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Planting configuration and levels of irrigation water effect on yield and water-use efficiency of hybrid *Bt* cotton (*Gossypium hirsutum*) under drip and check-basin irrigation*

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With reduced water availability for agricultural use, food security of future generations is at stake. Obviously, there is an urgent need to improve water-use efficiency of agricultural crops. The system of flood irrigation practised widely in South Asia must be replaced with furrow, drip or sub-irrigation systems (Lal, 2000; Buttar *et al.* 2006; Aujla *et al.* 2007) to reduce wastage of water. In a study on cotton, Aujla *et al.* (2005) observed that under drip irrigation, seed cotton yield increased by 32% and water use efficiency (WUE) increased by 26% under normal sowing compared with the check-basin irrigation. In paired sowing under drip, which saved 50% irrigation water and the cost of laterals, a decline of 9% in yield but there was 24% improvement in WUE compared with drip under normal sowing. Thus, the present investigation was undertaken to evaluate different planting configurations to improve the yield and water-use efficiency in recently introduced hybrid of *Bt* cotton (*Gossypium tirsutum* L.).

The field experiments were conducted during 2005 and 2006 at the Research Farm of the Punjab Agricultural University Regional Station, Bathinda, India (30º9' N and 74º56'E; altitude 211 m above sea level). The site was semi-arid (dry) with mean rainfall of 401 mm. The soil belongs to the Gahri Bhagi series (mixed, hyperthermic, Ustochreptic camborthid) and has loamy sand texture. The organic carbon content of the surface soil layer (0–15 cm) was 0.19%, *p*H 8.5 and electrical conductivity 0.39 dS/m. The available nitrogen, phosphorus and potassium in the surface layer were 123, 13.7 and 324 kg/ha, respectively. The treatments comprised three levels of water under drip irrigation and three planting configurations under drip and check-basin irrigation. The methods of planting were: normal sowing with row-to-row spacing of 67.5 cm, normal paired row sowing with row-to-row spacing of 35 and 100 cm alternately so that the total number of rows remained the same and dense paired sowing with row-to-row spacing of 35 and 55 cm alternately, so that the total number of rows were 1.5 times greater than in the normal sowing and normal paired treatments.

The optimum IW/CPE is 0.4 for cotton grown on loamy sand soils. Thus 7.5 cm of irrigation water was applied using a Parshall flume in all the three methods of planting under check-basin. Under drip irrigation three water levels equivalent to CPE of 0.4, 0.3 and 0.2 were tried under normal sowing conditions. In normal sowing there was one lateral along each row while in paired sowings there was one lateral between 2 rows of each pair. Thus laterals required were 50% and 75% in normal paired and dense paired, respectively as compared with normal sowing. Due to variation in number of laterals, water delivered was proportional to the number of laterals as the water flow was constant in all laterals. Consequently the quantity of water delivered was 50% and 75% in normal paired and dense paired, respectively, compared with normal sowing under each irrigation water level tried.

The experiment was conducted in a split-plot design with methods of planting as main-plots and water levels as sub-plots having three replications. Plant-to-plant spacing was 75 cm in all treatments and sub-plot size was 5.40 m × 15.0 m. The hybrid 'RCH 134' *Bt* cotton (*Gossypium hirsutum* L.) was sown during both years. In check-basin irrigation, half the recommended N of 150 kg/ ha was applied at the time of first irrigation and the remaining half was applied at flowering. All the phosphorus (30 kg P_2O_5/ ha) was drilled before sowing in all treatments. In drip irrigation, N was applied at 10-days interval in six equal splits of N 25 kg/ ha starting from 30 days after sowing (DAS). For determining soil water used by the crop, soil profile water content was measured at sowing and at harvest in 0–180 cm of soil by

*Short note

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Table 1 Effect of methods of planting and amount of irrigation water on seed cotton yield and stick weight during different years

Treatment	Seed cotton yield (kg/ha)	Cotton stick weight (kg/ha)	Harvest index	Seed cotton yield (kg/ha)	Cotton stick weight (kg/ha)	Harvest index
		2005			*2006*	
$CB_{0.4}$ NS_{100}	3 193	8 057	0.396	4 263	10 247	0.416
$DP_{!00}$	3 435	8 449	0.407	4 678	10 904	0.429
NP_{100}	3 098	7 768	0.399	3 908	9 555	0.409
$D_{0.4}$ NS_{100}	3 391	8 367	0.405	4 456	10 509	0.424
DP_{75}	3 791	9 313	0.407	4 714	10 812	0.436
NP_{50}	3 384	8 447	0.401	4 216	9 897	0.426
$D_{0.3}$ NS_{75}	3 344	7 408	0.451	4 175	9 319	0.448
DP_{56}	3 696	8 447	0.449	4 283	9 331	0.459
NP_{38}	3 195	7 213	0.470	4 116	8 795	0.468
$D_{0.2}$ NS_{50}	2 998	7 169	0.418	4 021	9 139	0.440
DP_{38}	3 302	8 374	0.394	4 164	8 878	0.469
NP_{25}	2 950	7 056	0.432	3 670	8 137	0.451
LSD (*P*=0.05)						
Method	157.0	NS	0.019	134.3	NS	0.023
Water	124.2	NS	0.015	101.4	NS	0.019
Interaction	194.4	391.1	0.030	162.3	478.2	0.033

the thermo-gravimetric method (Prihar and Sandhu 1987). The profile water used by cotton was calculated by the difference method (available water at sowing minus available water at crop harvest) in the 0–180 cm soil profile. Total rainfall during the season was 532 mm and 371 mm during 2005 and 2006, respectively. For computing water use efficiency, seed cotton yields/ha were divided by total water use and expressed as kg/m^3.

Dense paired (DP_{100}) sowing under check-basin irrigation significantly increased the seed cotton yield from 3 193 to 3 435 kg/ ha (an increase of 8%) in 2005 and from 4 263 to 4 678 kg/ ha (an increase of 10%) in 2006 (Table 1). However, normal paired (NP_{100}) sowing under check-basin resulted in a decrease in seed cotton yield than normal sowing (NS_{100}) by 3% (3 098 from 3193 kg/ ha) and 9% (3 908 from 4 263 kg/ ha) in 2005 and 2006, respectively. When water equivalent to check-basin irrigation was applied through drip to normal sown crop (NS_{100} at $D_{0.4}$), a significantly higher seed cotton yield was produced than normal sowing under check-basin irrigation (NS_{100} at $CB_{0.4}$) in both the years. However, when the quantity of irrigation water in drip method was reduced to 75% to normal sown crop (NS_{75} at $D_{0.3}$), seed cotton yield was reduced by only 1% in 2005 and by 6% in 2006. Further reduction in irrigation water to 50% (NS_{50} at $D_{0.2}$) resulted in lowering of yield by 12% in 2005 and 10% in 2006 as compared to levels observed with NS_{100} at $D_{0.4}$.

Under dense paired sowing (DP_{75} at $D_{0.4}$), in which number of plants were 1.5 times than NS_{100} but the quantity of water applied was 25% less as compared with drip under normal sowing (NS_{100} at $D_{0.4}$), the seed cotton yield was significantly higher in both years. The reduction in quantity of water applied to dense paired sowings (DP_{56} and DP_{38}) reduced seed cotton yield by 3 and 13% in 2005 and by 9 and 12% in 2006 as compared with $DP_{75.}$ At all levels of water application, seed cotton yield was consistently higher under dense paired than normal sowing in both years, although irrigation water applied was 75% in DP as compared with NS.

Normal paired sowing under drip (NP_{50} at $D_{0.4}$) gave seed cotton yield to equivalent normal sowing (NS_{100} at $D_{0.4}$) in 2005 but in 2006 it produced significantly lower yield (4 216 from 4 456 kg/ha) although the amount of water applied under NP_{50} was 50% of used in normal sowing (NS_{100} at $D_{0.4}$). It is interesting to note that under normal paired sowing (NP_{50} at $D_{0.4}$) although the quantity of water applied was half compared with NP_{100} under check-basin, NP_{50} gave significantly higher seed cotton yield (an increase of 9 and 8%) in both the years. These results demonstrate the superiority of drip irrigation over check-basin for efficient water use and higher production.

Under check-basin method, higher number of plants (1.5 times) in dense paired than in normal sowing resulted in significant increase in stick biomass of 5 and 6% during 2005 and 2006, respectively. Drip irrigation under NS_{100} at $D_{0.4}$, where the quantity of water applied was equal to used in check-basin, resulted in an increase in stick weight of 4% in 2005 and 3% in 2006 than NS_{100} under check-basin. The harvest index (ratio of seed cotton yield to above ground stick biomass) in NS_{100} at $D_{0.4}$ was higher than in check-basin in both the years. The decrease in quantity of water applied through drip irrigation resulted in an increase in harvest index in all the methods of planting in both the years. The plant height was significantly higher under dense paired and under drip method of irrigation in both years (Table 2). The data further revealed that primary branches, secondary branches

Table 2 Effect of methods of planting and amount of irrigation water on yield-attributing characteristics during different years

Treatment	Plant height (cm)	Primary branches (m^2)	Secondary branches (m^2)	Number of bolls (m^2)	Plant height (cm)	Primary branches (m^2)	Secondary branches (m^2)	Number of bolls (m^2)
		2005				*2006*		
$CB_{0.4}$ NS_{100}	151	8.16	74	111	152	6.98	85	118
$DP_{!00}$165	9.57	91	151	172	9.48	111	158	
NP_{100}	168	6.97	69	110	155	6.59	83	107
$D_{0.4}$ NS_{100}	160	7.51	77	124	169	6.55	85	112
DP_{75} 167	9.48	106	155	186	9.88	116	160	
NP_{50} 168	7.25	76	119	155	6.93	69	97	
$D_{0.3}$ NS_{75}	161	7.64	84	117	166	5.27	65	99
DP_{56} 168	11.26	101	152	184	9.48	102	144	
NP_{38} 166	8.55	75	123	167	6.72	96	112	
$D_{0.2}$ NS_{50}	155	8.43	72	99	148	6.54	97	113
DP_{38} 163	9.27	111	137	176	10.27	107	145	
NP_{25} 159	7.51	73	108	169	6.54	83	116	
LSD (P=0.05)								
Method	NS	1.24	13.5	25.3	NS	1.12	11.6	22.7
Water	NS	0.85	NS	17.3	3.25	NS	NS	14.9
Interaction	7.0	1.48	17.6	29.3	5.62	1.33	14.3	25.1

Table 3 Effect of methods of planting and amount of irrigation water on water use and water-use efficiency during different years

Treatments	Irrigation water applied (mm)	Profile water use (mm)	Rainfall (mm)	Total water use (mm)	Water-use efficiency (kg/m^3)
			2005		
$CB_{0.4}$ NS_{100}	364	183	532	1079	0.296
$DP_{!00}$	364	138	532	1034	0.332
NP_{100}	364	177	532	1073	0.289
$D_{0.4}$ NS_{100}	364	165	532	1061	0.320
DP_{75}	273	214	532	1019	0.372
NP_{50}	182	203	532	947	0.369
$D_{0.3}$ NS_{75}	273	125	532	930	0.360
DP_{56}	205	220	532	957	0.397
NP_{38}	137	191	532	860	0.372
$D_{0.2}$ NS_{50}	182	189	532	903	0.332
DP_{38}	137	232	532	901	0.366
NP_{25}	91	216	532	839	0.353
			2006		
$CB_{0.4}$ NS_{100}	300	78	371	749	0.569
$DP_{!00}$	300	47	371	718	0.652
NP_{100}	300	51	371	722	0.541
$D_{0.4}$ NS_{100}	300	72	371	743	0.600
DP_{75}	225	62	371	658	0.716
NP_{50}	150	74	371	595	0.709
$D_{0.3}$ NS_{75}	225	78	371	674	0.619
DP_{56}	169	31	371	571	0.750
NP_{38}	113	91	371	575	0.716
$D_{0.2}$ NS_{50}	150	85	371	606	0.664
DP_{38}	113	67	371	551	0.756
NP_{25}	75	63	371	509	0.721

and number of bolls were significantly higher in dense paired as compared to normal sowing and normal paired under all the irrigation treatments. Drip irrigation is beneficial in water-scarce areas because optimum availability of water results in higher dry matter allocation to bolls (Mateos *et al.* 1991) as indicated by a higher harvest index under drip (NS_{100})

than check-basin (NS_{100}). Radin *et al.* (1989) observed that cotton yield increased as the interval between water applications decreased even if the amount of water was unchanged in the arid climate of Arizona.

As compared with NS_{100} under check-basin irrigation, DP_{100} resulted in an increase in WUE of 12 % (0.332 from 0.296 kg/ m^3) and 15% (0.652 from 0.569 kg/ m^3) in 2005 and 2006, respectively (Table 3). Drip irrigation under NS_{100} at $D_{0.4,}$ in which the same quantity of water was applied as in NS_{100} under check-basin, the WUE increased from 0.296 to 0.320 kg/ m^3 (an increase of 8%) in 2005 and from 0.569 to 0.600 kg/ m^3 (an increase of 5%) in 2006. The reduced use of water (25%) under DP_{75} as compared to in NS_{100} at $D_{0.4}$ improved WUE by 16 and 19% in 2005 and 2006, respectively, although the increase in corresponding seed cotton yield was only 12 and 6% (Table 2). Similarly, as compared with fertigation under NS_{100} reduction in irrigation water (50%) through drip irrigation under NP_{50} improved the WUE by 15 and 18% in 2005 and 2006, respectively. This is in spite of yield reductions of 0 and 5%. A comparison of DP_{75} and NS_{75} treatments where water applied was same, it was found that WUE was higher under DP_{75} by 3 and 16% in 2005 and 2006, respectively. Similarly, compared to NS_{50}, NP_{50} resulted in increased WUE by 20 and 7% in 2005 and 2006, respectively. Bozkurt *et al*. (2006) observed 24% higher WUE in corn when one lateral was placed between two rows alternately. They further observed that 33% deficit irrigation decreased the yield but did not affect WUE. However, our results showed further increase in WUE when water was reduced by 25% under all the methods of planting indicating that corresponding yield reduction was lower than the water reduction (25%).

SUMMARY

The field experiments were conducted in 2005 and 2006 to evaluate the effect of planting configurations and levels of irrigation water on seed cotton yield and water-use efficiency under drip irrigation in hybrid *Bt* cotton. Application of the same quantity of water under normal sowing (equally spaced rows, 67.5 cm apart), drip irrigation resulted in an average increase of 5% in seed cotton yield as compared with check-basin. Dense paired sowing (35–55 cm spaced paired rows) under drip irrigation produced 14% higher mean seed cotton yield but saved 25% irrigation water as compared with normal sown crop under check-basin. Normal paired sowing (35–100 cm) under drip irrigation saved 50% irrigation water compared with check-basin but gave 2% higher seed cotton yield. Dense paired sowing under drip irrigation could achieve the highest mean seed cotton yield (4 253 kg/ ha) and water-use efficiency (0.544 kg/ m^3), followed by normal paired sowing. Due to reduced length of laterals, dense paired sowing and normal paired sowing also resulted in saving of 25 and 50% in the cost of laterals, respectively.

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