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Performance evaluation of Border irrigation method for cotton field

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Abstract: Performance evaluation of Border irrigation method was carried out for cotton field in village Kirarkot, Sirsa (Haryana). Water application, storage and distribution efficiency were estimated using measurements of soil moisture (%), infiltration rate (cm/hr), water advance and recession time (minute) during different irrigation events. The advance time increased during the growing season due to increased infiltration rate and increased resistance to flow by the growing crops. The water application efficiency of cotton field was 100 per cent as average applied depth (8.26 cm for canal irrigation and 9.06 cm for tubewell irrigation) of irrigation was less than the average required depth (10.30 cm for canal irrigation and 10.98 cm for tubewell irrigation) throughout the field plots. The observed water storage efficiency in different cotton fields varied from 72.92 - 90.08 per cent indicating under irrigation. Water distribution efficiency of cotton fields (97.8 -99.2per cent) indicated a relatively high degree of uniformity of water application. Stratified soil profile (sandy loam: 0-30 cm and sandy clay loam: 30-120 cm) of the selected fields reduced the infiltration rate to relatively very low value after 10-15 minutes creating favourable condition for uniformity of water application under border irrigation.

Keywords: Border irrigation, Cotton, Storage efficiency, Water application efficiency

INTRODUCTION

Agriculture is the largest consumer upto 70% of the Earth's available freshwater approximate 0.3% (globalagriculture.org). Increased pressures on the finite water resources of the world are requiring the irrigation sector to become more accountable for their water use. Despite lot of emphasis being given to the adoption of sprinkler and micro irrigation system (efficiency 75-90%), majority of the irrigated area is still and will continue to be under different method of surface irrigation. Therefore, evaluation of the surface irrigation methods is essential to identify various management practices to improve the irrigation efficiency and/or uniformity of the system. Surface method (Border) of irrigation is the oldest and most common method of irrigation in which water flows over the soil surface and distributed over the field by gravity flow. Surface irrigation, though looks very simple, is a very complex process due to spatial and temporal variations in soil infiltration and crop resistance which influence the movement of water over the field and thus the water distribution. Typically, there may be four phases during a surface irrigation event: (i) water advance in the field, (ii) wetting or ponding to supply desired amount of water, (iii) depletion of ponded water, and (iv) recession of water along the reach of the field.

Surface irrigation systems may become ineffective and inefficient due to physical constraints (improper land slopes, shallow soils, poor water supplies, etc.), inappropriate design and layout, or improper operation and management. (Clemmens *et al.*, 2008). Surface irrigation systems need special attention not only due to potential risk of higher water losses but also due to higher costs of replacing with alternative methods (Holzapfel and Arumi, 2010). Performance evaluation usually considers three points of view: (i) irrigation system performance as governed by effectiveness of physical system and operating decisions, (ii) uniformity of water application and (iii) the response of the crop to irrigation (Irmak, 2011). In surface irrigation, it is always desirable to obtain high water distribution and application efficiency. It is also requisite for lengths of the irrigation runs to be as long as possible because of the high labor requirements for irrigating farms with short runs. The water losses are deep seepage and runoff, which cannot be avoided, thus the application efficiency of surface irrigation is sometimes low (Amer, 2009).The application efficiency depends upon user-selected required depth of application. So, it is possible to obtain 100 per cent application efficiency by selecting a high required depth of application (Anwar *et al.*, 2016).Despite this progressive water shortage farmers continue to use flooding irrigation. Poor management, uniformity and distribution of water have been cited as the most frequent problems of

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flooding irrigation, resulting in waterlogging, salinization and less water use efficiency(Ali & Mohammed, 2015).The efficiency with which water is applied under surface irrigation methods is often assessed through predefined performance parameters. Most common performance measures include application efficiency, storage efficiency and distribution uniformity. The actual performance of a surface irrigation depends on a number of design, management and site specific factors. In the present study, the surface irrigation method was evaluated with the objectives to quantify of water application efficiency of surface irrigation for cotton crop and to identify the design aspects of surface irrigation for improved water management.

MATERIALS AND METHODS

Performance evaluation of Border irrigation method was carried in village Kirarkot having 75°06′34″E and 29°37′44″Sas longitude and latitude angle of Sirsa district of Haryana. Sirsa district is located in the western part of Haryana adjoining the state of Punjab and Rajasthan. The irrigation system in the district consists of a network of branch canals, distributaries, minors and watercourses through Bhakra Main Branch which originates from the Gobind Sagar Storage Reservoir located across the river Sutlej in the State of Himachal Pradesh. Groundwater quality is a major issue in the utilization of groundwater in the area.

Field layout: Existing plot size as used by the farmer was considered for the study and no attempt was made to change any of in the practices adopted by the farmer. Two types of the plots i.e. irrigated with canal and tubewell water were considered as their plot sizes were exceptionally different. Plot size and the code assigned to different plots are given in Table 1.The layout of the selected field plots is shown in Fig.1. Wooden stakes were placed at regular interval along the length of different plots to determine the advance and recession time along the length of plots. During study period, the farmer applied seven irrigation to cotton crop including pre-sowing condition, however, three irrigation events i.e. pre-sowing irrigation (I), first post sown irrigation (II) and irrigated at full vegetative growth (III) were considered for performance evaluation of surface irrigation.

Field measurements/observation: For the measurement of field capacity, a field site with no vegetation on it was saturated with water and covered with a plastic cover to prevent evaporation. After 24-hour, soil water content was measured upto the depth of 120 cm (0-15, 15-30, 30-60, 60-90, 90-120 cm). The measured moisture content was taken as moisture content corresponding to field capacity for different soil layers. The soil of the field was found as sandy loam upto 30 cm and sandy clay loam 30-120 cm for different soil layers. For the calculation of soil moisture, soil samples were taken before irrigation from soil depths of 0-15, 15-30, 30-60, 60-90 and 90-120 cm. The soil samples were taken at three locations in each plot with the help of auger. Infiltration measurements were made for 60 minutes (at the interval of 5 minutes) before each irrigation using single cylinder infiltrometer. Measured infiltration data were fitted to the following form of Kostiakov infiltration equation (Michael, 2008):

$$I = k\, t^n \quad \ldots(1)$$

Where, I: cumulate depth of water infiltrated (cm), k: constant of Kostiakov equation, t: cumulative time (minute) and n: exponent of Kostiakov equation

Bulk density was determined using mass volume relationship of the soil upto depth 120 cm (0-15, 15-30, 30 -60, 60-90, 90-120 cm). For the measurements of water advance and recession**,** wooden stakes were inserted at an interval of 20 m starting from upstream to the downstream end of the field to observe the time taken by the water to advance and recede at different position in the field. The time taken by the water to reach to different stakes since turning on the inflow stream into the border strip was noted down. Likewise, the time at which water receded from different stakes was also noted down. The difference between the time when the water front reaches a particular point along the field and the time at which the water recedes from the same point was taken as the infiltration opportunity time. Required net depth of the irrigation estimated by following formula:

$$d_n = \frac{(\theta_{fc} - \theta_{bi}) \times \rho_b \times RD}{100} \quad \ldots(2)$$

Where, d_n: required net depth of the irrigation (cm), Θ_{fc}: moisture content at field capacity (%), Θ_{bi}: average moisture content before irrigation (%), ρ_b: bulk density (g/cm^3), RD: rootzone depth (cm)

RD for cotton was taken as 120 cm (Michael, 2008). Applied depth of the irrigation was calculated using Kostiakov equation. Depth of water delivered to field was estimated as volume of water delivered (discharge x cutoff time of field) to the field divided by the area (length x width) of the field.

Performance Evaluation Parameters: The water application efficiency (E_a) was estimated as under (Michael, 2008):

$$E_a = \frac{W_s}{W_f} \times 100 \quad \ldots(3)$$

Where, W_s: water stored in the root zone (cm) and W_f: water delivered to the field (cm)

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

$$E_d = 100\,[1 - (y/d)] \quad \ldots(4)$$

Where, y: average absolute numerical deviation in depth of water stored from average depth stored during the irrigation (cm) and d: average depth of water stored during irrigation (cm)

The water storage efficiency (E_s) was estimated as under:

$$E_s = \frac{W_s}{W_n} X\ 100 \qquad \ldots (5)$$

Where, W_s: water stored in the root zone (cm) and W_n: water needed to the field (cm)

RESULTS AND DISCUSSION

Infiltration characteristics: Infiltration characteristics of soil plays important role in the performance of surface irrigation. In general, infiltration rate decreases with time till basic infiltration rate is achieved. The selected fields for the study showed relatively very high infiltration rate for first 10-15 minutes and then

Table 1. Plot code and plot size for cotton and wheat crop.

Plot No.	Cotton crop			
	Canal water		Tubewell water	
	Plot code	**Plot size** W (m) x L (m)	**Plot code**	**Plot size** W (m) x L (m)
1	CP_1	17.0 x 69.0	TP_1	13.2 x 133.7
2	CP_2	15.8 x 69.0	TP_2	11.3 x 133.7
3	CP_3	16.0 x 69.0	TP_3	12.0 x 133.7

W: width of plot; L: length of plot

Table 2. Required net depth of irrigation for different field plots during different irrigation events.

Plots/Border	Required net depth of irrigation (cm)		
	Pre-sowing irrigation	**First post sown irrigation**	**Irrigation at full vegetative growth**
CP_1	11.19	9.71	10.82
CP_2	10.56	9.70	10.52
CP_3	10.44	9.81	10.03
TP_1	11.94	11.06	10.60
TP_2	11.39	10.98	10.18
TP_3	11.60	10.79	10.24

Table 3. Field observed water advance and recession time (minutes) during different irrigation events for cotton crop.

Distance from Upstream end (m)	Advance time			Recession time		
	Pre-sowing irrigation	**First post sown irrigation**	**Irrigation at Full vegetative growth**	**Pre-sowing irrigation**	**First post sown irrigation**	**Irrigation at Full vegetative growth**
Field plot CP_1						
0	0	0	0	105	99	86
20	6.24	6.70	10.77	122	117	101
40	15.48	17.63	23.11	139	133	118
60	25.96	29.19	36.52	151	140	132
69	30.28	32.24	39.65	140	134	123
Field plot TP_1						
0	0	0	0	166	151	137
20	7.31	8.44	9.61	184	171	166
40	15.99	17.39	21.87	217	199	173
60	24.62	29.70	36.46	229	214	160
80	33.83	43.80	51.58	249	243	192
100	42.69	56.50	61.42	238	256	210
120	54.08	69.08	69.86	266	258	230
133.7	65.32	79.67	78.41	261	255	226

Table 4. Average estimated depth of water applied (d_a) and delivered (W_f) to the field.

Plot/Border	Irrigation events					
	I		II		III	
	d_a (cm)	W_f(cm)	d_a (cm)	W_f(cm)	d_a (cm)	W_f(cm)
Cotton						
CP_1	8.16	8.63	8.17	8.78	8.34	8.81
CP_2	8.17	8.75	8.12	8.58	8.39	9.01
CP_3	8.06	8.64	8.36	8.76	8.54	9.13
Mean	8.13	8.67	8.22	8.71	8.42	8.98
Mean Deviation	0.047	0.051	0.097	0.083	0.077	0.117
Standard Deviation	0.050	0.054	0.103	0.090	0.085	0.132
TP_1	9.09	9.31	8.94	9.12	8.91	9.09
TP_2	9.36	9.58	9.11	9.45	9.17	9.58
TP_3	8.54	8.90	9.24	9.63	9.16	9.51
Mean	9.00	9.26	9.10	9.40	9.08	9.39
Mean Deviation	0.303	0.243	0.103	0.187	0.113	0.113
Standard Deviation	0.341	0.280	0.123	0.211	0.120	0.216

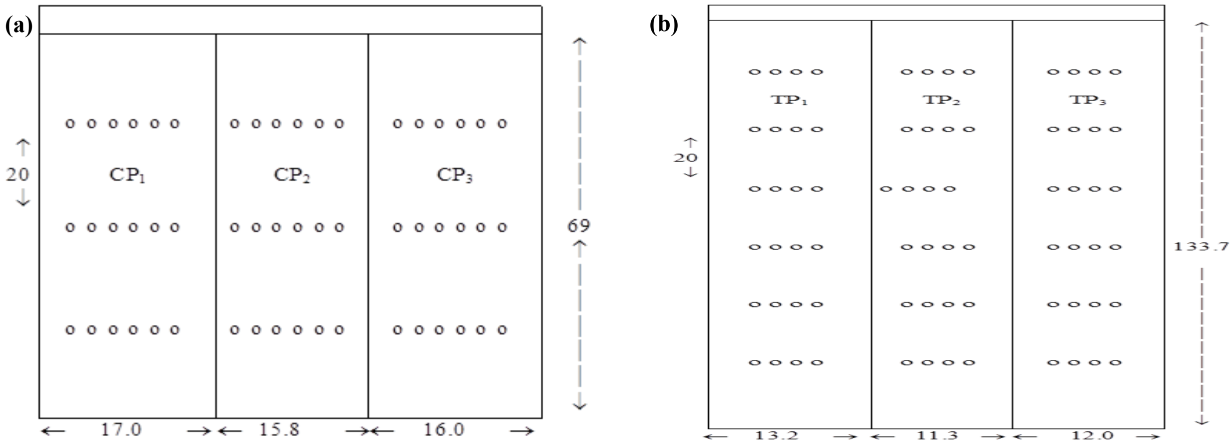


Fig.1. *Layout of the experiment field (a) using canal water (b) using tubewell water.*

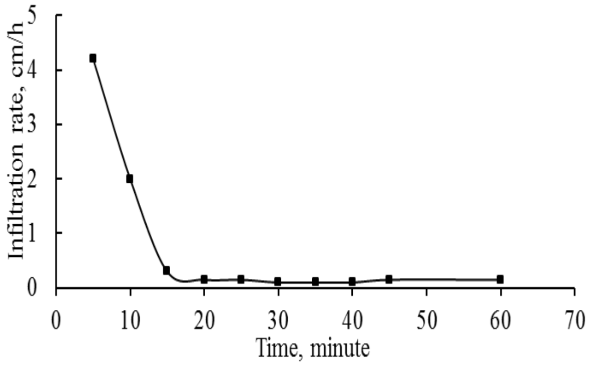
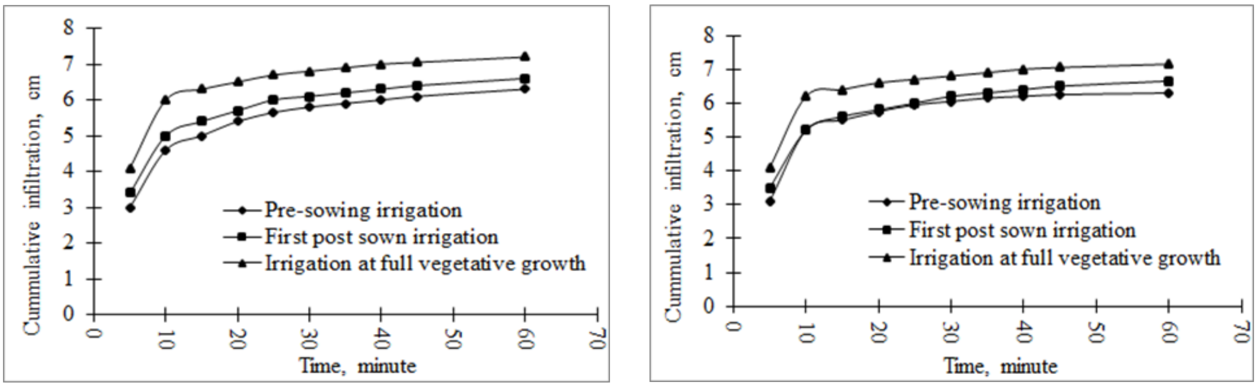


Fig. 2. *Instantaneous infiltration rate for field plot CP_2 before IIIrd irrigation.*

the infiltration rate decreased to relatively low value. Fig. 2 shows typical example of behavior of instantaneous infiltration rate observed for the selected fields. Similarly, Dagadu and Nimbalkar (2012) was studied infiltration of different soils under different soil conditions and found that infiltration rates against time initially high and then decreased with time up to constant infiltration rate. One of the reason for initial very high infiltration rate was the nature of soil texture and soil stratification in the selected field. The upper soil layer in the selected field was sandy loam upto 30 cm and sandy clay loam for 30-120 cm depth. Such a soil layers coupled with the decreased infiltration rate after 10-15 minutes may prove to be favorable for achieving high value of water distribution efficiencies under surface irrigation method. The water distribution efficiency was estimated for different irrigation events and its value was ranging between 91.37-98.18 percent, indicated a relatively high degree of uniformity of water application.

Required net depth (d_n): The cumulative depth of infiltration for 60 minute of some of the selected field plots is shown in Fig. 3. It can be observed that cumulative depth of infiltration for the same duration of 60 minutes increased during the growing season of crops i.e. cumulative depth of infiltration was less before first irrigation and more for last irrigation. The different infiltration behavior of different plots during different irrigation events highlight the importance of infiltration measurement before each irrigation. For instance, consider plot CP_2 the predicted applied depth of water for IIIrd irrigation at 0 m distance is 8.28 cm using the infiltration characteristics measured just before IIIrd irrigation. If one uses the infiltration characteristics measured just before Ist irrigation to predict the applied depth of water for IIIrd irrigation at 0 m it would be 7.61 cm. Therefore, it is important to have infor-



(a) Canal irrigated

(b) Tubewell irrigated

Fig. 3. *Cumulative infiltration depth (d_i) of selected field plots*.

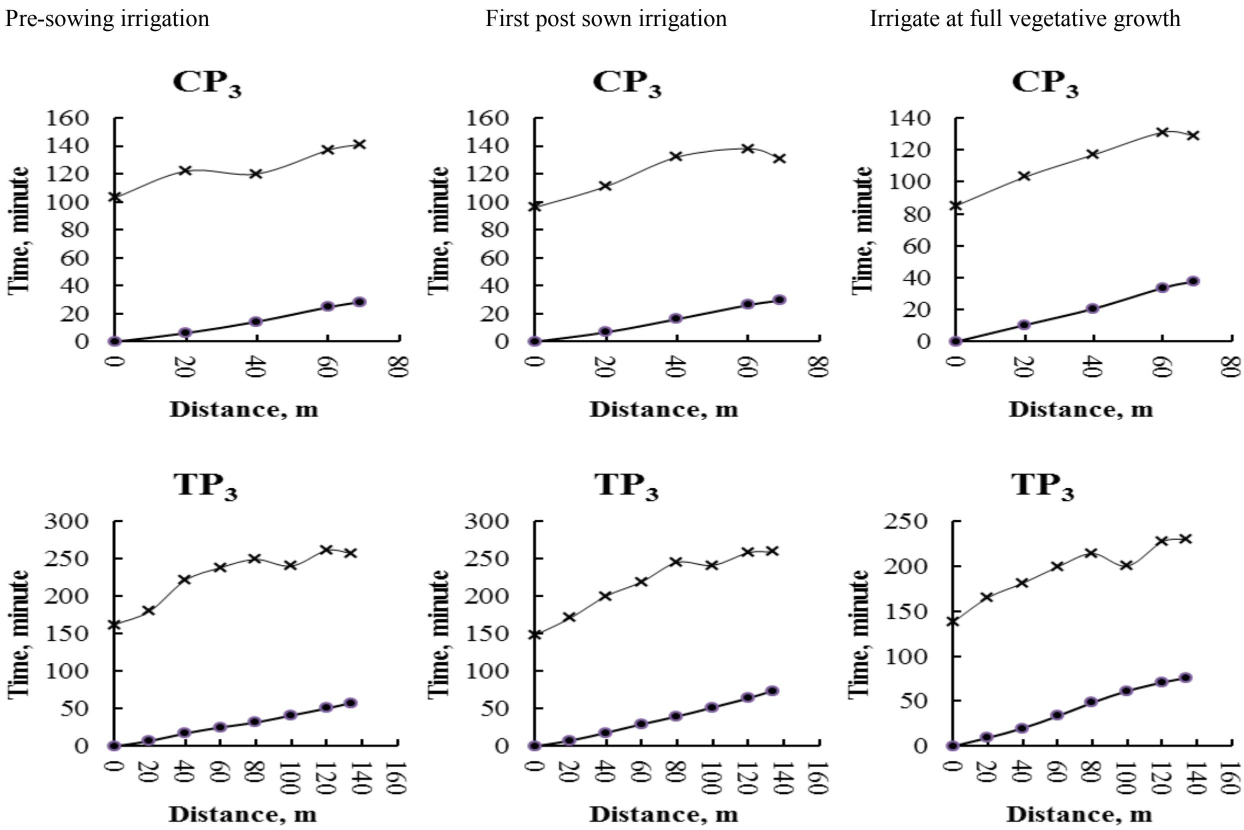


Fig. 4. *Advance (•) and recession (×) curve for different irrigation events when using canal and tubewell water.*

mation on infiltration characteristics just before the irrigation.

Estimation of required net depth of irrigation depends upon the field capacity, bulk density, moisture content before irrigation and rootzone depth. The required net depth of irrigation was estimated separately for different border strips as well as for different irrigation events and is given in Table 2. The largest d_n value was observed for pre-sowing irrigation. As expected, more moisture was depleted from shallow layers (0-15 cm) as compared to deeper layers (Yang *et al.*, 2012). For instance before pre-sown irrigation, top 15 cm soil layer (0-15 cm) for CP_1 plot showed 2.69 cm of moisture deficit (1.79 mm/cm depth) while the bottom 30 cm soil layer (90-120 cm) showed 2.05 cm of moisture deficit (0.68 mm/cm depth). One of the reason for more moisture depletion from shallow depth is direct evaporation from surface layer. However similar trend was also observed at the time of full vegetative stage (IIIrd) irrigation, indicating that crop is also preferably using more moisture from shallow depths as compared to deeper depths.

Water advance and recession: Water advance and recession curves for different field plots during different irrigation events were prepared and these curves for plot CP_3 and TP_3 are shown in Fig. 4. In general, advance time increased with growing season. In canal irrigated plotCP_1, advance time increased slightly from 30.28 to 32.24 minutes (Table 3) for Ist to IInd irrigation, despite higher inflow stream size during IInd irrigation (52 lps) as compared to Ist irrigation (48.2 lps). But advance time increased tremendously from 32.24 to 39.65 minutes from IInd to IIIrd irrigation. Similar results were also obtained in plots CP_2 and CP_3. This may be due to increase in infiltration rate from Ist to IInd irrigation as well as increased resistance to flow by the growing crops. In tubewell irrigated plot TP_1, advance time increased from 65.32 to 79.67 minutes from Ist to IInd irrigation but its value remained nearly equal afterward from the time of the first post sown irrigation to full vegetative growth. Similar results were also obtained in plots TP_2 and TP_3. In both, canal and tubewell irrigated plots, the advance time increased with growing season but it increased more from II to III irrigation in canal irrigated plots, whereas, it increased more from I to II irrigation in tubewell irrigated plots. This may be due to low water supply rate in tubewell irrigated (33 lps) plot than canal irrigated (48 lps) plot. In general, recession time decreased with growing season. For instance in field plotCP_1 and TP_1 recession time decreased from 140 to 123 and 261 to 226 minutes (Table 3) for Ist to IIIrd irrigation, respectively. This is due to increase in infiltration rate from Ist to IIIrd irrigation.

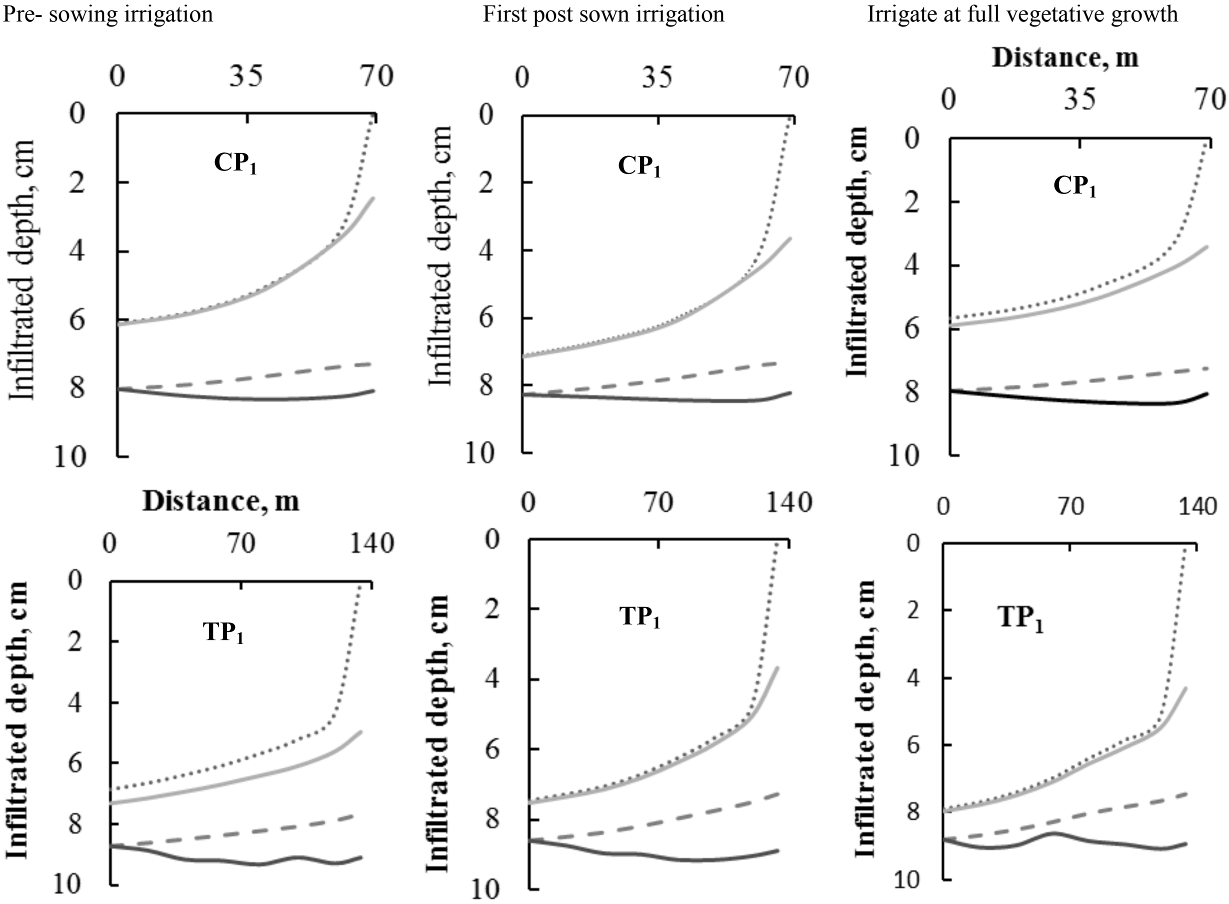


Fig. 5. *Infiltrated water depth (end of advance stage (••••), end of storage (——-), end of depletion (– – –) and end of .recession stage (———) using canal and tubewell water.*

Infiltration opportunity time and applied depth of irrigation: Infiltration opportunity time (computed as difference of water advance and recession time) and applied depth of irrigation (computed based on cumulative infiltration depth and time relationship) was estimated for the all plots at different points along the length. Properly designed border irrigation aims at achieving a uniform infiltration opportunity time throughout the entire length of the field to apply a uniform depth of water (Michael, 2008). Observed infiltration opportunity time for most of the studied field plots (canal and tubewell irrigated) was quite uniform

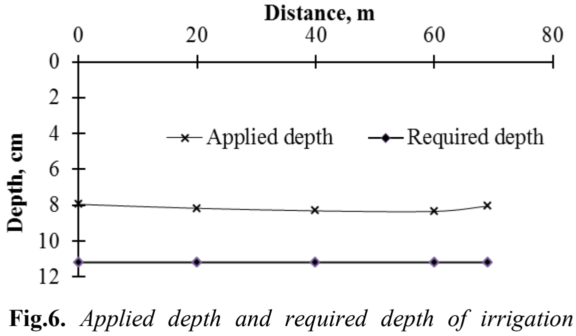


Fig.6. *Applied depth and required depth of irrigation forCP$_1$for cotton field.*

with respect to irrigation number except at few locations in some of the fields. But its value decreased from 111.82 to 90.75 and 195.66 to 152.04 minutes in canal and tubewell irrigated plots with the maturity of the crop (i.e.Pre-sowing irrigationto Irrigation at Full vegetative growth). Likewise, the applied depth of irrigation, throughout different field plots also showed quite a uniform application. Its mean value increased from 8.13 to 8.42 and 9.00 to 9.08 cm in canal and tubewell irrigated plots with the maturity of the crop (Table 4). In general, observed infiltration opportunity time decreased with the growing season. However, decreased infiltration opportunity time could not cause corresponding decrease in the applied depth of water due to increased infiltration rate with growing season.

Slight difference in the depth of water applied (as estimated based on infiltration opportunity time) and depth of water delivered (as estimated based on inflow stream discharge and cutoff time) was also observed. The estimated applied depth was always less than the depth of water delivered to the field. The difference in applied and delivered depth may be attributed to (i) conveyance losses in the channel reach from point of discharge measurement to the field (ii) spatial variability in the infiltration characteristics of the soil. The

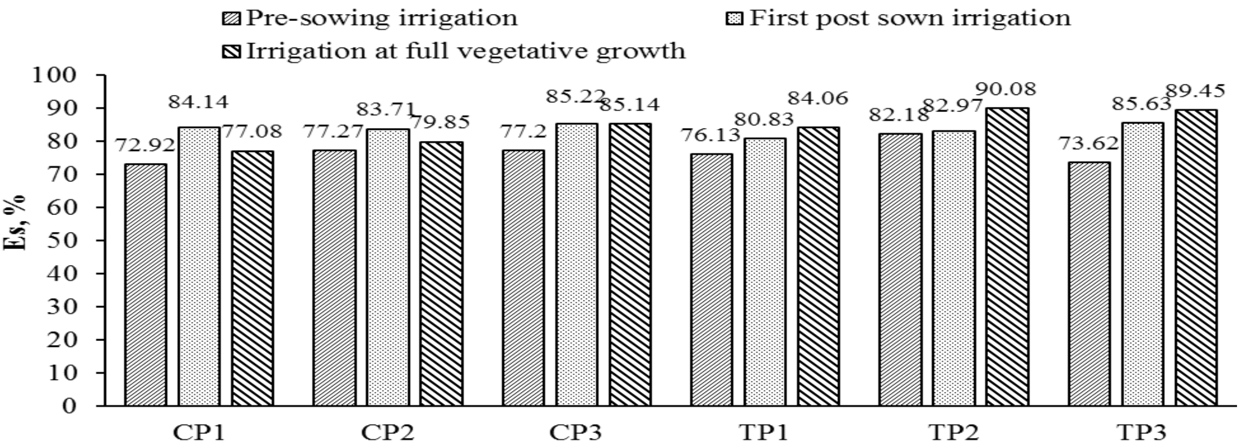


Fig.7.*Water storage efficiency for cotton crop for different irrigation events.*

discharge measurements for canal water, was made in the lined portion of the water course which was about 150 m away from the irrigated field. The tubewell was located very close to irrigated fields. Accordingly, the difference between the estimated applied depth and delivered depth is less in case of tubewell irrigation as compared to canal irrigation.

Water application depth during different stages of irrigation events: The applied water depths at the end of advance, storage, depletion andrecession stagein different plotswere estimated and graphs were prepared to observe under which stage, more was infiltrated into the soil. The graphs for applied water depths in CP_1 and TP_1 plots under the three different irrigations are shown in Fig. 5.At the upstream end, of the total water depth infiltrated, most of the depth infiltrated during advance stage followed by depletion stage. At the downstream end, storage and depletion stage contributed the major share of total depth of water infiltrated.

Water application efficiency: The applied depth of water was less than the required depth for all irrigation events. As a typical example, the applied and required depth for plot CP_1 is shown in Fig. 6 and similar results were obtained in other plots of canal and tubewell irrigated. Since there was no deep percolation loss due to under irrigation, the water application efficiency was 100% for all the plots.

Water storage efficiency: As observed earlier, the farmer under irrigated all the cotton fields, therefore, the water storage efficiencies was less than 100% (Fig. 7). In canal irrigated plots, the lowest water storage efficiency (72.92 per cent) was observed for Ist irrigation (pre-sown irrigation), whereas, in tubewell irrigated plots, the lowest water storage efficiency (73.62 per cent) was observed for IIIrd irrigation (Irrigation at Full vegetative growth). Observed water storage efficiency in different cotton fields varied from 72.92-90.08 per cent indicating different degrees of deficit irrigation to cotton crop.

Conclusion

Stratified soil profile (Sandy loam: 0-30 cm and Sandy clay loam: 30-120 cm) of the selected fields caused the infiltration rate to reduce to relatively very low value after 10-15 minutes creating favorable condition for uniformity of water application under surface irrigation, particularly where the required infiltration opportunity time is more than 15 minutes. Periodic moisture measurements showed that cotton utilised more water from shallow depths as compared to deeper depths. Changes in the cumulative depth of water infiltrated, for a given time, during the growing season of cotton suggested the need to determine infiltration characteristics immediately before each irrigation for performance evaluation. Observed advance time increased during the growing season due to increased infiltration rate and increased resistance to flow by the growing crops. The observed water application efficiency of different cotton fields was 100 % as applied depth of irrigation was less than the required depth throughout the field plots.

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