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Research Paper

Evaluation of water-use efficiency and soil physical properties under different sowing methods, mulch levels and irrigation schedules in wheat (*Triticum aestivum*)

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ABSTRACT

A field experiment was conducted at Ludhiana, Punjab, during winter (*rabi)* season of 2013–14 and 2014–15, to study the effect of sowing methods, mulch levels and irrigation schedules on water-use efficiency and soil physical properties in wheat (*Triticum aestivum* L.). Bed sowing registered significantly higher apparent water productivity (14.5%), root density in 0–15 cm soil layer (1.7%) and infiltration rate of water (13.4%) and lower bulk density of 0–15 cm soil layer (3.1%) and soil-penetration resistance at 15 cm soil depth (18.2%) over flat sowing. Paddy straw mulch application @ 6 t/ha significantly increased leaf-area index, photosynthetically active radiation interception, dry-matter production and grain yield as compared to paddy straw mulch @ 3 t/ha and no-mulch. Mulch application @ 6 t/ha increased the water-use efficiency (WUE) by 16.5 and 32.9 kg/ha/cm over mulch @ 3 t/ha and no-mulch, respectively, and lowered the maximum soil temperature, bulk density and soil-penetration resistance than no-mulch. Irrigation schedule of 1.0 irrigation water/cumulative pan evaporation (IW : CPE) significantly increased the dry-matter production and grain yield. However, irrigation schedule of 0.6 IW : CPE significantly increased the WUE and apparent water productivity than 0.8 and 1.0 IW:CPE schedules.

Key words: Bed sowing, IW : CPE ratio, Mulch, Water-use efficiency, Wheat

India ranks second in wheat (*Triticum aestivum* L.) production in the world, after China. Punjab's share in wheat production is 18% (15.78 million tonnes) from 11% area (3.51 million ha) with the highest productivity of 4.49 t/ha as compared to country's average productivity of 2.87 t/ha (www.indiastat.com, 2016). In Punjab, water requirement of wheat is generally met through artificial irrigation to maintain high yields because of an average rainfall of 145 mm against pan evaporation of 695 mm during this season (Gill and Kingra, 2011). Moreover, 73% of total irrigation requirement is met through underground water and remaining 27% from the surface water resources (www.indiastat.com, 2016), resulting in fast depletion of the groundwater table in Punjab. Therefore, water saving becomes the utmost need of the hour for sustainable crop production.

Of the several practices used for improving WUE, furrow-irrigated raised-bed planting system (FIRBS) is very effective. This planting system proves beneficial as compared to flat planting because of substantial saving of irrigation water results in enhanced water-use efficiency (Singh *et al.,* 2010); secondly, the soil physical status is greatly improved (Jat *et al.,* 2013) and thirdly, the micro-climate within cropped area is improved owing to the better arrangement of the wheat plants on surface (Tripathi *et al.,* 2005). These advantages while interacting together are found to improve growth and yield of crop as compared to conventional flat sown.

Another way to improve WUE is to increase plant transpiration and decrease soil evaporation. There are many methods to reduce evaporation for improving WUE and use of surface mulch has been widely advocated in recent years. Mulch acts as a barrier to check the soil evaporation (Singh *et al*., 2011), buffers the soil temperature, improves plant growth, reduces weed growth, improves soil physical properties and hence increases water-use efficiency (Ram *et al.,* 2013a). In Punjab, huge quantity of paddy straw is burnt for preparation of seed-bed for wheat which causes air pollution. This paddy straw can be used as surface mulch in wheat to conserve soil moisture, improve soil physical, chemical and biological properties and solve the problem of air pollution.

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Scheduling of irrigation is also a solution of water saving and increasing WUE. As the water scarcity becomes increasingly serious, there is a need for adopting optimum irrigation scheduling. There are numerous ways to schedule the irrigation. A simple approach using meteorological parameters to schedule irrigation to crops based on the ratio between fixed depth (75 mm) of irrigation water (IW) and net cumulative pan evaporation since previous irrigation (PAN-E minus rainfall) has been extensively tested by many scientists and reported substantial saving of water (Singh *et al*., 2011; Kaur *et al.,* 2017). Thus, water being the prime natural resource for assured crop production, has to be used judiciously and in scientific manner. Hence, the present investigation was planned to study the effect of mulching and irrigation schedules on water-use efficiency and soil physical properties of bed- and flat-sown wheat.

MATERIALS AND METHODS

A field experiment was conducted during the winter (*rabi)* season of 2013–14 and 2014–15 at the Punjab Agricultural University, Ludhiana (30°54' N, 75°48' E, 247 m above mean sea-level), Punjab, India. This area is situated in the central plain region of Punjab state under Trans-Gangetic agro-climatic zone of India. The climate of this region is characterized as subtropical with normal annual and during the winter (*rabi*) season rainfall of 705 and 115 mm respectively. The total rainfall during the wheat season was 171.4 and 221.0 mm during 2013–14 and 2014–15 respectively. The average weekly maximum air temperature ranged between 15.1 and 32.6°C and average weekly minimum temperature between 3.8 and 16.7°C during crop season of 2013–14. During 2014–15, average weekly maximum air temperature ranged between 12.5 and 34.7°C and average weekly minimum temperature between 5.2 and 20.3°C. The soil was loamy sand, normal in reaction (*p*H 7.4) with electrical conductivity of 0.12 dS/m, low in organic carbon (0.21%) and available nitrogen (182.2 kg/ha) and medium in available phosphorus (20.0 kg/ha) and potassium (213.6 kg/ha). The average bulk density of soil was 1.60 g/cm^3 and the soil-moisture storage at field capacity (–0.3 bar) and permanent wilting point (–15 bar) of 0–180 cm soil profile was 382.9 and 127.1 mm respectively. The experiment was laid out in split-plot design, keeping combination of 2 sowing methods (bed sowing and conventional flat sowing) and 3 mulch levels (no mulch, paddy straw mulch @ 3 t/ha and paddy straw mulch @ 6 t/ha) in main plots and 3 irrigation schedules [0.6, 0.8 and 1.0 irrigation water: cumulative pan evaporation ratio (IW : CPE)] in subplots. Bed sowing of crop was done with tractor-operated bed planter, which makes 37.5 cm wide bed and 30 cm wide furrow between 2 beds and sow 2 rows/bed at 20 cm spacing on bed top. Flat sowing was done with tractor-mounted seed-cum-fertilizer drill with row-to-row spacing of 20 cm. Wheat variety 'HD 2967' was sown on 12 and 8 November during 2013–14 and 2014–15 respectively, by using recommended seed rate, i.e. 100 and 75 kg/ha for flat and bed sowing respectively. Half dose of N and whole of P of recommended nutrients (125 kg N and 62.5 kg P_2O_5/ha) were applied at sowing and remaining half dose of N was applied after the first irrigation. The loose paddy straw was applied immediately after sowing of crop as per treatments. The depth of each irrigation was measured with Parshall flume keeping 50 mm for bed sown and 75 mm for flat-sown plots during each irrigation. The crop was harvested on 22 and 21 April during 2013–14 and 2014–15 respectively, with sickle.

Emergence count was taken from 1 metre row length from 2 randomly selected places in each plot 15 days after sowing (DAS) and was expressed as number of seedlings/m^2. Leaf-area index was determined by SunScan probe v1.02R at anthesis stage, i.e. 120 DAS, and root density was taken layer wise from 0–15, 15–30, 30–45, 45–60 and 60–90 cm soil depths at 100 DAS. To take root density, plants were cut from the base and the auger was placed on the soil by taking base of plant in the centre of the auger. The root-soil cores were collected using an iron auger of 7 cm inner diameter which was hammered to required soil depth from the ground surface. The samples containing roots from different soil layers were thoroughly washed by putting on a sieve under slow-moving water. The roots left on the sieves were collected and then dried at 65°C till constant weight and density was expressed as root weight in g/m^3. To determine the dry-matter production, above-ground plant samples from 50-cm-row length were taken at maturity. The samples were first sun-dried and thereafter, kept in oven at temperature of 60°C till constant weight. The dry weight thus obtained was recorded and expressed as g/m^2. Grain yield was recorded from the net plot size and then expressed as t/ha. Soil temperature was recorded at a soil depth of 5 cm at 8:30 AM and 2:30 PM from sowing up to emergence of the crop with the help of soil thermometer. The photosynthetically active radiation (PAR) interception was measured between 12:00 to 2:00 PM, at anthesis stage (120 DAS) with LI-COR-LINE Quantum Sensor Photometer. Consumptive use of water was calculated as per Singh *et al.* (1960). Water-use efficiency was calculated by dividing the grain yield with water use. The apparent water productivity (AWP) was calculated by dividing the grain yield with irrigation water applied (m^3/ha). Soil samples for determination of bulk density of undisturbed soil were taken after the crop harvesting using a 5 cm long scoop having 2.5 cm internal diameter from 0–15 cm soil depth. In bed-sown plots, samples were taken from top of the bed. The soil samples were then oven-dried and bulk density was expressed as g/ cm^3 (Blake, 1965). Soil-penetration resistance was measured after harvesting of crop using penetrometer (base diameter 1.3 cm and base area 1.33 cm^2) from 5, 10, 15, 20, 25 and 30 cm soil depths at field capacity and expressed as kPa. The infiltration rate was measured after the crop harvesting with the help of double ring infiltrometer of 34 and 40 cm diameter and 28 cm height in the way specified by Black (1965).

Statistical analysis of the data recorded was done as per split plot design (Gomez and Gomez, 1984), using CPCS1 software developed by the Department of Mathematics and Statistics, PAU, Ludhiana and treatment means were compared at 5% level of significance.

RESULTS AND DISCUSSION

Sowing methods

Emergence count was significantly higher in conventional flat sowing method than bed sowing (Table 1). However, the leaf-area index (LAI) and dry-matter production were not adversely affected by lower emergence count in bed-sowing method. The pooled data on LAI at 120 days after sowing (DAS) revealed that LAI was not significantly affected by different sowing methods (Table 1). The data pertaining to root-mass density (g/m^3) at 100 DAS (Table 1) showed that about 59.1% of total root-mass was confined in upper 0–15 cm soil layer. Bed-sowing method recorded about 1.72% higher root mass density than flat sowing method in 0–15 cm soil depth. Root density was 2.61, 9.13, 2.74 and 1.23% higher in bed-sown crop in 15–30, 30–45, 45–60 and 60–90 cm soil layers than flat-sown crop respectively. This attributed to less soil-penetration resistance in bed sowing method (Fig. 2). Singh *et al.* (2010) also reported enhanced root growth under bed-sown crop owing to lower soil-penetration resistance on beds. The pooled data on biomass production recorded at maturity (Table 1) revealed that biomass production was not significantly affected by sowing methods. The results are in line with findings of Ram (2006). The pooled data on grain yield (Table 1) showed that sowing methods had no significant effect on grain yield.

The data on soil temperature (at 5 cm soil depth) during emergence (Table 1) revealed that the minimum soil temperature was comparatively less on beds (15.2°C) than on flat surface (15.5°C) but the maximum soil temperature was higher on beds (20.9°C) than flat surface (20.5°C) during both the years. This resulted from more exposure of beds to high and low air temperatures at day and night respectively, as compared to flat surface. Ram (2006) also recorded 0.2 to 3.0°C higher temperature on beds than on

Table 1. Effect of sowing methods, mulch levels and irrigation schedules on soil temperature, growth and productivity of wheat (pooled data of 2 years)

Treatment	Soil temperature (°C) up to emergence		Emergence count/m^2	Root density (g/m^3) at 100 DAS					LAI at 120 DAS	PARI (%) at 120 DAS	Dry-matter accumulation at harvesting (g/m^2)	Grain yield (t/ha)
	Min.	Max.		0–15 cm	15–30 cm	30–45 cm	45–60 cm	60–90 cm				
Sowing method												
Bed	15.2	20.9	149.2	914.6	279.4	178.1	108.9	73.8	4.03	75.1	1071.9	5.01
Flat	15.5	20.5	175.8	899.1	272.3	163.2	106.0	72.9	4.14	76.7	1070.6	5.11
SEm±	–	–	5.27	–	–	–	–	–	0.08	1.12	10.38	0.03
CD (P=0.05)	–	–	16.4	–	–	–	–	–	NS	NS	NS	NS
Mulch level (t/ha)												
0	14.7	22.5	173.8	890.1	264.2	162.3	106.5	75.1	3.78	70.2	988.2	4.71
3	15.4	20.8	166.6	907.0	276.1	170.6	107.2	73.3	4.08	75.9	1084.2	5.08
6	16.0	18.8	147.1	923.5	287.2	179.1	108.6	71.7	4.40	81.8	1141.4	5.38
SEm±	–	–	3.05	–	–	–	–	–	0.10	1.28	12.71	0.04
CD (P=0.05)	–	–	9.3	–	–	–	–	–	0.22	3.95	40.04	0.12
Irrigation schedule (IW : CPE)												
0.6	15.3	20.7	162.0	906.6	275.1	170.2	107.7	73.5	4.09	75.9	1033.5	4.87
0.8	15.4	20.6	160.4	907.1	276.0	170.8	107.6	73.4	4.07	75.6	1073.7	5.05
1.0	15.4	20.6	165.2	906.8	276.5	170.9	107.0	73.2	4.11	76.3	1106.5	5.25
SEm±	–	–	2.83	–	–	–	–	–	0.09	1.12	14.09	0.05
CD (P=0.05)	–	–	NS	–	–	–	–	–	NS	NS	41.13	0.17

DAS, Days after sowing; LAI, leaf-area index; PARI, photosynthetically active radiation interception; Min., minimum; Max., maximum; IW : CPE, irrigation water: cumulative pan evaporation**;** NS, non-significant flat surface. The data on PAR interception at anthesis stage (120 DAS) (Table 1) showed that different sowing methods did not influence the PAR interception significantly, as there was non-significant difference in leaf-area index between the 2 sowing methods (Bed and flat sowing).

The data on seasonal water use (consumptive use) is presented in Table 2, and showed that the bed-sown crop used 6.65% less water than conventional flat-sown crop. The less water use in bed-sown crop attributed to less quantity of irrigation water applied in bed-sown crop. The results are in line with Singh *et al.* (2010), who also recorded less consumptive use by bed-sown crop. The data on water-use efficiency (WUE) (Table 2) showed that WUE was significantly affected by different sowing methods. The WUE was significantly higher (166.2 kg/ha/cm) under bed sowing than conventional flat sowing method (158.2 kg/ha/cm). The higher WUE under bed sowing method attributed to less water use by the crop. These results confirm the findings of Maurya and Singh (2008) and Singh *et al.* (2010). The data on irrigation water applied (Table 2) indicated that, there was 18.5% saving of irrigation water with bed sowing method over conventional flat sowing method. Apparent water productivity (Table 2) was significantly higher in bed sowing than conventional flat sowing method during both the years. Under bed sowing method, 14.5% increase was observed over flat sowing method. Higher apparent water productivity in bed sowing method resulted from less irrigation water applied.

The data showed that bulk density of 0–15 cm soil layer after harvesting of crop was significantly lower in bed sowing method than conventional flat sowing method (Fig. 1). Flat sowing recorded 3.42% increase in bulk density than under beds. This attributed to more compaction of upper layer by irrigation application in flat sowing method. Soil-penetration resistance (SPR) measures impedance offered by soil to root growth. Generally, SPR increases with increase in compaction. The data on SPR up to 30 cm soil depth, presented in Fig. 2, showed that SPR increased with the increase in depth up to 25 cm and then declined at 30 cm soil depth. The SPR was less under bed sowing than flat sowing. This might be due to less bulk density on beds. The results confirm the findings of Jat *et al.* (2013). The data recorded on infiltration rate (cm/hr) of water (Fig. 2) showed that sowing methods had a marked effect on infiltration of water into soil. There was maximum rate of infiltration in first 2 minutes and subsequently, it decreased sharply. The infiltration rate was more in bed sowing (4.39 cm/h) than to flat sowing method (3.84 cm/h). More infiltration rate on beds might be due to loosened soil on beds. Jat *et al.* (2013) also recorded higher infiltration rate under bed sowing.

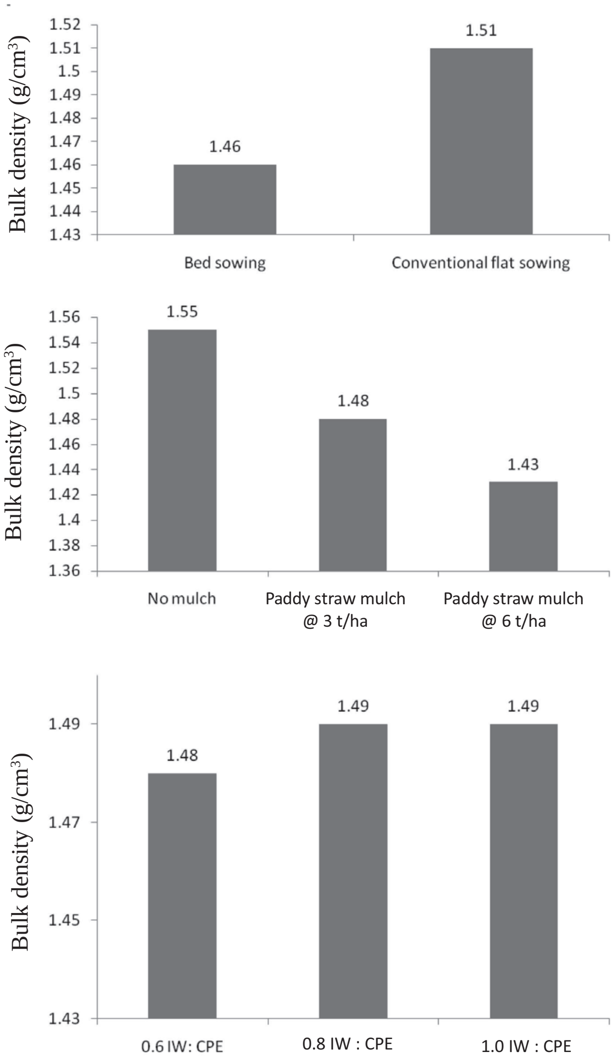

Fig. 1. Effect of sowing methods, mulch levels and irrigation schedules on bulk density of 0–15 cm soil depth (g/cm^3) at harvesting of wheat after 2 years of study (IW : CPE, irrigation water: cumulative pan evaporation)

Straw mulching

Paddy straw mulch application @ 6 t/ha significantly decreased the emergence count, i.e. by 12.1 and 15.8%, as compared with 3 t/ha and no-mulch application respectively (Table 1). This might be due to straw load to emerging seedlings. Ram *et al.* (2013a) also reported similar results. Mulching @ 6 t/ha increased the LAI significantly than 3 t/ha and no-mulch application and the LAI under 3 t/ha mulch was significantly more than no-mulch (Table 1). Higher LAI under mulch attributed to higher number of tillers with increase in mulch level. Similar findings were reported by Ram *et al.* (2013a) that mulch application significantly increased the LAI. Root mass density was the maximum under mulch @ 6 t/ha (923.5 g/m^3) and it increased the root density in 0–15 cm soil depth by 1.82 and 3.75% than 3 t/ha and no-mulch application respectively (Table 1). However, in lower layer (60–90 cm), crop without mulch recorded higher root density than 3 t/ha and 6 t/ha mulch. Niu *et al.* (2004) also reported that, wheat crop with mulch had a greater root dry weight (RDW) between 10 and 60 cm soil depth than crop with no-mulch. But, below 60 cm soil depth, RDW did not differ with or without mulch. Application of paddy straw mulch @ 6 t/ha resulted in significantly more dry-matter than 3 t/ha and no-mulch application (Table 1). This attributed to more plant height, number of tillers and spikes/m^2 in plots where mulch was applied, by improving the growth conditions. Dadhwal (2011) also reported higher biomass accumulation under mulching. Grain yield was also significantly affected by different mulch levels (Table 1). The mulch application @ 6 t/ha resulted in significantly higher grain yield (6.5 and 14.2%) than where 3 t/ha and no-mulch were applied respectively. This might be owing to better growth where mulch was applied in comparison to no-mulch application. Nandan *et al.* (2018) also reported 4.6–9.3% higher grain yield of wheat with rice-residue retention over residue removal.

The data indicated that during emergence, mulching @ 6 t/ha increased the minimum soil temperature by 0.6 and 1.3°C and decreased the maximum soil temperature by 2.0 and 3.7°C than 3 t/ha and with no-mulch application respectively (Table 1). Increase in minimum soil temperature might be due to less loss of soil temperature and exposure to lower air temperature at night because of surface mulching and decrease in maximum soil temperature might be due to less penetration of solar radiation to the soil surface. Ram *et al.* (2013b) also recorded 2.0–3.3°C lesser temperature under mulch than with no-mulch application, and Singh *et al.* (2011) also recorded 1.6°C decline in mean daily temperature during emergence period by mulch. Mulch application @ 6 t/ha helped to intercept significantly more PAR than mulch application @ 3 t/ha and with no-mulch (Table 1). The PAR interception was significantly more under mulch application @ 3 t/ha than with no-mulch application. This resulted from more leaf area in plots where mulch was applied. Dadhwal (2011) also reported more PAR interception where mulch was applied to the crop.

The minimum water use was observed under mulch application of 6 t/ha (302.8 mm) as compared to 3 t/ha mulch (314.8 mm) and with no-mulch (324.4 mm) application (Table 2). The less water use by mulched crop might be due to conservation of more moisture by reducing the evaporation losses. Ram *et al.* (2013a) also reported lower water use by mulched crop. Significantly higher water-use efficiency (WUE) was observed with progressive increase in mulch level up to 6 t/ha (Table 2). Maximum WUE was recorded under 6 t/ha mulch application which was significantly more than where 3 t/ha and no-mulch was applied during both the years. Mulch @ 6 t/ha increased the WUE by 10.2 and 22.6% over 3 t/ha and

Table 2. Effect of sowing methods, mulch levels and irrigation schedules on water use, water-use efficiency, irrigation water applied and apparent water productivity of wheat (pooled data of 2 years)

Treatment	Water-use (mm)	Water-use efficiency (kg/ha/cm)	Irrigation water applied (cm)	Apparent water productivity (kg/m^3)
Sowing method				
Bed	303.2	166.2	9.2	5.75
Flat	324.8	158.2	11.3	5.02
SEm±	–	1.75	–	0.08
CD (P=0.05)	–	5.39	–	0.23
Mulch level (t/ha)				
0	324.4	145.8	10.3	5.02
3	314.8	162.2	10.3	5.40
6	302.8	178.7	10.3	5.73
SEm±	–	1.31	–	0.05
CD (P=0.05)	–	3.96	–	0.15
Irrigation schedule (IW : CPE ratio)				
0.6	291.6	167.7	7.6	6.80
0.8	313.3	162.0	10.7	4.99
1.0	337.1	157.0	12.5	4.36
SEm±	–	1.79	–	0.07
CD (P=0.05)	–	5.56	–	0.22

IW : CPE, irrigation water : cumulative pan evaporation no mulch application, respectively. This might be owing to more grain yield and less water use by mulched crop than no-mulch application. Ram *et al.* (2013a) also reported higher water-use efficiency of mulched crop than no-mulch. Irrigation water applied did not differ with the different mulch levels. There was a significant effect of different mulch levels on apparent water productivity (Table 2). The apparent water productivity was significantly higher where 6 t/ha mulch was applied than 3 t/ha mulch and with no-mulch application. More apparent water productivity in mulched treatments resulted from more grain yield obtained from unit quantity of irrigation water applied.

Mulch application reduced the bulk density significantly as compared to no-mulch application and bulk density values of 1.43, 1.48 and 1.55 g/cm^3 were recorded under mulch application of 6 t/ha, 3 t/ha and no mulch respectively (Fig. 1). This might be due to prevention of crust formation on soil surface by raindrop impact and surface irrigation. These findings are in accordance with those of Ram *et al.* (2013a). Mulch levels also influenced the soil-penetration resistance (SPR) up to 15 cm soil depth (Fig. 2). After that, no effect of mulch on SPR was observed. The minimum SPR at 5 cm soil depth (590.8 kPa) was observed where 6 t/ha mulch was applied as compared to 3 t/ha mulch (830.2 kPa) and no-mulch (1,038.7 kPa) application. Shah *et al.* (2013) also reported less SPR under mulching. Mulch application @ 6 t/ha resulted in the maximum value of infiltration rate as compared to the other levels of mulch application, i.e. 3 t/ha and no-mulch (Fig. 2). This might be attributed to less compaction of soil by raindrop impact and more porosity created by mulch due to burrowing activity of some species. These results are in line with Shah *et al.* (2013).

Irrigation schedules

Different irrigation schedules did not significantly affect the emergence of seedlings, LAI and PAR at 120 DAS and root density at 100 DAS (Table 1), as there was no differential irrigation application up to 120 DAS. However, biomass accumulation at harvesting was significantly affected by different irrigation schedules (Table 1). Irriga-

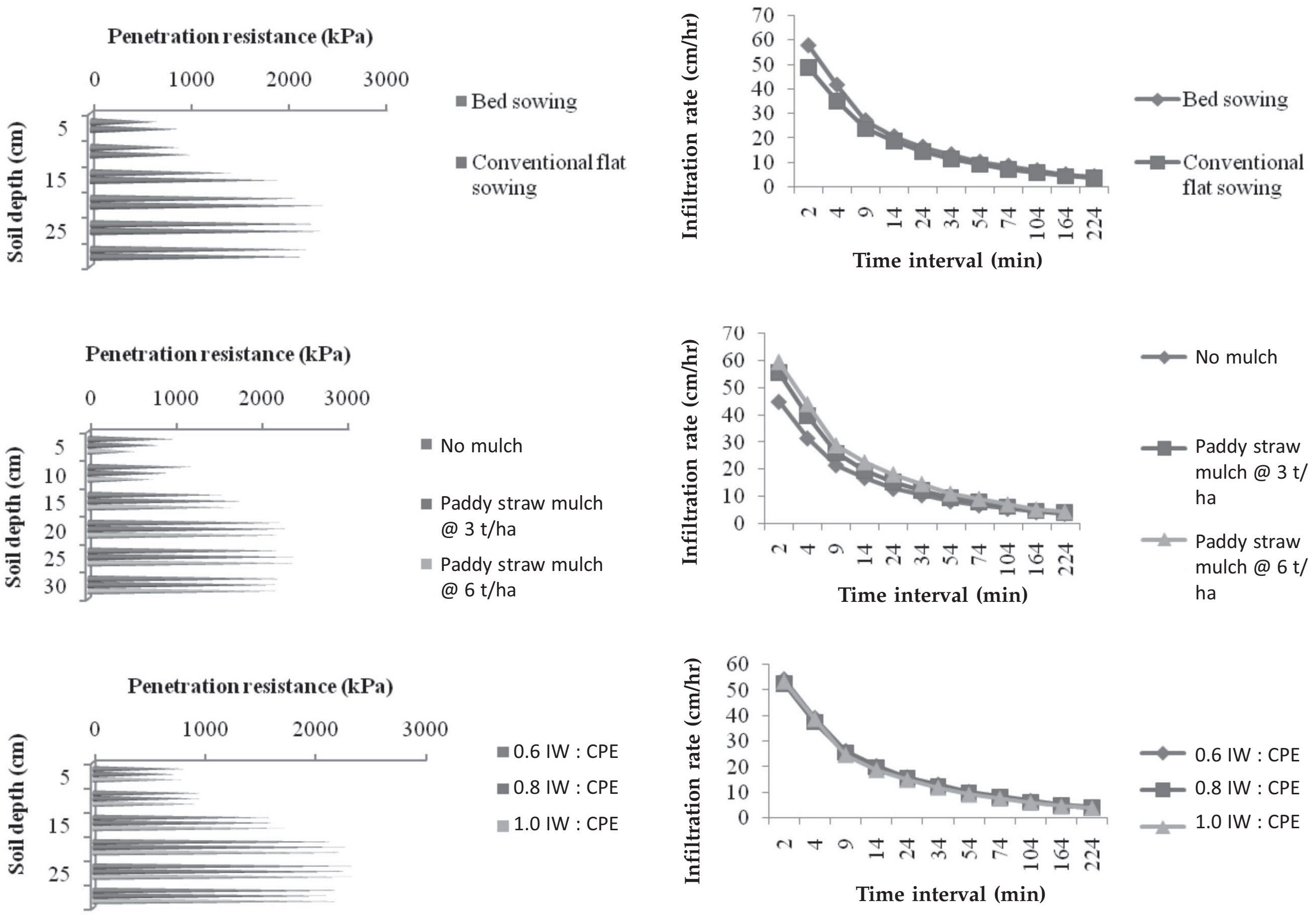

Fig. 2. Effect of sowing methods, mulch levels and irrigation schedules on soil penetration resistance and infiltration rate of water after 2 years of study

tion scheduling at 1.0 IW : CPE helped in producing significantly higher biomass than 0.6 but statistically at par with 0.8 IW : CPE, might be due to more plant height, number of tillers and spikes/m^2 at harvesting in irrigation schedule of 1.0 IW : CPE. Irrigation schedules of 0.8 and 0.6 IW : CPE were statistically at par with each other in producing dry matter. Different irrigation schedules significantly influenced the grain yield (Table 1). The maximum grain yield (5.25 t/ha) was obtained with irrigation scheduled at 1.0 IW : CPE which was significantly higher than 0.8 (5.05 t/ha) and 0.6 (4.87 t/ha) IW : CPE. Kaur *et al.* (2017) also reported higher grain yield where more number of irrigations were applied. There was no difference in the minimum and the maximum soil temperature during emergence and PAR interception (Table 1) due to different irrigation schedules, viz. 0.6, 0.8 and 1.0 IW : CPE.

The pooled data showed that irrigation schedule of 1.0 IW : CPE recorded maximum water use, being 23.8 and 45.5 mm more than irrigation schedules of 0.8 and 0.6 respectively (Table 2). The water use increased with the increase in irrigation water applied. Irrigation schedule of 0.6 IW : CPE resulted in significantly higher WUE (167.7 kg/ha/cm) than 0.8 (162.0 kg/ha/cm) and 1.0 (157.0 kg/ha/cm); however, irrigation schedules of 0.8 and 1.0 IW:CPE were statistically at par with each other. Higher WUE under irrigation schedule of 0.6 IW:CPE might be due to less water use than irrigation schedule of 0.8 and 1.0 IW:CPE. Higher water expense and water-expense efficiency in wheat was also reported by Kaur *et al.* (2017). Among the different irrigation schedules, irrigation schedule of 0.6 IW:CPE saved 29.0 and 39.2% irrigation water than 0.8 and 1.0 IW:CPE respectively. Irrigation schedules had a significant influence on apparent water productivity (Table 2). The maximum apparent water productivity was observed in irrigation schedule of 0.6 IW:CPE (6.80 kg/m^3) which was significantly higher than 0.8 (4.99 kg/m^3) and 1.0 (4.36 kg/m^3) and irrigation schedule of 0.8 IW:CPE also proved significantly superior to 1.0 IW:CPE. Different irrigation schedules did not show any significant effect on soil properties i. e. bulk density (Fig. 1), soil-penetration resistance and infiltration rate of water (Fig. 2).

Thus, it can be concluded that bed sowing method registered saving in irrigation water, higher water-use efficiency and apparent water productivity over flat sowing method along with improved soil physical properties, viz. bulk density, soil-penetration resistance and infiltration rate of water. Mulch application @ 6 t/ha recorded the minimum consumptive use of water and significantly higher water use efficiency and apparent water productivity followed by 3 t/ha mulch and no-mulch application. Mulch application also had positive effect on soil physical properties. The consumptive use of water and irrigation water applied were minimum and water-use efficiency and apparent water productivity were significantly higher under irrigation schedule of 0.6 IW : CPE than 0.8 and 1.0 IW : CPE schedules.

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