/CPE=0.9 and decreased with decrease in moisture regimes. This was highly correlated with the amount of irrigation water applied. Four, three and two irrigations with a total depth of 23.6, 17.2 and 11.9 cm were applied under the moisture regimes of IW/CPE of 0.9, 0.7 and 0.5, respectively (Fig 1). The total water use increased with increase in moisture regimes from CRI+IW/CPE=0.5 to 0.9 as also observed by Kumar and Dhindwal, 2009.

Grain yield

Planting of wheat under FIRBS produced 1.7 and 4.5% more grain yield as compared to conventional sowing in the 1st and 2nd crop season, respectively but the differences in grain yield between these two methods of planting were not significant during both the seasons (Fig 2). This was primarily attributed to better yield parameter, viz. effective tillers, and grains/spike and grain weight as under FIRBS as compared to the conventional planting. Similar results have also been reported by Kumar *et al*. (2014) who observed 12.6% higher grain and 7.8% straw yield of wheat under FIRBS over conventional sowing. They also reported higher weed control efficiency especially of *Phalaris minor* under FIRBS.

Grain yield in the two crop seasons, under shallow water table conditions which fluctuated between 75 to 130 cm, were highest (4 464 and 5 088 kg/ha) with the application of irrigation at IW/CPE=0.9 closely followed by IW/

Table 3 Cumulative water use during different periods of wheat crop in 2010-11 and 2011-12

Treatment	Up to 40 DAS		Up to 85 DAS		Up to 105 DAS		Up to maturity	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Planting methods								
Conventional	6.36	3.99	12.91	13.68	26.65	26.45	38.24	40.83
Bed (FIRBS)	6.44	4.07	13.02	13.00	25.45	24.66	37.43	36.84
Moisture regime, irrigation at								
IW/CPE=0.5	6.40	3.97	13.16	7.75	28.29	21.19	36.83	33.98
IW/CPE=0.7	6.48	4.06	13.05	13.53	27.93	25.58	36.40	38.74
IW/CPE=0.9	6.32	4.08	18.50	12.88	26.94	24.34	40.44	43.71

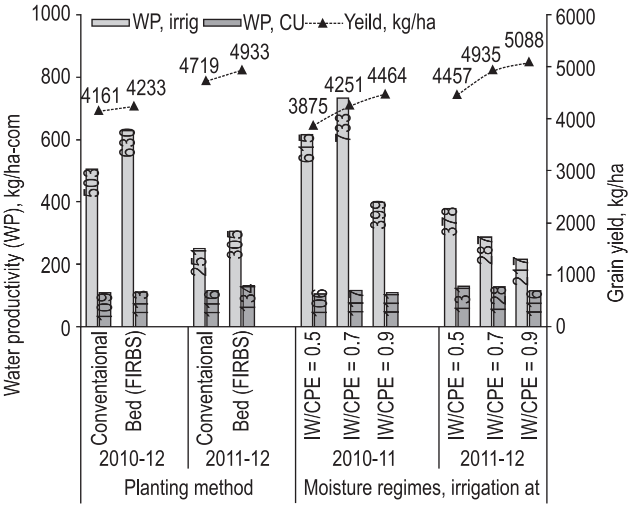


Fig 2 Grain yield and water productivity of wheat under bed (FIRBS) and varying moisture regimes during 2010-11 and 2011-12

CPE=0.7 which were significantly higher than with IW/CPE=0.5 which can be attributed to poor growth due to reduced stomatal activities under drier moisture regimes (Yang *et al*. 2004). Bandyopadhyay and Mallick (2003) and Kumar and Dhindwal (2009) also reported higher grain yield of wheat with irrigation at CRI+IW/CPE=0.9/1.2 than at CRI+IW/CPE=0.5/0.7 under shallow water table conditions.

Water productivity

The water productivity (WP) of the applied irrigation water under bed planting (FIRBS) was higher by 25.2 and 21.5% (630 and 305 kg/ha-cm) than conventional sowing (503 and 251 kg/ha-cm) in the respective two crop seasons (Fig 2). Similar trend was observed for the WP of total water use. This was due to combined outcome of better yields and lesser amount of irrigation water applied under FIRBS than conventional. The higher WP in 2010-11 was because of less input of irrigation water, i.e. 7.8 cm as compared to 17.6 cm in 2011-12.

Among the varying moisture regimes, the WP of irrigation water applied was highest (733 kg/ha-cm) with irrigation at IW/CPE of 0.7 closely followed by IW/CPE of 0.5 and the lowest (399 kg/ha-cm) under IW/CPE of 0.9 in 2010-11. However, in 2011-12, it was highest (378 kg/ha-cm) with lowest moisture regimes of irrigation at IW/CPE of 0.5 and decreased with increase in moisture regimes. Corroborative results in wheat have also been reported by Bandyopadhyay and Mallick (2003) and Kumar and Dhindwal (2009) under shallow water table conditions.

On the basis of the two crop season results, it is conduced that on a sandy loam soil, planting of three rows of wheat on bed (FIRBS) saved 15% of irrigation water with an additional yield of 143 kg/ha. The water productivity of the irrigation water applied in bed planted (FIRBS) has increased by 23.5%. Under shallow water table condition, about 23% of crop ET requirement was met through the upward flux from shallow ground water table.

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