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Comparison of Surface Irrigation Application under Different Land Configurations and Management Practices

Kuldeep Singh[1*], Ram Naresh[2], R. K. Jhorar[2], Jogender Singh[3], Yogesh[4] and M. K. Mehla[5]

[1]Dept. of Soil and Water Engineering, [3]Dept. of Agriculture Extension Education, C. C. S. Haryana Agricultural University, Krishi Vigyan Kendra, Sonipat, Haryana (131 001), India

[2]Dept. of Soil and Water Engineering, College of Agricultural Engineering and Technology, C. C. S. Haryana Agricultural University, Hisar, Haryana (125 004), India

[4]Dept. of Agronomy, College of Agriculture, C. C. S. Haryana Agricultural University, Hisar, Haryana (125 004), India

[5]Texas A &M Agri Life Research, Temple, TX 76502, USA

Corresponding Author

Kuldeep Singh
e-mail: dkuldeepv@gmail.com

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Abstract

Field experiments were carried out during October, 2017–April, 2018 and October, 2018–April, 2019 at the KVK research farm, Sonipat, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana (125 004), India to evaluate efficiency of surface irrigation application under different management practices (zero tillage, conventional tillage, laser-guided land levelling, and farmers' practice). In treatment check basin and zero tillage (CB-ZT), pre-sowing irrigation was applied after harvesting of paddy crop without any tillage operation and the slope of this field was not altered. In treatment border irrigation and conventional tillage (BI-CT), the field was prepared with the help of conventional tillage implements. In treatment border irrigation and laser guided land leveling (BI-LL), the field was levelled with the help of a laser guided land leveller and a longitudinal slope of 0.3% was given. In treatment farmers' practice (FP), field was kept as per general practices adopted by farmers on their fields. i.e., without any specific slope or land levelling operation. The irrigation application performance was evaluated by estimating the infiltration opportunity time, water application, and distribution efficiency. Water application and distribution efficiency of 87.5 and 91.8%, respectively, was recorded when irrigation was carried out in borders of laser levelled plot having 0.3% longitudinal slope as compared to respective values of 66.2 and 85.7 % in farmer's practice. These findings pointed to substantial opportunity to conserve water through adoption of laser guided land levelling in the region.

Keywords: Irrigation efficiency, application efficiency, groundwater, water saving, tillage

1. Introduction

Providing sufficient water for crop production and ensuring food security remain significant challenges in the 21st century. The unsustainable use of freshwater in agriculture poses a significant threat to crop productivity and food security (Yang et al., 2015; Li et al., 2019b; Xu et al., 2019). Water scarcity is a global issue that affects regions worldwide (Liu et al., 2017; Hoekstra, 2016). Furthermore, the world is grappling with the impacts of climate change (Leroy Poff, 2015; Al-Kalbani et al., 2014; De Nicola et al., 2015) and evolving water consumption patterns (Khan, 2017), leading to predictions of expanding water scarcity (Hong et al., 2016). Consequently, the supply and demand of water to safeguard human beings and the environment have become matters of great concern in contemporary times (Leroy Poff, 2015). To meet the demands of a growing population and escalating food requirements, global crop production will likely need to double by 2050 (Tilman et al., 2011; Alexandratos and Bruinsma, 2012; Valin et al., 2014). Currently, 47% of the global population faces water scarcity, a figure projected to rise to 57% by 2050, with over half the world experiencing at least one month of water scarcity annually (Anonymous, 2018a). In water-stressed India, declining per capita water availability from 1453 m^3 to a projected 1170 m^3 by 2050 makes efficient water use critical (Anonymous, 2015). Agriculture consumes about 80% of groundwater, accelerating groundwater depletion, especially in states such as Punjab, Uttar Pradesh, and Uttarakhand, where irrigation efficiency is low (Harsh, 2017; Manivannan et al., 2017; Jain et al., 2019; Singh et al., 2021). The water-intensive rice–wheat system dominates the Indo-Gangetic Plains, covering 13.5 million ha and driving groundwater over-extraction and energy-intensive pumping (Singh and Singh, 2012; Ladha et al., 2009; Hira et al., 2004; Jain et al., 2021; Singh et al., 2023a). In Sonipat, Haryana, 80% of irrigation depends on inefficient surface flooding (25–40% efficiency) (Singh et al., 2023b; Amarasinghe, 2007). Improving surface irrigation requires better design, inflow control, scheduling, and land levelling (Van der Kooij et al., 2013; Lamm et al., 2021; Kang, 2014). Laser-assisted land levelling and optimized basin dimensions enhance uniformity, reduce water use, and shorten irrigation time (Devkota et al., 2021; Smith et al., 2020). The infiltration characteristics of soil play a pivotal role in the design, evaluation, and management of surface irrigation systems. Empirical infiltration models and methods, such as the double-ring infiltrometer (DRI), are widely used to estimate infiltration functions in surface irrigation (Amer et al., 2010; Amer et al., 2011; Bautista et al., 2009a; Bautista et al., 2009b). The advance and recession times in irrigation are essential parameters that have been thoroughly studied (Perea et al., 2011; Pereira, 1999). For border irrigation, these times are influenced by border dimensions, slope, inflow rate, cut-off time, and soil infiltration properties (Perea et al., 2011; Pereira, 1999). Researchers have effectively improved border irrigation performance by optimizing these factors (Anwar et al., 2016; Bai et al., 2016; Chen et al., 2012; Miao et al., 2015; Nie et al., 2018; Salahou et al., 2018; Wang et al., 2020). Hence, efficient utilization of groundwater for irrigation demands special attention. Water use for irrigation has become a field of keen interest among researchers, with various studies aimed at optimising water use in the agricultural sector (Singh et al., 2023c). In this context, it is essential to explore innovative approaches to utilize the ever-decreasing freshwater resources in agriculture efficiently. Consequently, the current study sought to evaluate the impact of different irrigation and cultural practices on the efficiency of water application and water use in the wheat crop.

2. Materials and Methods

Field experiments were carried out during October, 2017–April, 2018 and October, 2018– April, 2019 at the KVK research farm, Sonipat. The different irrigation methods (Check basin and border flood irrigation) and agricultural practices (zero tillage, conventional tillage, and laser-guided land levelling) were evaluated for irrigation efficiency in wheat to understand water conservation prospects in Sonipat district, Haryana. The area under the Sonipat district was 2260.53 sq. km, comprising 5.1% of the state area. The average elevation of the area was 230 m above mean sea level. The district's normal annual rainfall was 567 mm. Based on long-term records, about 76% of the yearly rainfall occurs during the South-West monsoon in June-September. Irrigation in the district was done by using both surface and groundwater resources. The area irrigated by groundwater and surface water in the district was 42% and 58%, respectively. About 96% of the district's net sown area was irrigated. The district had a high irrigation intensity of 159%. The area irrigated by surface water lied towards the west, where groundwater was primarily saline. In contrast, groundwater irrigation was highest in the eastern parts adjoining the Yamuna River, which have fresh groundwater resources. Canal irrigation was mainly through the Western Yamuna Canal. Due to overexploitation of groundwater resources, a general decline in the water table at 0.05 to 0.95 m year^{-1} has been observed in the region. Hence, restraining groundwater overdraft and adopting water-saving practices were becoming increasingly important.

2.1. Experimental details

Field experiments were conducted during the rabi seasons of 2017–18 and 2018–19 at the Krishi Vigyan Kendra, Sonipat, Haryana, India (28.933 N, 77.053 E). Comparative performance of different management practices (Table 1) in terms of irrigation efficiency was evaluated in the wheat crop to assess water-conservation prospects in the region. The plot size for treatments CB-ZT, BI-CT, and BI-LL was 10×40 m^2, and for FP, it was 20×67 m^2. In the treatment CB-ZT, pre-sowing irrigation was applied after paddy harvest, without tillage, and the field slope was not altered. In the treatment BI-CT, the field was prepared with conventional tillage implements. In treatment BI-LL, the field was levelled using a laser-guided land leveller, and a longitudinal slope of 0.3% was applied. In treatment FP, the field was kept as per the general practices adopted by farmers (Singh et al., 2023c) on their fields. i.e., without any specific slope or land levelling operation.

Table 1: Treatment details of the experiment

Sl. No.	Treatment description	Code
1.	Check basin irrigation with zero tillage, having zero slope	CB-ZT
2.	Border irrigation with conventional tillage	BI-CT
3.	Border irrigation with laser-guided land leveling, having 0.3% slope	BI-LL
4.	Farmer's practice	FP

2.2. Measurement of advance and recession time

Water advance and recession time were measured at 0, 25, 50, 75, and 100 % downstream distance from the upstream end of the irrigation plots. The layout and placement of wooden stakes for measuring water advance and recession times in the field were shown in Figure 1. The time taken for the water to reach (advance time) the upstream/downstream end and the time recorded at each stake since turning on the inflow stream into the border strip were recorded. Similarly, the time at which water receded (recession time) from the upstream/downstream ends and from different stakes was also noted. The difference in advance and recession was time taken as the infiltration opportunity time.

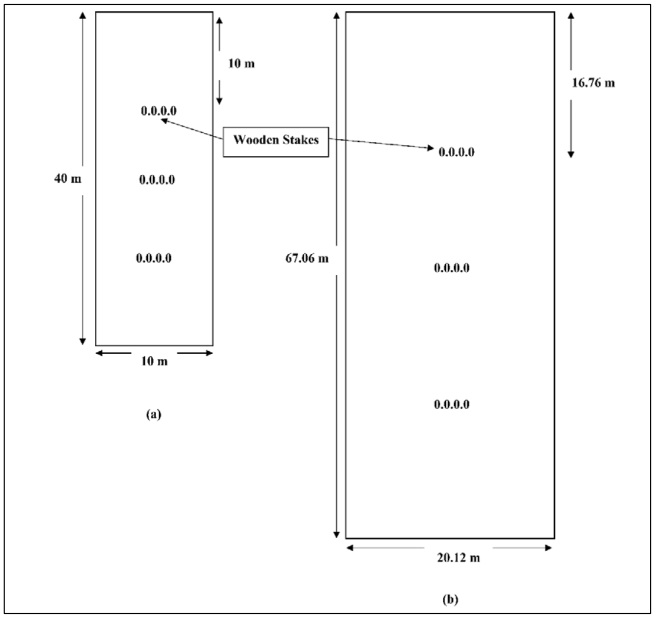

Figure 1: Layout and placement of wooden stakes for measuring water advance and recession in treatment (a) CB-ZT, BI-CT, BI-LL, and (b) farmers' practice

2.3. Soil parameters

Undisturbed soil samples up to the depth of 120 cm (0–15, 15–30, 30–60, 60–90, 90–120 cm) were collected with the help of a metal core. These samples were tested to determine field capacity using the pressure plate membrane apparatus (Richards and Fireman, 1943; Cassel and Nielsen, 1986), as per standard procedure. Soil texture was determined using the international pipette method (Miller et al., 1987) to a depth of 120 cm. The soil types at the experimental site were loamy sand at depths 0–15, 15–30, and 30–60 cm, and sandy at depths 60–90 and 90–120 cm. The water quality was found to be marginally alkaline, with a pH of 8.10. Bulk density was determined using the mass-volume relationship of the soil to a depth of 120 cm (0–15, 15–30, 30–60, 60–90, 90–120 cm). A metal core of volume 1013 cm^3 was used to carefully collect undisturbed soil samples, which were then dried in an oven for 24 hrs at 105°C to determine the soil's dry weight. Soil moisture was determined from soil samples taken before and after each irrigation at soil depths of 0–15, 15–30, 30–60, 60–90, and 90–120 cm from each plot. The wet samples were weighed in the field. Soil samples were then dried in an oven for 24 hrs at 105°C. The moisture content on a dry weight basis was calculated as follows:

$$\theta=(W_w-W_D)/W_D\times100 \qquad (1)$$

Where,

θ: Soil moisture content on dry weight basis (%).

W_w: Wet weight of soil sample (g)

W_D: Dry weight of soil sample (g)

Infiltration rate measurements were made using a single-cylinder infiltrometer. During the first hour, readings were recorded at 2 min, 5 min, 10 min, 20 min, 30 min, and 1 hr. Then, hourly readings were recorded until a constant infiltration rate was reached before each irrigation event. Measured infiltration data were then fitted to the Kostiakov Infiltration equation (Michael, 2008) (Figure 2).

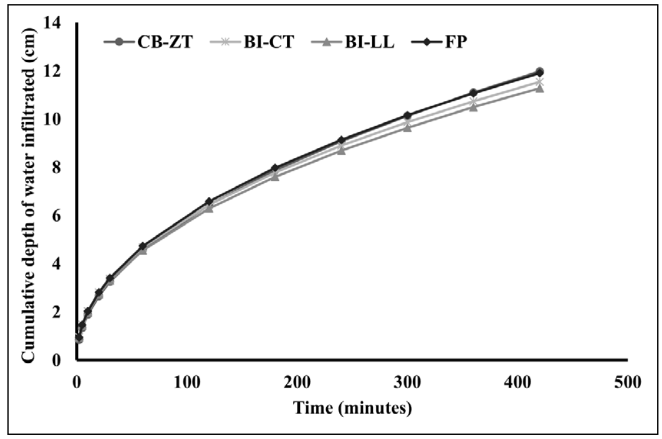

Figure 2: Variation of cumulative depth of water infiltrated (cm) with time under various treatments based on the Kostiakov Infiltration equation

$$I = k\,t^{n} \qquad (2)$$

Where,

I: Cumulative depth of water infiltrated (cm)

k: Constant of the Kostiakov equation

t: Cumulative time (min.)

n: Exponent of the Kostiakov equation

2.4. The depths of the irrigation

The following formula estimated required net depth of the irrigation:

$$dn=((\theta_{fc}-\theta_{bi})\times P_b\times R.D)/100 \qquad (3)$$

The following formula estimated stored net depth of the irrigation:

$$d_s=((\theta_{ai}-\theta_{bi})\times P_b\times R.D)/100 \qquad (4)$$

Where,

d_n: required net depth of the irrigation (cm)

d_s: stored net depth of the irrigation (cm)

$_{fc}$: moisture content at field capacity (%)

$_{bi:}$ average moisture content before irrigation (%)

$_{ai:}$ average moisture content after irrigation (%), taken 48 hrs after irrigation

P_b: bulk density (g cm^{-3})

RD: root zone depth (cm), *RD for wheat was taken as 90 cm

The applied irrigation depth was calculated using the Kostiakov equation. The exponent and constant of the Kostiakov equation were calculated from the plot infiltration rate observed just before the respective irrigation event, and the corresponding infiltration opportunity time for each plot was used to compute the applied irrigation depth. Depth of water delivered to the plot was estimated as volume of water supplied (Inflow stream discharge×cut off time of plot) to the plot divided by the area (length×width) of the plot.

2.5. Water application efficiency (E_a)

The performance of the border irrigation system was evaluated by estimating the water application and distribution efficiency. It was estimated as the ratio of water stored in the root zone to the water delivered to the field (Michael, 2008)

$$Ea=W_s/W_f\times100 \quad (5)$$

Where,

W_s: water stored in the root zone (cm)

W_f: water delivered to the field (cm)

2.6. Water distribution efficiency (E_d)

The water distribution efficiency (Ed) denoted the degree of uniformity in the amount of water infiltrated into the soil. It was estimated by following formula:

$$Ed=100\ [1\ -Y/D] \quad (6)$$

Where,

Y: average absolute numerical deviation in depth of water stored from average depth stored during the irrigation (cm)

D: average depth of water stored during irrigation (cm)

3. Results and Discussion

3.1. Infiltration opportunity time (IOT)

Observed IOT (difference of recession and advance time) along the length of irrigation plots for different treatment during 2017–18 and 2018–19 was presented in Figure 3. For all but BI-LL treatment, the observed IOT was more at the upstream end and decreased towards the downstream end of the irrigation plots. This means, in treatments BI-ZT, CB-ZT and FP, more irrigation depth was applied at the upstream end as compared to the downstream end. In case of BI-LL irrigation plots, the observed IOT increased towards the downstream end of the irrigation plots. This means, in treatment BI-LL, more irrigation depth was applied at the downstream end as compared to the upstream end. Highest and lowest overall IOT was observed for respectively FP and BI-LL irrigation plots. Ideally the IOT should be same everywhere to achieve uniform application of irrigation water throughout the irrigation plots and should be sufficient to apply the desired depth of water. The difference in IOT between upstream (0% distance, Figure 3) and downstream (100% distance, Figure 3) end was maximum in FP, followed by BI-CT, BI-ZT and BI-LL irrigation plots. The error bars (Figure 3) indicated the standard deviation of IOT as observed for different irrigation events during the growing season of wheat crop. The standard deviation was maximum for FP and least for BI-LL, particularly in the upstream part of the irrigation plots. In general, due to differences in crops

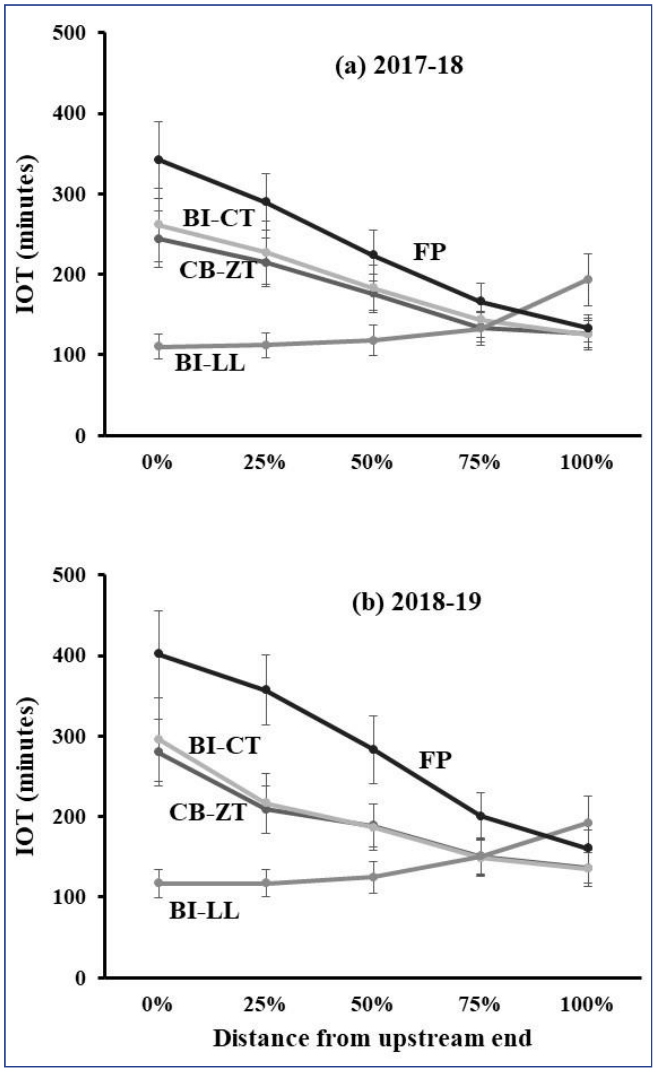

Figure 3: Variation of infiltration opportunity time (IOT) along the length (expressed as percent of total length from upstream end) of irrigation plots. Error bars indicate the standard deviation among different irrigation events

growth, weather and field conditions irrigation performance varies significantly through the season and lead to main problems in determining the best combination of effective parameters in irrigation performance (Xu et al., 2019). For annual crops, like wheat, variation in seasonal crop growth was inevitable during different irrigation events. However, the lower standard deviation values for BI-LL (Figure 3) indicated that field conditions (size and slope) could be managed suitably to ensure relatively stable performance of the surface irrigation during different irrigation events. Variation of infiltration rate (cm hr^{-1}) at different irrigation events was presented in Figure 4.

3.2. Depth of irrigation

The required, applied, and stored irrigation depths for the wheat crop under different treatments were shown in Figure 5.

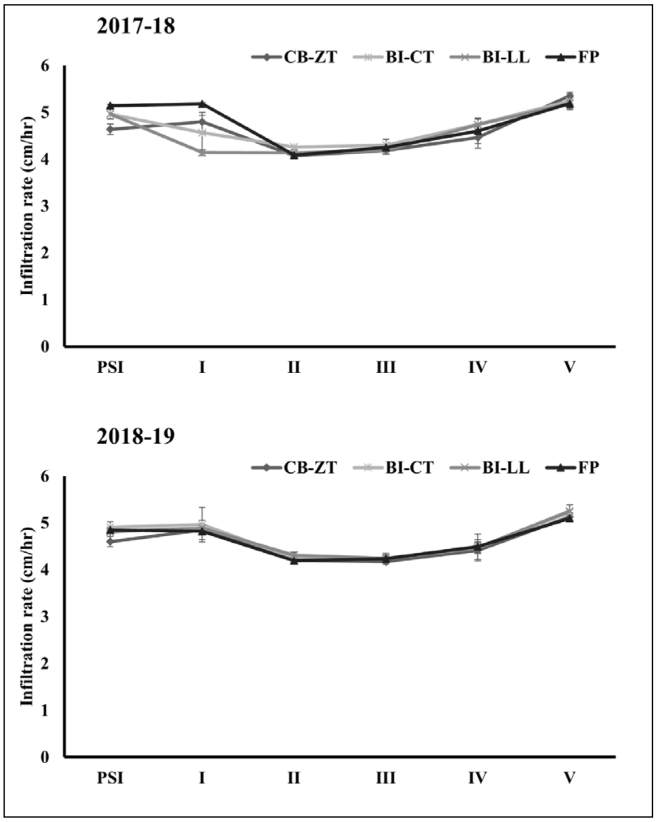

Figure 4: Variation of infiltration rate (cm hr^{-1}) at different irrigation events during the 2017–18 and 2018–19 seasons. Error bars indicate the standard deviation among different irrigation events

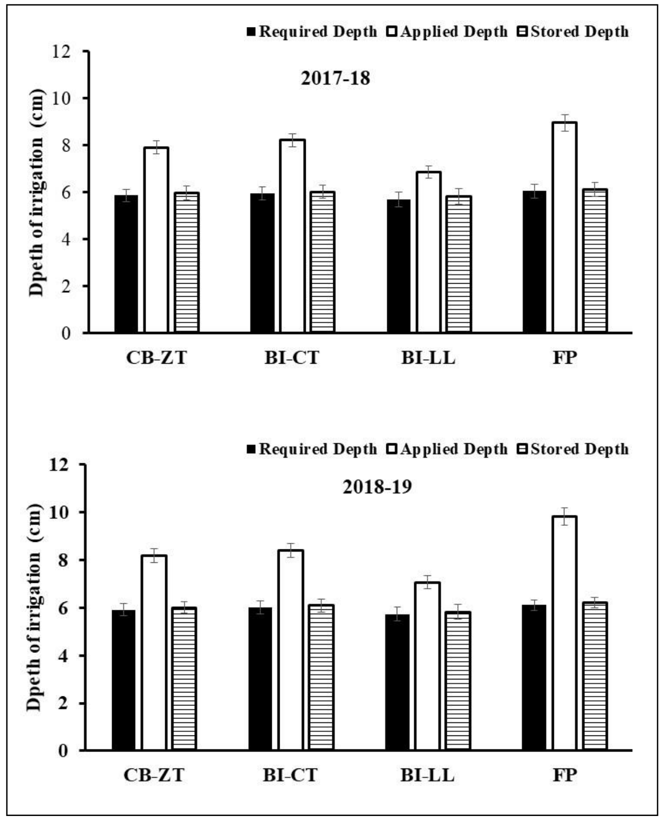

Figure 5: Required, applied, and stored depth of irrigation for wheat crops during different treatments during 2017–18 and 2018–19. Error bars indicate the standard deviation among different irrigation events

To estimate the required net depth of irrigation, field capacity, bulk density, moisture content before each irrigation event, and root zone depth were measured. Field capacity, soil texture for different soil layers, and bulk density for the farm's experimental area at KVK, Sonipat, were determined. The estimated values of field capacity, Soil texture and bulk density at depths up to 120 cm in a wheat field. The surface layer showed a slightly higher field capacity (17.02%), which might be due to the addition of FYM and incorporation of crop residues in the farm area. The field's texture was loamy sand in the upper layer, transitioning to sand as it deepened. The bulk density was minimum in the upper layer (1.44 g cm^{-3}) and increased with depth, reaching a maximum (1.56 g cm^{-3}) at 90–120 cm, mainly due to the presence of sand.

The required net depth of irrigation for different surface irrigation events for wheat crop varied from 5.55 to 6.26 cm with a mean depth of 5.90 cm during 2017–18 and 5.61 to 6.32 cm with a mean depth of 5.95 cm during 2018–19 (Table 2).

Applied depth of irrigation was calculated by using the observed IOT (Figure 2) as the cumulative time in the Kostiakov infiltration equation. The mean applied depth of irrigation for the different surface irrigation treatments (CB-ZT, BI-CT, BI-LL, and FP) ranged from 6.66 to 8.53 cm during 2017–18 and from 6.83 to 9.34 cm during 2018–19. The applied irrigation depth among surface irrigation treatments was highest for treatment FP and lowest for treatment BI-LL in both years of the study. Similar results were observed by (Naresh et al., 2014).

Table 2: Average required net depth of irrigation during different irrigation events in 2017–18 and 2018–19

Year	Average required net depth of irrigation (cm)						
	Pre sowing irrigation	Ist irrigation	IInd irrigation	IIIrd irrigation	IVth irrigation	Vth irrigation	Mean
2017–18	6.26	6.03	5.60	5.55	5.88	6.07	5.90
2018–19	6.32	6.08	5.74	5.61	5.95	5.97	5.95

3.3. Applied depth of irrigation based on stream discharge

Applied depth of irrigation was calculated from the discharge of the tube well used for irrigation and the irrigation time (cut-off time). The applied irrigation depth for different treatments and irrigation events across the study years is presented in Table 3. The mean applied depth based on stream discharge for different surface irrigation treatments (CB-ZT, BI-CT, BI-LL, and FP) varied from 6.88 to 8.96 cm during 2017–18 and 7.06 to 9.82 cm during 2018–19. The maximum applied irrigation depth, based on stream discharge, among surface irrigation treatments was observed in treatment FP (Farmers' practice) and the minimum in treatment BI-LL (Laser land levelling field) during both years of the study. A slight difference in the depth of water applied (estimated based on infiltration opportunity time) and the depth of water delivered (calculated based on inflow stream discharge and cut-off time) was observed in surface irrigation treatments. The difference in applied and delivered depth might be attributed to i) conveyance losses in the channel from the location of the submersible tube well to the entry point of water to the experimental plot, ii) spatial variability in infiltration characteristics.

Table 3: Applied depth of irrigation based on stream discharge for different treatments during different irrigation events in 2017–18 and 2018–19

Treatment	Applied irrigation depth based on stream discharge (cm)						
	Pre sowing irrigation	Ist irrigation	IInd irrigation	IIIrd irrigation	IVth irrigation	Vth irrigation	Mean
2017–18							
CB-ZT	8.30	8.09	7.67	7.63	7.72	8.09	7.92
BI-CT	8.68	8.30	7.99	7.96	8.05	8.41	8.23
BI-LL	7.32	7.02	6.67	6.64	6.67	6.97	6.88
FP	9.50	9.09	8.64	8.66	8.74	9.15	8.96
2018–19							
CB-ZT	8.60	8.38	7.94	7.90	7.99	8.38	8.20
BI-CT	8.86	8.47	8.15	8.12	8.21	8.58	8.40
BI-LL	7.51	7.19	6.85	6.81	6.82	7.15	7.06
FP	10.41	9.96	9.46	9.51	9.57	10.02	9.82

Water application efficiency was calculated as the average required irrigation depth divided by the applied irrigation depth for treatments CB-ZT, BI-CT, BI-LL, and FP. Moisture measurements for surface irrigation methods were taken at 20 m from the head end of the field. The calculated applied depth, based on the infiltration opportunity time, was greater than the required depth at all points in the field. Therefore, it was assumed that the whole required net depth of irrigation was stored in the root zone hence accordingly, water application efficiency for these treatments was calculated based on the required depth of irrigation.

Water application efficiency for different treatments as well as for different irrigation events during different years of study was given in Figure 6. Water application efficiency during different irrigation events varied between 68.8 to 88.1% and 63.5 to 86.8% in the years 2017–18 and 2018–19, respectively (Figure 6). Maximum application efficiency was recorded in treatment BI-LL (Border irrigation with laser guided land levelling having 0.3% longitudinal slope) in both the year. On

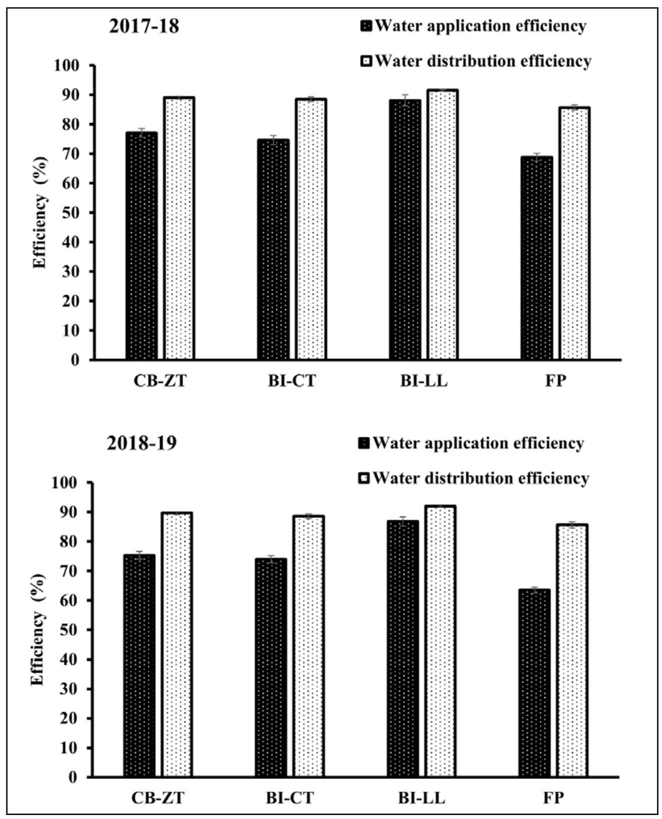

Figure 6: Water application efficiency and distribution efficiency for wheat crops in different treatments during 2017–18 and 2018–19. Error bars indicate the standard deviation among different irrigation events

the other hand, it was the least for treatment FP (Farmer's practice) in both years. Similar observations were found by (Abdullaev et al., 2007).

Water distribution efficiency was calculated by dividing average mean deviation of applied depth at 0, 10, 20, 30 and 40 m by mean applied depth of irrigation infiltrated in the field. Water distribution efficiency for different irrigation events varied between 85.7 to 91.5% and 85.7 to 92.0 % in the years 2017–18 and 2018–19, respectively (Figure 6). Highest water distribution was obtained in BI-LL (Border irrigation with laser guided land levelling having 0.3% longitudinal slope) in both the year. Similarly, it was lowest for T_5 (Farmer's practice) in both years.

4. Conclusion

Farmers' practice exhibited the highest applied depth, and border irrigation with laser land levelling field had the lowest. Border irrigation with laser-guided land levelling at a 0.3% longitudinal slope showed the highest efficiency, 32.4% higher than farmers' practice on average. Similar trends were observed for water distribution efficiency (7.1% higher than farmers' practice on average). Findings emphasized the potential of border irrigation with laser-guided land levelling at a 0.3% longitudinal slope to achieve higher irrigation efficiency and save water.

5. Acknowledgement

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