

Effect of variable irrigation supply based diversification of Bt cotton (*Gossypium hirsutum*)–wheat (*Triticum aestivum*) system on productivity, profitability, soil fertility and water expense efficiency

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ABSTRACT

A field experiment was conducted during 2010–2013 at Punjab Agricultural University, Regional Station, Bathinda, Punjab to study the options for diversification of existing Bt cotton (*Gossypium hirsutum* L.)–wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.] cropping system under water scarce conditions. Three crop sequences, viz. wheat–Bt cotton, wheat–clusterbean [*Cyamopsis tetragonoloba* (L.) Taub], wheat–greengram [*Vigna radiata* (L.) Wilezek] in the main-plots and 3 irrigation regimes [optimum (O), sub-optimum (SO) and sub-sub optimum (SSO)] were taken in sub-plots with 3 replications under split-plot design. The sowing of the wheat was done according to the time of harvesting of previous crop (cotton, clusterbean and greengram) in same plots. The wheat grain yield was significantly higher where greengram and clusterbean were the preceding crop in rainy (*kharif*) season than cotton. There was 15.6% and 53.1% decrease in wheat grain yield, respectively under sub-optimum and sub-sub optimum irrigation supply than optimum level. Among the 3 wheat-based cropping sequences, cotton–wheat system gave significantly higher cotton equivalent yield (CEY), which was at par with clusterbean–wheat system under limited water supplies. The CEY in cotton–wheat sequence, where 4 irrigations (SO) were given was at par with the SO level (1 irrigation) of clusterbean–wheat system. At SSO irrigation, where 3 irrigations to cotton and no-irrigation to clusterbean, the CEY's of both the systems were at par. The highest water productivity (0.358 kg/m³), net returns (52.3 × 10³ ₹/ha) and benefit: cost ratio (2.38) were found under clusterbean–wheat crop sequence. This sequence also sustained soil health with higher values of organic carbon (0.37%), available nitrogen (118 kg/ha), available phosphorus (18.9 kg) and available potassium (332 kg/ha) levels than other crop sequences. Significantly the highest yield was recorded in optimum water regime in all rainy season (*kharif*) crops. Under sub-sub optimum irrigation, the seed cotton yield decreased significantly compared to sub-sub optimum level of clusterbean, where no irrigation was given to clusterbean.

Key words : Bt Cotton–wheat system, Cotton-equivalent yield, Diversification, Profitability, Water productivity,

Declining irrigation water supplies threaten the sustainability of irrigated agricultural production in India and worldwide. Projected increases in temperature, evaporation, and drought frequency with climate change magnify this concern. The water economization is a mandatory aspect in cropping pattern. As, the south western zone of Punjab is at the tail end of the canal system, it is prone to the uncertainty and inadequacy of canal water. The monoculture of cotton–wheat is exhaustive in light soils of

the region as 4.13 lakh ha area was under this system during 2014–15 (PAU, 2016). Continuous adoption of this sequence over a long period without prerequisite replacement of other crops (mainly legumes) can result in declining of soil fertility. Thus the efficient cropping system should include low water demanding leguminous crop, which can increase soil fertility ultimately leading to sustenance of soil health and higher monetary gains. Wheat is an important and assured food crop, which cannot be replaced by any other crop due to bread and butter of millions of population. Cotton is highly exhaustive crop which requires higher doses of fertilizers every year with considerable amount of water. Such exhaustive crop/cropping systems deteriorates the soil health by excessive mining of nutrients, leaving hardly any crop residue which is

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necessary to maintain desired level of organic matter (Usadadiya and Patel, 2013). Therefore, the nature and selection of the preceding crops having lower water requirement, justify greater importance in the yield of succeeding crop. Greengram is low water requiring legume and imperative source of protein for home consumption. But, the yield potential is low in the south-western Punjab. Thus clusterbean being a leguminous crop, which require less irrigation water (can even tolerate drought) and solve the purpose of crop diversification can replace cotton in rainy (*khariif*) season. The present study with 3 crops (cotton, clusterbean and greengram) in rainy (*khariif*) season with varied physiology and water requirement were undertaken to find out the feasible wheat-based cropping sequence under variable supplies of irrigation for system productivity and water expense efficiency.

MATERIALS AND METHODS

A 3-years field study was conducted at Research Farm of the Punjab Agricultural University, Regional Station, Bathinda, during 2010–2013 on sandy loam soil in semi arid region of South-West Punjab. The experimental site is characterized by semi-arid climate, with high temperature during the months of May and June ranging from 42–46°C and very low temperature during December–January (0.6–2.0°C). The rainfall during monsoon season is erratic, which varies from 0.0 to 140.3 mm. The mean meteorological data on total evaporation and rainfall is illustrated in Fig. 1. The total rainfall received in cotton growth period was 42.8 cm, 21.04 cm and 53.2 cm during 2011, 2012 and 2013 respectively. The clusterbean crop received 31.3 cm, 19.94 cm and 31.7 cm in its growth period and 31.3 cm, 17.38 cm and 30.1 cm to greengram crop during three years of experimentation, respectively. In winter (*rabi*) season, wheat crop received 4.82, 1.78 and 7.04 cm rainfall, respectively. The organic carbon content, pH and

CaCO₃ were 0.29%, 8.40 and 4.63%, respectively. The available phosphorus and potash in the surface layer were 15.9 and 326 kg/ha, respectively. Crop sequences, viz. wheat–Bt cotton, wheat–clusterbean, wheat–greengram in main-plots and 3 irrigation regimes [optimum (O), sub-optimum (SO) and sub-sub optimum (SSO)] were taken in sub-plots with 3 replications under split-plot design. The sowing of the wheat was done according to the time of harvesting of previous crop (cotton, clusterbean and greengram) in same plots. Wheat and greengram were planted at 22.5 cm and 30 cm row spacing respectively. Whereas, cotton and clusterbean were widely row spaced at 67.5 cm × 75 cm and 45 cm × 10 cm, respectively. The date of sowing, harvesting and irrigation scheduling in different years is presented in Table 1. All the recommended packages and practices relating to weed control, plant protection measures and other agronomic practices were followed. For calculating the water-expense efficiency (WEE), the water expense (WE) was calculated for different treatment combinations. The water expense is sum total of irrigation water applied, profile water used (PWU) and rainfall received during growing season of crop. Profile water was measured in 0–180 cm soil profile by gravimetric method. For computation of WEE, seed yields per hectare were divided by the water expense and expressed as kg/ha/cm. The economics was worked out on the prevailing prices (mean of three years) for the inputs and outputs during the study period. The mean minimum support price or prevailing market rate of the produce of rainy (*khariif*) and winter (*rabi*) seasons were used for computing cotton equivalent yield (CEY) of all the cropping sequences. The data over 3 years were pooled and statistically analyzed by using statistical methods described by Gomez and Gomez (1984) and the software used was CPCS1 developed by the Department of Statistics, Punjab Agricultural University, Ludhiana.

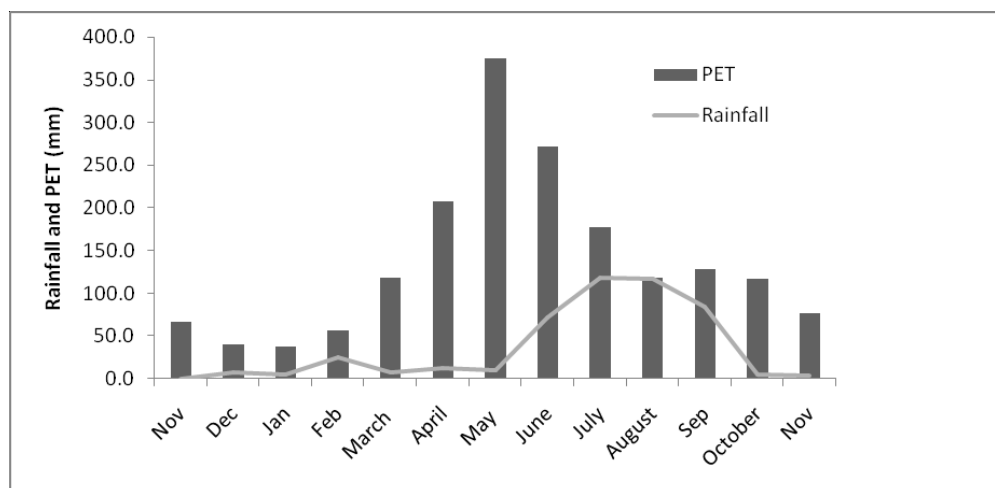


Fig. 1. Rainfall and potential evapo-transpiration (mean) during crop growth period at Bathinda

Table 1. Sowing, harvesting dates and irrigation regimes of different crops of the experiment

Crops	Variety	Sowing date		Irrigation regimes IW/CPAN E and number of irrigations			Harvesting date	
		2010–11	2011–12 2012–13	O	SO	SSO	2010–11	2011–12 2012–13
<i>Rabi</i>								
Wheat	'PBW 343'	23 Nov	16 and 27 November	21 November and 4 December	0.9 (4)*	0.7 (3)	0.5 (2)	11 April 19 April 11 April
<i>Kharif</i>								
Bt Cotton	'MRC-6304' / 'MRC-7017'	24 May	14 May	13 May	0.7 (5)	0.5 (4)	0.3 (3)	02 November 11 Nov 12 November
Clusterbean	'AG 112'	20 July	02 July	11 July	(2)	(1)	(1)	12 November 16 Nov 22 November
Greengram	'SML 668'	21 July	06 July	11 July	(3)	(2)	(1)	02 November 18 Sept 04 October

*No. of irrigations are given in parenthesis

RESULTS AND DISCUSSION

Yield attributes and wheat grain yield

Significantly the highest wheat grain yield was observed succeeding greengram and the lowest after cotton. About 12.9% and 5.3% grain yield reduction was observed under wheat–cotton cropping sequence than wheat–greengram and wheat–clusterbean cropping sequence. Usadadiya and Patel, (2013) also reported higher yield of succeeding crop (wheat), where legumes (soybean and green gram) were taken as preceding crop than preceded cereal (maize). As preceding legumes played important role in restoring the soil fertility in terms of N and other biological parameters due to atmospheric N₂-fixation through symbiotic process, which in turn improved the yield of succeeding crop. Wheat grain yield, all yield attributing characters, viz. plant height and tillers/meter row length were significantly higher under optimum (O) irrigation level than sub-optimum (SO) and sub-sub optimum (SSO) irrigation supply. There was 7.1% and 18.3% decrease in tillers per metre row length and 15.6% and 53.1% decrease in grain yield, respectively under sub-optimum and sub-sub optimum irrigation supply than optimum level. There was also significant reduction in plant height and total number of tillers per plant in SO (3 irrigations) and SSO (2 irrigations) than optimum (4 irrigations) level of irrigation. Mirbahar *et al.* (2009) reported that water stress experienced by a wheat crop during growth stages is known to have cumulative effects expressed as a reduction in total biomass as compared to well-watered conditions. Consequently, water stress caused significant reduction in vegetative growth, yield and yield components of wheat. The higher irrigation frequency may have maintained better water relations particularly during reproductive phase, when the atmospheric temperature starts increasing to supra-optimal level, thus helping in better grain filling leading to higher yields (Singh *et al.*, 2014).

Cotton equivalent yield

The pooled average yield of the greengram and clusterbean was converted into the cotton equivalent yield (CEY). The cotton yield and equivalent cotton yield of clusterbean and greengram (Table 3) implies that significant yield increase was noticed in cotton, followed by clusterbean and lowest CEY was found in greengram. Significantly the highest yield (1.55 t/ha) was recorded in optimum water regime than SO and SSO irrigation regime. While comparing interaction (Table 4) there was yield increase in cotton under optimum irrigation regime only than other crops. But, under SO irrigation supply (4 irrigations) and SSO (3 irrigations), the seed cotton yield decreased significantly compared to SO (1 irrigation) and SSO level (no irrigation) of clusterbean. It implies that

Table 2. Growth, yield attributes, yield and WEE of wheat under different cropping sequences at varying irrigation regimes (pooled mean of 3 years)

Treatment	Plant height (cm)	Tillers/m row length	Profile water use (cm)	Water expense (cm)	Grain yield (t/ha)	Water-expense efficiency (kg/ha-cm)
<i>Crop sequence</i>						
Wheat-cotton	72.5	86.1	12.4	36.4	2.98	81.6
Wheat-green gram	74.6	87.8	13.7	37.4	3.36	90.1
Wheat-clusterbean	71.3	84.7	13.2	38.2	3.14	81.7
SEm±	0.83	0.91	–	–	0.40	–
CD (P=0.05)	NS	NS	–	–	0.15	–
<i>Irrigation regime</i>						
Optimum	76.6	93.1	14.7	45.0	3.77	83.7
Sub-optimum	73.6	86.9	12.7	37.4	3.26	87.1
Sub-sub optimum	68.2	78.7	11.8	29.7	2.46	82.7
SEm±	0.59	1.17	–	–	0.05	–
CD (P=0.05)	2.1	4.1	–	–	0.18	–

Table 3. Yield, cotton equivalent yield (CEY), water expense (WE), water expense efficiency (WEE) and profile water use (PWU) of cotton, clusterbean and green gram under wheat-based cropping sequence at varying irrigation regimes (pooled mean of 3 years)

Treatment	Yield (t/ha)	CEY (t/ha)	WE (cm)	WEE (kg/ha-cm)	PWU (cm)
<i>Crop</i>					
Cotton	1.89	1.89	61.2	36.4	2.88
Green gram	0.58	0.72	42.8	15.3	5.45
Clusterbean	0.83	1.62	41.9	22.4	0.80
SEm±	–	0.06	–	–	–
CD (P=0.05)	–	0.24	–	–	–
<i>Irrigation regime</i>					
Optimum	1.23	1.55	53.8	24.8	2.2
Sub-optimum	1.10	1.41	49.2	24.5	3.0
Sub-sub optimum	1.96	1.27	42.9	24.7	3.9
SEm±	–	0.07	–	–	–
CD (P=0.05)	–	0.12	–	–	–

Table 4. Interaction effect of treatments on cotton equivalent yield

<i>Crop</i>	Cotton equivalent yield (t/ha)		
	<i>Irrigation regime</i>		
	Optimum	Sub-optimum	Sub-sub optimum
Cotton	2.27	1.88	1.50
Green gram	0.74	0.70	0.73
Cluster bean	1.63	1.66	1.57
SEm±	0.07		
CD (P=0.05)	0.12		

where there is scarcity (1 or 2 irrigations available) of irrigation water, clusterbean is better option than cotton.

System equivalent yield

The CEY of system (*rabi* + *kharif* crops) was also computed (Table 6). Among all the wheat-based crop sequences, cotton-wheat crop sequence gave significantly

the highest cotton equivalent yield. While observing the interaction (Table 7) it can be inferred that the CEY in cotton-wheat sequence, where four irrigations (SO) were given was at par with the SO level (1 irrigation) of clusterbean-wheat system. Whereas, the lowest level where total 3 irrigations (SSO) were given to cotton and clusterbean grown without irrigation, the CEY of both the systems were at par. The green gram-wheat recorded lowest CEY amid all the sequences.

Water-expense efficiency indices

The water-expense by wheat crop was almost same in all the crop sequences. However, water-expense efficiency (WEE) of wheat was higher in green gram (90.1 kg/ha-cm) cropping sequence and almost same under cotton and clusterbean system. Characteristically the optimum irrigation regime recorded the highest water expense followed by sub-optimum and sub-sub optimum level. Whereas, water expense efficiency under wheat was maximum in

sub-optimum regime. Singh *et al.* (2016) also reported maximum irrigation water-use efficiency under IW: CPE of 0.75 than IW: CPE of 1.0 under loamy sand soil conditions.

The WEE was maximum in cotton (36.4 kg/ha-cm) followed by clusterbean (22.4 kg/ha-cm) and lowest in greengram (15.3 kg/ha-cm). This may be due to lower CEY in clusterbean and greengram. The highest water expense (61.2 cm) was noticed under cotton. Whereas, clusterbean (41.9 cm) and greengram (42.8 cm) recorded lower water expense, which implies lesser water use by clusterbean and greengram than cotton. The maximum profile water-use (PWU) was noted in, greengram whereas the lowest PWU was under clusterbean. The highest water expense was recorded under optimum irrigation regime, followed by sub-optimum and sub-sub optimum regime. In cotton the order of water expense efficiency was eventually same as water expense. But, in case of

greengram results were contrary, as the highest WEE was found under SSO and the lowest WEE was recorded under optimum irrigation regime. The same trend was noticed in clusterbean based sequence. It implies that in greengram and clusterbean same level of yield/unit of irrigation water can be realized by even applying lesser quantity of water.

Soil fertility

The soil fertility status was analyzed after completion of the experiment (2012–13). The data presented in Table 5 revealed that the pH was maintained under various crop sequences, whereas electric conductivity (EC) was maintained under clusterbean–wheat and greengram–wheat crop sequence in surface layer of soil (0–15 cm). The decrease in EC was observed in cotton–wheat cropping sequence. The highest organic carbon (OC) was obtained under clusterbean–wheat (0.37 %) followed by green

Table 5. Effect of wheat-based cropping sequences on various soil properties (0–15 cm) under varying irrigation regimes

Crop sequence	Irrigation regimes	pH	EC (dS/m)	OC (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
Wheat–cotton	O	8.53	0.219	0.30	109.4	18.0	308
	SO	8.49	0.210	0.30	107.2	17.1	313
	SSO	8.46	0.211	0.29	104.6	15.4	315
	Mean	8.49	0.213	0.30	107.0	16.8	312
Wheat–clusterbean	O	8.51	0.174	0.39	121.4	19.5	330
	SO	8.44	0.173	0.37	117.1	18.9	326
	SSO	8.44	0.172	0.34	115.3	17.4	339
	Mean	8.46	0.173	0.37	118.0	18.9	332
Wheat–greengram	O	8.45	0.170	0.36	123.4	19.8	328
	SO	8.36	0.169	0.34	121.1	19.4	334
	SSO	8.40	0.162	0.30	119.5	18.7	340
	Mean	8.40	0.167	0.33	121.3	19.3	334

O, Optimum; SO, sub-optimum; SSO, sub-sub optimum

Table 6. CEY of system, water productivity and economics of various crop sequences under variable irrigation regimes

Treatment	System yield (on cotton equivalent basis) (t/ha)	Total variable cost ($\times 10^3$ ₹/ha)	Gross returns ($\times 10^3$ ₹/ha)	Net returns ($\times 10^3$ ₹/ha)	Benefit: cost ratio	Water productivity (kg/m ³)
<i>Crop sequence</i>						
Wheat–cotton	3.28	70.9	97.2	26.3	1.37	0.327
Wheat–greengram	2.17	47.8	64.3	16.5	1.34	0.272
Wheat–clusterbean	3.04	37.8	90.1	52.3	2.38	0.358
SEM \pm	0.08	–	–	–	–	–
CD (P=0.05)	0.22	–	–	–	–	–
<i>Irrigation regime</i>						
Optimum	3.25	52.3	96.5	44.2	1.92	0.319
Sub-optimum	2.90	52.1	86.1	34.0	1.75	0.326
Sub-sub optimum	2.32	52.0	68.9	16.9	1.42	0.312
SEM \pm	0.03	–	–	–	–	–
CD (P=0.05)	0.12	–	–	–	–	–

gram-wheat (0.33%) cropping system. The potassium content decreased in cotton based crop sequence (312 kg/ha) from initial status (326 kg/ha), but slight increase in available K was noticed in clusterbean-wheat (332 kg/ha) and greengram-based (334 kg) cropping system. Sharma and Jain (2014) also reported the highest available K status and actual K status in clusterbean-wheat cropping system compared to maize-wheat and groundnut-wheat system. There was increase in available P under clusterbean-based sequence than initial status, while available N also showed similar trend. This could be due to addition of large amount of biomass in the form of leaf fall and nitrogen-fixation through nodulated roots. Jan and Ahmed (2013), also found that legumes retained more soil N compared to non-legumes and plots sown after groundnut, greengram and clusterbean produced higher wheat yield than preceding millets, sorghum and sesame. The soil properties, viz. pH, EC and OC were slightly affected by the irrigation regimes. The pH and EC showed trivial increase under optimum irrigation than SO and SSO regimes in all the crop sequences. Under various available nutrients, the available nitrogen and phosphorous showed a marginal increase in optimum irrigation regime when compared to SO and SSO regimes under all the crop sequences. Whereas, contrasting results were found in available potassium in which the highest values were recorded in SSO and the lowest in optimum irrigation regime in all the crop sequences. This may be ascribed to the lower biomass of cotton crop due to reduced withdrawal and uptake of nutrients by the crop owing to application of limited quantity of water.

Economics

The economic analysis of cropping systems as a whole (Table 5) revealed that the highest cost of cultivation (70.9×10^3 ₹/ha) was observed in cotton-wheat sequence followed by greengram-wheat (47.8×10^3 ₹/ha) and the lowest was with clusterbean-wheat (37.8×10^3 ₹/ha). Jain *et al.* (2015) also reported the lowest cost incurred on

clusterbean-wheat cropping system mainly owing to lower fertilizer requirement. Similar results were also reported by Sharma and Jain (2014). The higher cost of cultivation in cotton may be attributed to higher cost of *Bt* seed, heavy dose of fertilizers and more number of plant protection sprays and other input costs. The highest gross returns (97.2×10^3 ₹/ha) were observed under cotton-wheat cropping system, but net returns (26.3×10^3 ₹/ha) were lower than clusterbean-wheat (52.3×10^3 ₹/ha) system. Lowest net returns ($16,489 \times 10^3$ ₹/ha) were realized in greengram-wheat cropping system. Consequently, the benefit: cost ratio was the highest in clusterbean-wheat cropping system. Chauhan (2011), while experimenting at farmer's field in four blocks of Rajasthan, reported the highest water-use efficiency (79.51 ₹/ha/mm) as compared to clusterbean-chickpea (74.0 ₹/ha/mm) and clusterbean-mustard (59.48 ₹/ha/mm) crop sequence. He also found that clusterbean-wheat cropping sequence was more lucrative (higher gross and net returns) among the above sequences.

The optimum water regime showed highest gross returns in all the crop sequences. The net returns were the highest in optimum irrigation regime of cotton and also lowest in cotton under sub-sub optimum. The discrepancy in net returns under clusterbean-wheat system was fewer. This implies that with decrease (one irrigation) under SO or no irrigation (SSO) to clusterbean the quantum of decrease in yield and net returns is less. This is also evident in benefit cost ratio of all the irrigation regimes. Furthermore, the maximum water productivity was deliberated in optimum irrigation schedule followed by sub-optimum and the lowest in sub-sub optimum in cotton-based cropping sequence. The lower water productivity was noticed in all irrigation regimes in greengram-based sequence. In clusterbean based sequence the highest water productivity was found in sub-optimum and sub-sub optimum regime and closely followed by optimum regime.

From the above, it can be inferred that the clusterbean-wheat cropping sequence is the best sequence for restoring soil fertility and fetching higher economic returns under water scarcity conditions. As, total water requirement in comparison to other wheat-based crop sequences is low and thus for judicious use of water it is therefore pertinent to shift area from cotton to clusterbean in rainy (*kharif*) season, which may help to conserve water, sustain soil quality and advantageous for making the production level integral.

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Table 7. Interaction effect of treatments on System yield (on cotton equivalent yield basis)

Crop sequence	System yield (t/ha)		
	Irrigation regime		
	Optimum	Sub-optimum	Sub-sub optimum
Wheat-cotton	3.96	3.32	2.54
Wheat-greengram	2.48	2.22	1.80
Wheat-clusterbean	3.32	3.17	2.62
SEM±	–	0.07	–
CD (P=0.05)	–	0.12	–

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