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Research Paper

Agronomic strategies for sustainable use of poor quality water in wheat (*Triticum aestivum*) and hybrid *Bt* cotton (*Gossypium hirsutum*) in a calcareous soil

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ABSTRACT

A field experiment was conducted from 2005–06 to 2008–09 on calcareous soil in semi-arid area, to evaluate the response of each furrow and alternate furrow irrigation in wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.]–hybrid *Bt* cotton (*Gossypium hirsutum* L.) cropping system using irrigation waters of different qualities. Irrigation was applied to each and alternate furrow on bed-planted wheat followed by cotton for comparison with standard check-basin method of irrigation to both the crops. Three water qualities, namely good quality water (GW), saline-sodic water (SSW) and pre-sowing irrigation to each crop with GW and all subsequent irrigations with SSW (GWpsi+SSW), were evaluated under 3 methods of irrigation (check-basin, each furrow and alternate furrow). The pooled results over 3 years revealed that wheat grain yield was not affected significantly by the quality of irrigation water. However, significant wheat yield reduction was observed in alternate bed irrigation in all the water qualities. In hybrid Bt cotton, saline sodic water significantly reduced the seed-cotton yield in all the 3 methods of planting. The pre-sowing irrigation with GW and all subsequent irrigations with saline sodic water improved the seed-cotton yield as compared to the application of saline sodic water alone. However, in alternate furrow the yield increase was significant and the yield obtained was equal to the yield under alternate furrow in GW. Reduced use of irrigation water under alternate furrow resulted in 21, 21 and 25% higher water-use efficiency in wheat under GW, SSW and GWpsi+SSW respectively. The corresponding increase under Bt cotton was 28, 19 and 36%.

Key words: *Bt* cotton, Cropping system, Good quality water, Saline sodic water, Wheat

The development of *Bt* cotton represents a significant technological landmark in the global cotton research. India adopted this technology in 2002–03 and derived the greatest benefit from the insect-resistance trait. Results of studies have indicated multiple benefits from the adoption of *Bt* cotton including increase in yield, decreased production costs, reduction in pesticide use and plant-protection costs, improved population of beneficial insects, substantial environmental and health benefits to farmer along with socio-economic benefits. However, to sustain the benefits of *Bt* cotton, effective management of irrigation water would be crucial. In Indo-Gangetic plains where the soils of cotton growing region are light in texture and underground water is brackish, drip irrigation to cotton is at experimental stage (Thind *et al*., 2008; Aujla *et al*., 2008). At present farmers' grow cotton in rotation with wheat by applying 4–5 irrigations to each crop through flood-irrigation method. In this region, the only source of good quality water for irrigation is river water supplied through canals. There is great need for judicious use of canal water because excess usage causes deep percolation resulting in high water table and secondary salinization (Datta and de Jong, 2002). Surface irrigation with poor quality waters usually leads build up of salinity and sodicity problems and thus causes reduction in crop yields (Choudhary and Ghuman, 2008). It has been emphasized that when poor quality waters are used for irrigation due attention should be given to minimize root-zone salinity. It has also been advocated that there is great need for selection and use of appropriate irrigation systems and practices that will supply just sufficient quantity of water to the root-zone to meet the evaporative demand and minimize salt accumulation in the root-zone (Munns, 2002). Higher yield potential and water-use efficiency were obtained under alternate furrow irrigation than each furrow irrigation in cotton (Stone *et al*., 1982). Irrigation with sodic waters high in carbonates and bicarbonates increases soil pH and sodium

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saturation of soils. Under such situations, it is suggested that for successful use of saline sodic waters, crops that are semi-tolerant to tolerant (wheat, cotton, mustards) as well as those with low water requirement should be grown (Minhas *et al*., 2004). When using poor quality waters, the period of germination and emergence of the seedlings is the most critical stage of crop growth and crops can tolerate higher salinity once good quality water was substituted for pre-sowing irrigation to leach out the salts of seeding zone (Boumans *et al*., 1988). Furthermore, the deleterious effects of poor quality water are reduced in calcareous soils as Na saturation of the soil is retarded due to higher amount of inherent $CaCO_3$ (Choudhary *et al*., 2011). Ahmed *et al*. (2006) concluded that smaller amounts of gypsum are required for reclamation of calcareous saline-sodic soil than non-calcareous saline-sodic soil.

Therefore, there is need to adopt specialized and efficient methods of irrigation which can help in attaining the twin objectives of higher productivity and rational use of poor quality water. The present investigation was undertaken to evaluate the response of each and alternate furrow irrigation in *Bt* cotton and wheat using good quality canal water and saline-sodic groundwater in a calcareous soil.

MATERIALS AND METHODS

A 3-year field study was conducted at Research Farm of Regional Station, Punjab Agricultural University, Bathinda (30°9’ N and 74°56’E; 211 m above sea-level), Punjab from 2005–09. The site is semi-arid (dry), with mean rainfall of 401 mm. Rainfall is monsoonal in nature, 70–80% is received during July–August and September which coincide with the active growing season of *Bt* cotton. The soil belongs to the Gehri Bhagi series (mixed, hyperthermic, Ustochreptic Camborthid) and has loamy sand texture. The organic carbon content of the surface soil layer (0–15 cm) was 0.28% and $CaCO_3$ 4.46%. Soil pH and electrical conductivity determined in 1:2 soil water suspension was 8.48 and 0.145 dS/m respectively. The available phosphorus and available potassium in the surface layer were 14.2 and 361 kg/ha respectively. The soil in the experimental field had no salinity or drainage problem and the watertable was deeper than 8.0 m; thus, it does not interfere in the root zone.

In wheat, flat sowing was compared with bed planting where each furrow or alternate furrow was irrigated. Similarly, in cotton, flat sowing was compared with ridge planting where each and alternate furrow was irrigated. The experiment was laid out in split-plot design with 3 water qualities in main plots and 3 methods of irrigation in subplots with 3 replications. Three water qualities in main plots were; good quality canal water: (GW), saline-sodic underground water (SSW) and pre-sowing irrigation (psi) to each crop with GW and all subsequent irrigations with SSW (GWpsi + SSW). Three methods of irrigation in subplots were: check basin (CB), each furrow (EF) and alternate furrow (AF). Under check-basin method of irrigation, the irrigations were based on 0.9 and 0.4 ratio between fixed depth (7.5 cm) of irrigation water and net cumulative pan evaporation since previous irrigation (PAN-E minus rainfall) in wheat and cotton respectively (Prihar and Sandhu, 1987). In check-basin irrigation, 7.5 cm irrigation water was applied for each irrigation by using Parshall flume; however, the water depth was 5.5 and 4.0 cm in EF and AF on total area basis in all the water qualities.

Wheat was planted with bed planter, in which 2 rows were sown 22.5 cm apart on 37.5 cm wide bed. The width of furrow between 2 beds was 30 cm. After wheat harvesting, these beds were converted to ridges spaced 67.5 cm and *Bt* cotton was planted with cotton planter by keeping plant-to-plant spacing of 90 cm. Sub plot size was 5.40 m × 19.80 m and area harvested was 4.05 m × 18.0 m. After cotton harvesting, fresh beds were prepared for wheat after ploughing the field. The details about the amount of rainfall received during each crop, water quality of SSW and GW, quantity of irrigation water applied, varieties of wheat and cotton sown during different years along with dates of sowing and harvesting are given in Table 1. The recommended amounts of fertilizers applied to wheat and cotton were 120 kg N and 26 kg P/ha and 150 kg N and 13 kg P/ha, respectively and these amounts were applied to all the plots. All the phosphatic fertilizers were drilled before sowing of wheat and cotton crop. In wheat, half N was applied at sowing and remaining half at the time of first irrigation at crown-root-initiation stage. In *Bt* cotton, half N was applied by broadcasting at the time of first irrigation (42 days after sowing) and the remaining at 50% flowering stage of the crop. Recommended practices were followed to control weeds and pests. Wheat grain yield and seed-cotton yield (lint + seed) were recorded in each plot after maturity of the crop. Surface (0–15 cm) soil samples were collected and analyzed for salinity (EC) and sodicity (pH) after each crop rotation. Soil pH and EC were measured in the 1:2 soil: water suspension.

Water-use efficiency (WUE) was calculated from total water use and economic yield. Water use is the sum of irrigation water, soil profile water used and rainfall received during the season. For determining soil water used by the crop, soil profile water content was measured at the time of sowing and at harvesting in 0–180 cm soil by thermo-gravimetric method in each crop. For soil water determination, soil samples were collected from 0–15, 15–30, 30–60, 60–90, 90–120, 120–150 and 150–180 cm depths. For each soil sample, the soil was collected randomly from 3 locations, representing top of ridge, middle of ridge and centre of furrow in each plot and mixed together for each depth, and a representative sample for each depth was taken for determination of soil water content in each replication to take care of variation in soil water content among plots. The profile water used by these crops was calculated by the difference method (available water at sowing minus available water at crop harvest) in 0–180 cm soil profile. For computing water-use efficiency (WUE), economic yields (air-dried wheat grain yield and seed-cotton yield) per hectare were divided by total water use and expressed as kg/m^3. Results were statistically analysed using standard procedures for split plot design. Means were compared using least significant differences (LSD) at the 5% probability level.

RESULTS AND DISCUSSION

The results pooled over 3 years revealed that wheat grain yield was not significantly different in check-basin (CB) and each furrow (EF) under all the 3 water qualities (Table 2). However, alternate furrow (AF) irrigation significantly reduced the wheat grain yield compared with respective CB and EF irrigation under all the 3 water qualities. The wheat yield reduction in AF as compared with CB was 11.9, 13.4 and 13.9% in GW, SSW and GWpsi + SSW respectively. However, the wheat grain yield was not affected with quality of irrigation water under all the 3 methods of irrigation. On the other hand, mean seed-cotton yield was not affected significantly by methods of irrigation under respective irrigation water quality in GW and SSW. But the use of SSW to cotton significantly reduced the seed-cotton yield in all the methods of irrigation as compared with these treatments under GW. However, a significant yield increase was observed under EF and AF as compared with CB when both waters were used in combination (GWpsi + SSW). The yield obtained in AF under GWpsi + SSW was comparable with yield obtained under GW in all the methods of irrigation.

Table 1. Rainfall, irrigation water quality cultural practices and irrigation water applied during different years of experimentation

	Year of experimentation			Mean
	Ist Year	IInd Year	IIrd Year	
Rainfall (mm)				
Wheat season	63	135	33	77
Cotton season	371	245	345	320
Water quality				
Saline-sodic water (SSW)				
EC (dS/m)*	2.30	2.20	2.20	2.23
RSC ($mmol_c$/litre)**	5.81	5.89	5.85	5.85
Good quality water (GW)				
EC (dS/m)*	0.49	0.55	0.52	0.52
RSC ($mmol_c$/litre)**	0.0	0.0	0.0	0.0
Irrigation water applied (mm)				
Wheat				
Check basin (CB)	300	225	375	300
Each furrow (EF)	220	165	275	220
Alternate furrow(AF)	160	120	200	160
Bt Cotton				
Check basin (CB)	300	300	300	300
Each furrow (EF)	225	225	225	225
Alternate furrow(AF)	160	160	160	160
Crop varieties, dates of sowing and harvesting				
Wheat				
Year	2005–06	2006–07	2007–08	
Variety	'PBW 502'	'PBW 502'	'PBW 502'	-
Date of sowing	03 December 2005	15 November 2006	20 November 2007	-
Date of harvesting	09 April 2006	09 April 2007	11 April 2008	-
Bt Cotton				
Year	2006–07	2007–08	2008–09	
Variety	'RCH 134' *Bt*	'RCH 134' *Bt*	'RCH 134' *Bt*	-
Date of sowing	24 April 2006	01 May 2007	13 May 2008	-
Date of harvesting	02 November 2006	02 November 2007	03 November 2008	-

*EC, Electrical conductivity; **RSC, residual sodium carbonate (CO_3^{2-} + HCO_3^-) – (Ca^{2+} + Mg^{2+}) (all cations and anions in $mmol_c$/litre)

The results revealed that AF in cotton, when irrigated with GW and SSW, resulted similar seed-cotton yield as produced in CB and EF under respective irrigation water quality.

In AF, one row of cotton is grown on each furrow thus each row received the water from one side, which proved to be sufficient for its requirement. The results showed that under these water qualities (GW and SSW) about the same seed-cotton yield can be obtained in AF with 47% less irrigation water than was applied in CB and with 25% less than in EF. Tang *et al.* (2005) also observed that AF required up to 30% less irrigation water as compared with EF irrigation without significant reduction in seed cotton yield. They further observed that stomatal conductance was lower in AF irrigation of cotton than in EF irrigation in early days after each irrigation but leaf water potential was comparable between both the treatments during whole crop season thus seed-cotton yield was comparable with both the treatments. The results revealed that higher rainfall during wheat season 2006–07 (Table 1) improved the wheat grain yield, whereas reduced rainfall in subsequent cotton season caused a spectacular decrease in seed-cotton yield.

The results of wheat indicated that without causing significant yield loss, 27% less irrigation water can be applied in EF than in CB. However, when 47% less water was applied in AF than in CB, significant reduction in wheat grain yield was recorded under GW (12%) as well as under SSW (13%). This significant reduction might be due to water stress experienced by 2 rows adjacent to un-irrigated furrow as EF was having 2 rows of wheat crop. It is evident that use of poor quality irrigation water failed to adversely affect the wheat grain in this calcareous soil. Recently, Choudhary *et al.* (2011) also observed that wheat yield was not affected significantly up to 9 years in a calcareous soil irrigated with sodic water having even higher sodicity (residual sodium carbonate 10 $mmol_c$/litre). Pre-sowing irrigation with good quality water (in GWpsi + SSW treatment) improved the seed-cotton yield as compared to SSW alone. This might be due to leaching of salts with good quality pre-sowing irrigation and thus providing favourable conditions for seed germination and seedling establishment, and enabling the cotton to withstand unfavourable conditions during subsequent crop-growth period (Boumans *et al*., 1988). Under GWpsi + SSW, AF irrigation resulted similar seed-cotton yield compared to CB but applied only 53% SSW. Lower salt-load in AF irrigation under GWpsi + SSW might be the reason for significantly higher seed-cotton yield compared with SSW and equal with GW. The combined use of GW and SSW (GWpsi + SSW) under AF fulfils the twin objectives of higher water-use efficiency and sustainable use of saline-sodic water. System productivity (Table 4) recorded was the ghiehst in EF irrigated with good quality water (GW), which was 1.9% higher than CB irrigated with same quality of water. EF and CB irrigation with GW resulted in 4.5 and 2.6% higher system productivity than AF respectively. The lowest system productivity was recorded in AF irrigated with SSW, which was 11.3% less than AF irrigation with GWpsi + SSW. The results revealed that pre-sowing irrigation must be given with good quality (GW) water before using saline-sodic water in cotton.

Table 2. Wheat grain yield and seed-cotton yield (t/ha) during different years of experimentation as influenced by irrigation water quality and methods of irrigation

Treatment*		Year of experimentation			Mean
Qualities	Methods	Ist Year	IInd Year	IIIrd Year	
Wheat					
GW	CB	3.69	3.81	3.25	3.59
	EF	3.43	3.72	3.06	3.41
	AF	2.18	4..00	3.29	3.16
SSW	CB	3.23	3.79	3.83	3.66
	EF	3.22	3.76	3.68	3.56
	AF	2.21	3.78	3.42	3.14
GWpsi + SSW	CB	3.23	4.25	3.11	3.53
	EF	2.82	4.16	3.15	3.38
	AF	2.50	3.63	3.00	3.04
SEm±		0.11	0.03	0.02	0.06
CD (P=0.05)		0.32	0.11	0.08	0.18
Bt cotton					
GW	CB	3.40	2.16	2.76	2.77
	EF	3.57	2.12	3.11	2.93
	AF	3.43	2.15	2.97	2.85
SSW	CB	3.16	1.50	2.48	2.38
	EF	3.39	1.23	2.68	2.43
	AF	2.85	1.51	2.52	2.29
GWpsi + SSW	CB	3.23	1.41	2.59	2.41
	EF	3.45	1.55	3.00	2.67
	AF	3.54	1.93	2.76	2.74
SEm±		0.10	0.06	0.06	0.07
CD (P=0.05)		0.30	0.20	NS	0.21

*GW, Good water; SSW, saline-sodic water; GWpsi + SSW, pre-sowing irrigation with GW and subsequent irrigations with SSW; CB, check basin; EF, each furrow; AF, alternate furrow

Soil properties

The application of SSW caused a spectacular increase in soil pH and electrical conductivity (EC) (Table 3). The increase was highest in CB followed by EF and AF irrigation, which followed the pattern of quantity of irrigation water applied. On the other hand, EC has increased progressively during all the years of saline-sodic water application although the small changes indicate equilibration in

Table 3. Mean profile water use, total water use and water-use efficiency as influenced by irrigation water quality and methods of irrigation (pooled over 3 years)

Treatment	Profile water use	Total water use (mm)	Water-use efficiency (kg/m^3)
Qualities Methods			
Wheat			
GW			
CB	58	491	0.84
EF	71	401	0.94
AF	70	330	1.02
SSW			
CB	62	488	0.83
EF	71	401	0.97
AC	73	324	1.00
GWpsi + SSW			
CB	62	486	0.80
EF	70	376	0.97
AF	69	336	1.00
SEm±	1.8	13.8	0.03
CD (P=0.05)	5.6	41.7	0.081
Bt. cotton			
GW			
CB	207	935	0.32
EF	192	862	0.39
AF	211	512	0.41
SSW			
CB	220	939	0.27
EF	213	840	0.31
AF	208	786	0.32
GWpsi + SSW			
CB	218	931	0.28
EF	204	832	0.34
AF	229	789	0.38
SEm±	4.22	26.16	0.01
CD (P=0.05)	12.7	78.7	0.03

*GW, Good water; SSW, saline-sodic water; GWpsi + SSW, pre-sowing irrigation with GW and subsequent irrigations with SSW; CB, check basin; EF, each furrow; AF, alternate furrow

the soil. The deleterious effects of SSW were significant in cotton although cotton crop is grown during monsoonal rainy season which received large amounts of rainwater (Table 2). Suarez *et al*. (2006) observed that under a combined rain-irrigation water use, the soil may go from relatively saline condition to a non-saline condition in the upper part of the profile after a significant rain. Under such conditions the decrease in sodium adsorption ratio (SAR) will be slower than the decrease in EC. This condition causes a potential sodium hazard leading to dispersion, loss of aggregate stability and decrease in infiltration rate during the rain event. It seems that monsoonal rainfall during cotton growth may be responsible for higher yield reduction than occurs with wheat owing to sodium hazard that exists when irrigated with saline-sodic water (Suarez *et al*., 2006) but the presence of $CaCO_3$ might have reduced the adverse effects. Small increase in soil pH may be ascribed to mobilization of Ca from inherent $CaCO_3$ present in the soil.

Water productivity

The total water use under different treatments was calculated from profile water use, irrigation water applied and rainfall received, and is presented in Table 4. The mean total water use in wheat was the highest in CB followed by EF and AF under all the 3 water qualities. The pattern of total water-use was similar in cotton, however, it was almost double in cotton than wheat. High total water use in cotton is mainly attributed to higher rainfall in the cotton season (Aujla *et al.,* 2008; Thind *et al.,* 2008). In wheat, mean water-use efficiency (WUE) increased significantly in EF as compared with CB and although it further increased in AF but increase was not significant in all the 3 water qualities. The increase in mean WUE under EF as compared with CB was 12% (from 0.84 to 0.94 kg/m^3), 17 and 21% under GW, SSW and GWpsi + SSW respectively. The corresponding increase in AF over CB was 21, 21 and 25%. On the other hand, WUE was not significantly affected with the quality of water in wheat because grain yield was not influenced with water quality. The WUE in cotton also increased significantly in EF as compared with CB in all the water qualities. However, further increase in AF was significant only in GWpsi + SSW. The application of SSW significantly reduced the WUE as compared with GW in all the methods of sowing. However, the application of GW as pre-sowing irrigation and all other irrigations with SSW (GWpsi + SSW) improved WUE over SSW. In cotton the extent of increase in WUE in EF and AF was higher than wheat. In AF increase in WUE as compared with CB was 28 (from 0.32 to 0.41 kg/m^3), 19 and 36% under GW, SSW and GWpsi + SSW respectively. The higher WUE with reduced irrigation water use indicates that there was comparatively lower reduction in yield than reduction in irrigation water applied. Similarly, higher WUE was observed in furrow irrigation than CB in transplanted *Brassica napus* (Buttar *et al*., 2006) and in eggplant (Aujla *et al*., 2007).

Economics

In wheat, the highest net returns were recorded in CB where irrigations were given with SSW, which was closely followed by CB where irrigations were given with GW (Table 5). The lowest net returns in wheat were recorded in AF with GWpsi + SSW. However, in cotton AF irrigation with SSW gave the lowest net returns. The maximum

Table 4. Effect of irrigation methods and quality of water on pH and electrical conductivity of the surface soil layer (0–15 cm) and system productivity under different treatment in cotton and wheat

Treatment Qualities	Methods	pH			EC (dS/m)			System productivity (t/ha)Mean
		Ist year	IInd year	III year	Ist year	IInd year	III year	
GW	CB	8.51	8.52	8.53	0.148	0.179	0.172	10.01
	EF	8.51	8.52	8.52	0.149	0.175	0.168	10.20
	AF	8.50	8.52	8.52	0.156	0.178	0.173	9.76
SSW	CB	8.62	8.66	8.72	0.302	0.335	0.349	9.13
	EF	8.60	8.64	8.70	0.291	0.315	0.322	9.19
	AF	8.59	8.62	8.65	0.289	0.309	0.315	8.44
GWpsi + SSW	CB	8.60	8.63	8.65	0.274	0.290	0.310	9.11
	EF	8.59	8.61	8.63	0.263	0.281	0.294	9.55
	AF	8.58	8.60	8.61	0.256	0.276	0.285	9.39

*GW, Good water; SSW, saline-sodic water; GWpsi + SSW, pre-sowing irrigation with GW and subsequent irrigations with SSW; CB, check basin; EF, each furrow; AF, alternate furrow

Table 5. Effect of irrigation methods and quality of water on economics under different treatments in cotton, wheat and cotton–wheat system

Treatments	Gross income (₹/ha)	Cost of cultivation (₹/ha)	Net profit (₹/ha)
Wheat			
GW			
CB	45,824	32,787	13,037
EF	43,648	33,162	10,486
AF	40,435	33,125	7,310
SSW			
CB	46,323	32,787	13,536
EF	45,517	33,162	12,355
AF	40,128	33,125	7,003
GWpsi + SSW			
CB	45,209	33,787	11,422
EF	43,200	34,162	9,038
AF	38,938	34,125	4,813
Bt cotton			
GW			
CB	69,300	53,828	15,522
EF	73,325	54,203	19,122
AF	71,300	54,166	17,134
SSW			
CB	59,575	53,828	5,747
EF	60,800	54,203	6,597
AF	57,300	54,166	3,134
GWpsi + SSW			
CB	60,300	54,828	5,472
EF	66,675	55,203	11,472
AF	68,575	55,166	13,409
Wheat-cotton system			
GW			
CB	1,15,124	86,615	28,559
EF	1,16,973	87,365	29,608
AF	1,11,735	87,291	24,444

Table 5. *Continued...*

Treatments	Gross income (₹/ha)	Cost of cultivation (₹/ha)	Net profit (₹/ha)
SSW			
CB	1,05,898	86,615	19,283
EF	1,06,317	87,365	18,952
AF	97,428	87,291	10,137
GWpsi + SSW			
CB	1,05,509	88,615	16,894
EF	1,09,875	89,365	20,510
AF	1,07,513	89,291	18,222

*GW, Good water; SSW, saline-sodic water; GWpsi + SSW, pre-sowing irrigation with GW and subsequent irrigations with SSW; CB, check basin; EF, each furrow; AF, alternate furrow

net returns in cotton were noticed in EF irrigated with GW. The economic data of cotton–wheat system revealed that GW irrigation in EF gave and maximum net returns and minimum in AF in SSW.

It was concluded that the application of saline-sodic water in *Bt* cotton significantly reduced the seed-cotton yield in all the 3 methods of planting. The pre-sowing irrigation with good quality water and all subsequent irrigations with saline-sodic water increased the seed-cotton yield over saline-sodic water alone.The increase was significant only in each furrow and alternate furrow irrigation methods, which was equal to yield obtained in good quality water. The results revealed that wheat grain yield was not affected significantly with quality of irrigation waters but significant yield reduction was observed in alternate furrow irrigation under all the 3 water qualities. Each furrow and alternate furrow irrigation resulted in 25 and 47 % saving in irrigation water in *Bt* cotton, whereas the corresponding potential "saving" in wheat was to the tune of 27 and 47% respectively.

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