



Evaluation of mustard (*Brassica juncea*) and barley (*Hordeum vulgare*) based cropping sequence under variable irrigation supplies

ANUREET KAUR¹, K S SEKHON², S THAMAN³, A S SIDHU⁴ and G S BUTTAR⁵

Punjab Agricultural University, Regional Station, Bathinda 151 001

Received: 1 August 2017; Accepted: 17 April 2018

ABSTRACT

A field experiment was conducted at Regional Station, Bathinda during 2010–2013 to evaluate various crop sequences under variable irrigation regimes. The experiment was conducted in split plot design with six crop sequences, viz. barley-*Bt* cotton, barley-cluster bean, barley-green gram, mustard-*Bt* cotton, mustard-cluster bean and mustard-green gram in main plots and three irrigation regimes [optimum (O), sub-optimum (SO) and sub-sub optimum (SSO)] were kept in sub plots with three replications. The grain yield of barley reduced significantly where grown after cotton to the tune of 10.8 and 9.2% as compared to green gram and cluster bean, respectively. The barley grain equivalent yield (BGEY) was higher in mustard under all the preceding crops (cotton, green gram and cluster bean). Significant increase in cotton equivalent yield (CEY) was noticed in cotton sown after barley than mustard. Amongst the CEY of the system, barley-cotton crop sequence gave significantly highest CEY which was at par with mustard-cluster bean and mustard-cotton crop sequence. Significantly higher barley grain yield, mustard grain yield and cotton equivalent yield was recorded in optimum water regime, followed by SO and lowest in SSO regime. Water expense efficiency (WEE) of barley was higher preceding greengram followed by cluster bean and lowest in cotton system. Whereas, WEE was almost same under mustard succeeding cotton and greengram but was lowest in mustard-cluster bean crop sequence. The maximum water productivity (WP) was recorded in cluster bean- mustard followed by cluster bean-barley crop sequence. The sub-sub-optimum irrigation regime recorded highest WP followed by SO and lowest in optimum. The highest organic carbon was observed under cluster bean-barley followed by cluster bean-mustard cropping system. The potassium content decreased in cotton based crop sequence as compared to cluster bean and greengram crop sequence. Whereas, increase in available N, and P was noticed in cluster bean and green gram based cropping systems than cotton based sequence. The highest cost of cultivation was recorded in cotton based cropping sequences and lowest in cluster bean based cropping sequences. Consequently, higher net returns, B: C ratio were obtained in cluster bean based crop sequence than cotton based sequence. The optimum water regime showed highest gross returns, net returns and benefit cost ratio.

Key words: Cotton equivalent yield, Crop sequence, Profitability, Water productivity

Choosing an ideal crop sequence for the particular area, pertaining to its climate, water supply and soil type, is the basic criteria to ponder upon. As, continuously growing same crops year after year may affect the yields and soil fertility. Moreover, water economization is a mandatory aspect in cropping system as declining irrigation water supplies threaten the sustainability of irrigated agricultural production in India and worldwide. The focus on increasing the cropping intensity as well as production per unit area, per unit drop and per unit time is now gaining importance. Cropping system not only brings change in farming system

but also influences social and economical activities of the farmers (Hirwe and Jadhav 2010). 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. Therefore, suitable crop sequence has to be adopted so that there is efficient use of canal water and necessitate increase in the agriculture productivity concomitant with high water use efficiency aiming at sustenance of soil health and higher monetary gains. Cotton is the predominating *kharif* crop of south-west Punjab. It needs high fertilizer inputs and water requirement (5-6 irrigations) resulting in exhaustion of the soil after completion of its life cycle. This grand challenge calls for a need to decrease supplemental irrigation on current cotton crops and adopt water-saving crops for generations to come for sustainability (Robert 2015). As proficient crop sequence is associated with leguminous crop in rotation, which helps in improving soil conditions, cluster bean (*guar*) and green gram (*moong*) may be better potential crops to

¹Assistant Agronomist (e mail: anureet_1@pau.edu), ²Senior Soil Physicist (e mail: sekhon_1313@rediffmail.com), ³Assistant Agriculture Engineer (e mail: sudhirthaman@pau.edu), ⁴Senior Scientist (Irrigation) (e mail: assidhu@pau.edu), ⁵Additional Director Extension Education (e mail: buttagrs@rediffmail.com), Punjab Agricultural University, Ludhiana.

replace cotton in *kharif* season. The area under *guar* (cluster bean) has increased under irrigated conditions particularly in light textured soils, as it helps in diversification of the region. Clusterbean is a low water requiring annual legume and completes its life cycle with 1-2 irrigations depending upon rainfall. It is grown for vegetable purpose, fodder, green manuring and mainly grown in recent history for its galactomannan gum. This gum is used in food as a thickener, toothpaste, explosives and other uses. Particularly during 2012, world demand for *guar* gum augmented and the price increased by approximately 230% mainly because of increased oil field shale gas demand (Grestaa *et al.* 2013). It can grow in wide range of soil conditions ranging from light to heavy soils. It vacates the field early than cotton for timely sowing of succeeding *rabi* crop in October. Being leguminous crop, it is an excellent soil improving crop. Increased crop yields can be estimated from crops succeeding *guar* due to improved soil fertility as it adds substantial amount of organic matter to the soil surface as mulch. Another identified leguminous crop for crop sequence is greengram (*moong*), which is lucrative as well as help improving the soil conditions. But not widely grown by farmers due to its unpredictable yields, which can be affected by uncertain rains and consequently insect-pest and disease attack. Therefore, it is not considered as assured crop by the cultivator.

Among *rabi* season crops, barley is an important cereal crop after wheat and considered fourth largest cereal crop in the world with a share of the global cereal production (Pal *et al.* 2012). It is frequently being described as the most cosmopolitan of the crops and also considered, as poor man's crop because of its low input requirement and better adaptability to drought, salinity, alkalinity and marginal lands (FAO 2002). The changing climate and depleting natural resources are general problems of crop production and barley cultivation can be a good option to mitigate with such challenges. Moreover, it is envisaged that barley is going to be important crop in semi-arid region for supplementing the grain feed as well as for green forage, due to its limited

water requirement and faster growth at early stages (Kumar *et al.* 2014). Another important oilseed crop of *rabi* season is Indian mustard commonly known as *raya*. It is also a low water requiring crop, with better resource utilization and high remuneration. Due to adoption of improved mustard varieties, its production has increased in the country during last five years. But considering the demand and supply gap of edible oil in India, there is still a huge growth potential in this segment (Rathore *et al.* 2015).

Number of irrigations is an important component for working out the most efficient use by any crop. Therefore, the present study was undertaken to find out the feasible cropping sequence under variable supplies of irrigation for system productivity and water expense efficiency.

MATERIALS AND METHODS

A 3-year field study was conducted at Research Farm of the Punjab Agricultural University Regional Station, Bathinda, during 2010-2013 on sandy loam soil. The organic carbon content, pH, CaCO₃ content of surface soil layer (0-15 cm) 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. Six crop sequences, viz. barley-*Bt*cotton, barley-clusterbean, barley-green gram, mustard-*Bt* cotton, mustard-cluster bean and mustard-greengram in main plots and three irrigation regimes [optimum (O), sub-optimum (SO) and sub-sub optimum (SSO)] were taken in sub plots with three replications under split plot design. Irrigation in cotton and barley was scheduled on the basis of IW:CPE whereas, irrigation in cluster bean, greengram and mustard were given on the basis of number of irrigations (Table 1). The sowing of the barley and mustard was done according to the time of harvesting of previous crop (cotton, clusterbean and greengram) in same plots. Barley and moong were planted at 22.5 and 30 cm row spacing, respectively. Whereas, cotton and *guar* 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 given in Table.1. The meteorological

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

Crops	Variety	Sowing date			Irrigation regimes IW/CPE and number of irrigations			Harvesting date		
		2010-11	2011-12	2012-13	O	SO	SSO	2010-11	2011-12	2012-13
<i>Kharif</i>										
<i>Bt</i> Cotton	MRC-6304 /MRC-7017	24 May	14 May	13 May	0.7 (5)	0.5 (4)	0.3 (3)	02 Nov	11 Nov	12 Nov
Cluster bean	AG-112	20 July	02 July	11 July	(2)	(1)	(0)	12 Nov	16 Nov	22 Nov
Green gram	SML-668	21 July	06 July	11 July	(3)	(2)	(1)	02 Nov	18 Sept	04 Oct
<i>Rabi</i>										
Barley	DWRUB52	23 Nov	14 & 27 Nov	21 Nov & 4 Dec	0.7 (3)*	0.5 (2)	0.3 (1)	11 April	16 April	9 April
Mustard	PBR91	23 Nov	14 & 27 Nov	20 Nov & 4 Dec	(3)	(2)	(1)	6 April	18 April	6 April

*No. of irrigations are given in parenthesis

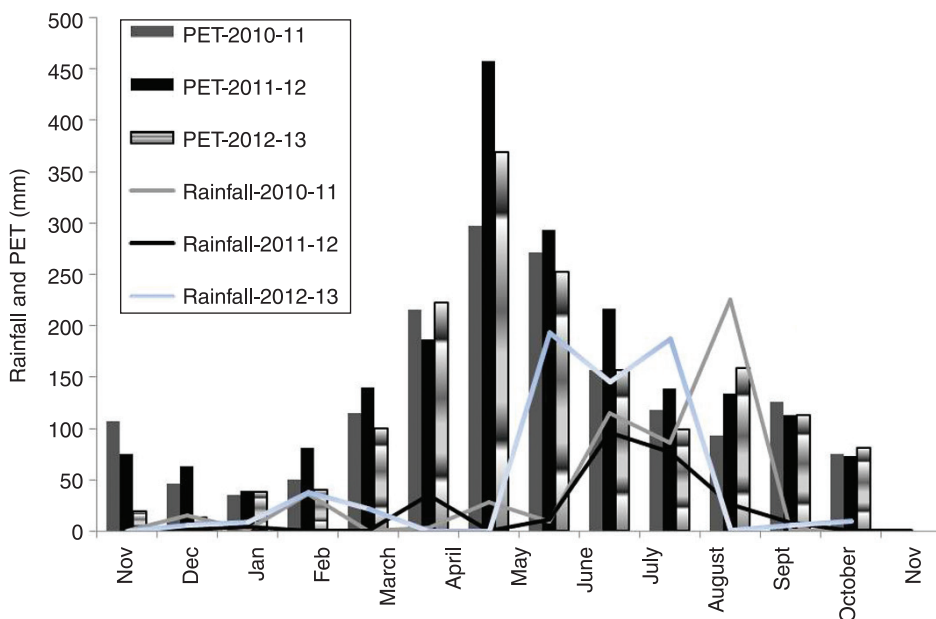


Fig 1 Rainfall and potential evapotranspiration in experimental years at Bathinda.

status. For calculating the water expense efficiency (WEE), the water expense was calculated for different treatment combinations. The water expense is sum total of irrigation water applied, profile water used and rainfall during growing season of crop. Profile water was measured in 0-180 cm soil profile by gravimetric method periodically. For computation of WEE, seed yields per hectare were divided by the water expense and expressed as $kg\ ha^{-1}cm^{-1}$. Existing market price of crop produce and inputs were used for computing economics of different crop sequences on the basis of equivalent yield.

data regarding total evaporation and rainfall is illustrated in Fig 1. The total rainfall received in cotton growth period was 42.80 cm, 21.04 cm and 53.20 cm during 2011, 2012 and 2013, respectively. The cluster bean crop received 31.3 cm, 19.94 cm and 31.7 cm rainfall in its growth period and contributed 31.3 cm, 17.38 cm and 30.1 cm to green gram crop during three years of experimentation, respectively. In *rabi* season, barley and mustard crops received 4.82 cm, 1.78 cm and 7.04 cm rainfall, respectively. All the recommended packages and practices relating to weed plant protection measures and other agronomic practices were followed.

The initial soil samples from site were drawn from 0-15 cm during the start of the experiment. These samples were used for determining pH, EC, organic carbon, available nitrogen, 0.5 N $NaHCO_3$ extractable P and NH_4OAC extractable K by standard procedures. The soil samples after the harvest of crops were also drawn from each plot using same procedure to analyze the soil fertility

RESULTS AND DISCUSSIONS

Economic yield

The data presented in Table. 2 shows that significantly highest barley grain yield was observed when succeeding cluster bean and green gram and lowest after cotton. The grain yield of barley was reduced where cotton was grown in *kharif* season to the tune of 10.8 and 9.2% than green gram and cluster bean based cropping sequence, respectively. Singh and Shivay (2013) also reported that inclusion of legumes in crop sequence increase the fertility resulting in higher productivity of the succeeding cereal crop. Whereas, plant height and number of tillers per metre row length showed non-significant results under various crop sequences. Barley grain yield and all yield attributing characters, viz. plant height and tillers per meter row length were significantly higher under optimum (O) irrigation level than sub optimum (SO) and sub-sub optimum (SSO)

Table 2 Growth, yield attributes, yield, WE and WEE of barley under different cropping sequences at varying irrigation regimes (Pooled mean of 3 years)

Treatment	Plant height (cm)	Tillers per m row length (no.)	Profile water use (cm)	Water expense (cm)	Grain yield (t/ha)	Water expense efficiency (kg/ha/cm)
<i>Crop sequence</i>						
Cotton-Barley	72.4	100.0	11.1	31.5	2.78	92.2
Green gram-Barley	72.5	101.7	12.3	32.7	3.04	98.3
Cluster bean-Barley	70.3	101.5	13.4	33.7	3.08	94.2
CD (P=0.05)	NS	NS			0.22	
<i>Irrigation regime</i>						
Optimum	76.7	105.8	38.8	119.8	3.40	89.8
Sub-optimum	69.4	100.8	35.6	94.1	3.02	100.8
Sub-sub-optimum	69.1	96.1	36.1	79.7	2.48	94.2
CD (P=0.05)	2.1	4.1			0.10	

Table 3 Growth, yield attributes, yield, WE and WEE of mustard under different cropping sequences at varying irrigation regimes (Pooled mean of 3 years)

Treatment	Plant height (cm)	Secondary branches (no.)	No. of pods per plant	Profile water use (cm)	Water expense, (cm)	Grain yield (t/ha)	Water expense efficiency (kg/ha/cm)
<i>Crop sequence</i>							
Cotton-Mustard	172.2	13.7	215.5	11.0	31.8	1.23	40.4
Green gram-Mustard	175.1	14.5	221.2	12.6	33.0	1.27	40.1
Cluster bean-Mustard	170.3	13.5	210.4	13.0	32.6	1.15	37.8
CD (P=0.05)	NS	NS	NS			NS	
<i>Irrigation regime</i>							
Optimum	177.8	15.7	233.3	13.0	40.4	1.43	37.1
Sub-optimum	172.0	14.0	216.6	11.7	32.1	1.18	37.8
Sub-sub-optimum	167.7	12.1	197.2	11.9	24.8	1.04	43.3
CD (P=0.05)	3.2	0.9	6.23			0.07	

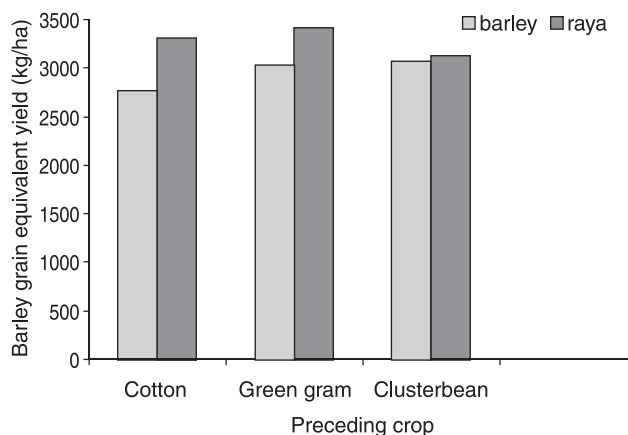
irrigation supply. There was 12.8% and 37.1% decrease in tillers/m row length and 12.8% and 37.1% decrease in grain yield, respectively under sub-optimum and sub-sub optimum irrigation supply than optimum level. The higher yield and yield attributes in IW:CPE ratio of 0.7 (O) and 0.5 (SO) than 0.3 (SSO) might be owing to less moisture regime under the latter. Tomar *et al.* (2016) also reported higher grain yield and yield attributes with three irrigations than two and one irrigation. They further enlightened that the adequate availability of irrigation water and plant nutrients with frequent, early and number of irrigations applied might resulted in higher yields than lesser number of irrigations applied.

The effect of preceding crop and various water regimes on mustard yield and yield attributes, water expense efficiency is given in Table 3. The mustard yield and its yield attributes were not affected statistically by various crop sequences. The results were in contrary to AICRP-RM (1998) report, where green manuring or *guar* enhanced seed yield of succeeding mustard at Bharatpur. Rathore *et al.* (2015) also observed maximum number of siliquae and grain yield of mustard under clusterbean-mustard cropping sequence than other sequences. Whereas, the optimum irrigation regime showed significantly higher mustard yield and its attributes followed by sub optimum regime and sub-sub optimum regime. Ray *et al.* (2015), in his study at West Bengal, also reported best growth, yield attributes, yield, sulphur uptake and oil per cent in seed with two irrigations compared to one irrigation. The availability of adequate moisture during critical growth stages (flower initiation and siliqua development) might have enabled the plants to attain a greater biomass, thereby increasing yield of the crop (Piri *et al.* 2011). The yield in optimum regime was significantly higher registering 4.6 and 13.1% increase in mustard-green gram than mustard-cotton and mustard-cluster bean crop) sequence, respectively. But, the difference was narrowed down in sub-optimum regime which showed nearly 3.1 and 7.6% lower yield of mustard preceding cotton and cluster bean than greengram. The barley grain equivalent yield kg/ha

(BGEY) was also computed to compare the effect of cereal and oilseed based crop sequence on succeeding crops in Fig 2. The BGEY was higher in mustard under all the preceding crops (cotton, green gram and cluster bean). But quantum of yield increase under mustard-cluster bean sequence was very low (1.47%) than barley-cluster bean. Whereas 16.1 and 11.27% higher BGEY in respect to mustard was observed under cotton and greengram, respectively.

The effect of preceding *rabi* crop and various irrigation schedules on yield and yield attributes of cotton (Fig 5) implies that higher number of sympods and number of bolls per plant and maximum seed cotton yield were observed under cotton-barley than cotton-mustard and optimum irrigation supply. Whereas, in case of clusterbean (Fig 6) and greengram (Fig 7) the preceding crop (barley and mustard) and irrigation schedules showed non-significant effect on grain yield and yield attributes of both succeeding crops.

The cotton equivalent yield (CEY) of greengram and cluster bean were also calculated. The cotton yield and equivalent cotton yield of cluster bean and greengram (Fig 3) implies that significant yield increase was noticed in cotton after barley than mustard. It may be ascribed to

Fig 2 Barley grain equivalent yield (kg/ha) influenced by various *kharif* crops.

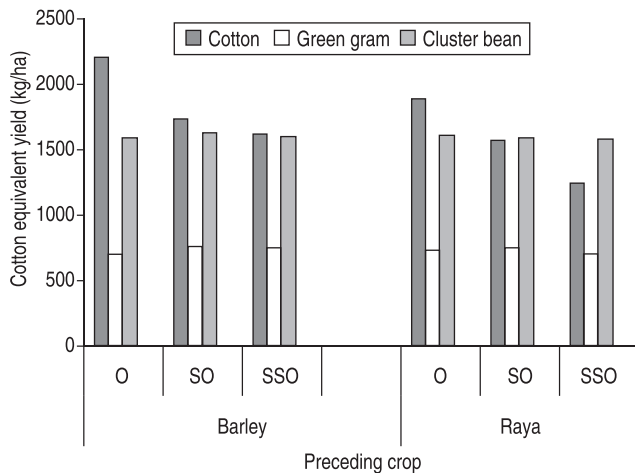


Fig 3 Cotton equivalent yield (kg/ha) under various irrigation regimes.

similar extraction behavior of nutrients from same depth due to identical tap root system of cotton and mustard crops. But, the CEY in respect to clusterbean was not much affected preceding *rabi* crop (barley and mustard). Clusterbean being legume has the ability to fix atmospheric N which might be the reason for obtaining similar yield preceding either barley or mustard in *rabi* season. The CEY of system (*rabi+kharif* crops) was also computed (Table 5). Amongst the all barley and mustard based crop sequences, barley-cotton crop sequence gave significantly highest CEY which was at par with mustard-clusterbean and mustard-cotton crop sequence. The system yield of barley-greengram and mustard-greengram was recorded to be lowest. Significantly higher yield was recorded in optimum water regime, followed by SO and lowest in SSO regime. In the interaction between crop sequences and irrigation regimes (Table 6) it was found that under optimum regime, CEY of barley-cotton and mustard-cotton system yields were at par. While under sub optimum level of irrigation, where four irrigations were given to cotton and one to cluster bean, gave almost same CEY under both barley and

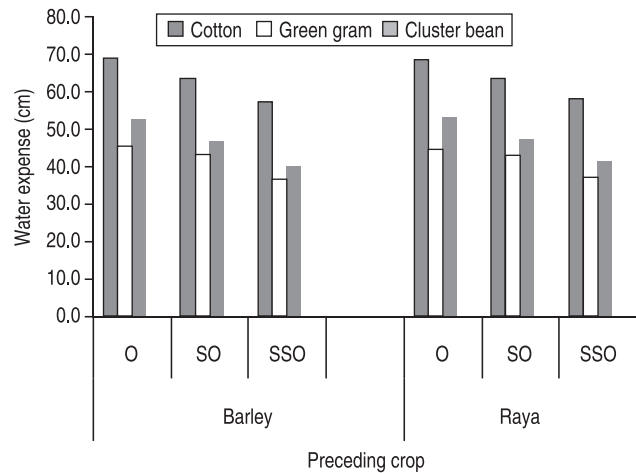


Fig 4 Water expense of *kharif* crops under various irrigation regimes.

mustard based crop sequence, thus saving three irrigations in the system. There was significant decrease in CEY under SSO level (3 irrigations to cotton) in cotton-mustard crop sequence than cluster bean-mustard (no irrigation applied during whole crop growth season, only rainfed except pre sowing irrigation). This implies that if there is scarcity of irrigation water, cluster bean is better option than cotton during *kharif* season, because the yield decrease is very high in case of cotton.

Water expense efficiency indices

Water expense efficiency (WEE) of barley was higher in green gram (98.3 kg/ha/cm) followed by cluster bean (94.2 kg/ha/cm) and lowest (92.9 kg/ha/cm) in cotton system (Table.2). The water expense (WE) of barley was highest (33.7 cm) where clusterbean was preceding crop, due to higher profile water use (PWU:13.4 cm) by the crop. Lowest WE (31.5 cm) and PWU (11.1 cm) was recorded in barley succeeding cotton. Characteristically the optimum irrigation regime recorded the highest water expense followed by sub-optimum and sub-sub-optimum level.

Table 4 Effect of barley and mustard based cropping sequences on various soil properties under varying irrigation regimes

Treatment	pH	EC (d/Sm)	OC (%)	Av. N (kg/ha)	Av. P (kg/ha)	Av. K (kg/ha)
<i>Crop sequence</i>						
Cotton-Barley	8.48	0.187	0.299	111	16.6	315
Green gram-Barley	8.36	0.148	0.345	119	17.9	337
Cluster bean-Barley	8.43	0.147	0.382	123	18.3	339
Cotton-Mustard	8.45	0.213	0.290	108	16.2	312
Green gram-Mustard	8.40	0.141	0.329	117	17.8	330
Clusterbean-Mustard	8.34	0.149	0.346	120	18.5	325
<i>Irrigation regime</i>						
Optimum	8.43	0.166	0.338	121	18.6	321
Sub-optimum	8.41	0.164	0.338	116	17.5	326
Sub-sub-optimum	8.39	0.163	0.319	111	16.5	333
Initial	8.40	0.23	0.291	109	15.9	326

Table 5 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 (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	B: C ratio	Water productivity (kg/m ³)
<i>Crop Sequence</i>						
Cotton-Barley	2.71	62427	80298	17871	1.28	0.286
Greengram-Barley	1.68	39303	49848	10545	1.27	0.227
Clusterbean-Barley	2.56	29297	75884	46586	2.59	0.323
Cotton-Mustard	2.58	62819	76505	13687	1.22	0.271
Greengram-Mustard	1.80	39695	53299	13604	1.34	0.242
Clusterbean-Mustard	2.62	29690	77589	47900	2.61	0.333
CD (P=0.05)	0.14					
<i>Irrigation regime</i>						
Optimum	2.58	44039	76541	32502	1.87	0.27
Sub-optimum	2.31	43863	68618	24755	1.72	0.28
Sub-sub-optimum	2.07	43714	61554	17840	1.57	0.30
CD (P=0.05)	0.07					

The PWU was maximum under optimum irrigation regime and nearly similar under SO and SSO regime. Whereas, water expense efficiency under barley was maximum in sub-optimum regime followed by SSO and lowest (89.8 kg/ha/cm) in optimum regime. The regression analysis of barley grain yield and water expense (Fig 5) shows nearly 94% contributions towards grain yield.

Highest PWU was under mustard preceding cluster bean followed by green gram and lowest under cotton. But, WE of mustard crop was high under mustard-green gram followed by mustard-cluster bean and mustard-cotton cropping sequences. The WEE was almost same under mustard succeeding cotton (40.4 kg/ha/cm) and green gram (40.1 kg/ha/cm) and lowest in mustard-cluster bean (37.8 kg/ha/cm). Among irrigation regimes highest WEE was recorded under SSO regime than SO and optimum regime which corroborates the highest values of PWU and WE in optimum regime and lowest in SSO level of irrigation. Piri (2008) also reported highest water use efficiency with one irrigation at 45 days after sowing than two irrigations.

Comparing *kharif* crops, the water expense (Fig 4) was highest in cotton. Whereas, cluster bean and green gram recorded lower water expense after both preceding crops (barley and mustard) which entails lesser water use by cluster bean and green gram than cotton. The highest water expense was recorded under optimum irrigation regime, followed by sub-optimum and sub-sub-optimum regime. Furthermore the maximum water productivity (WP, kg/m³) (Table 5) was found in clusterbean-mustard (0.333) followed by clusterbean-barley (0.323) and lowest WP (0.227) under greengram-barley sequence. The marginal difference in WP of clusterbean-mustard or barley may be due to the difference in price of both the crops. The sub-sub-optimum irrigation regime recorded highest WP followed by SO and lowest in optimum. Kaur and Mahal (2016) also reported higher WP

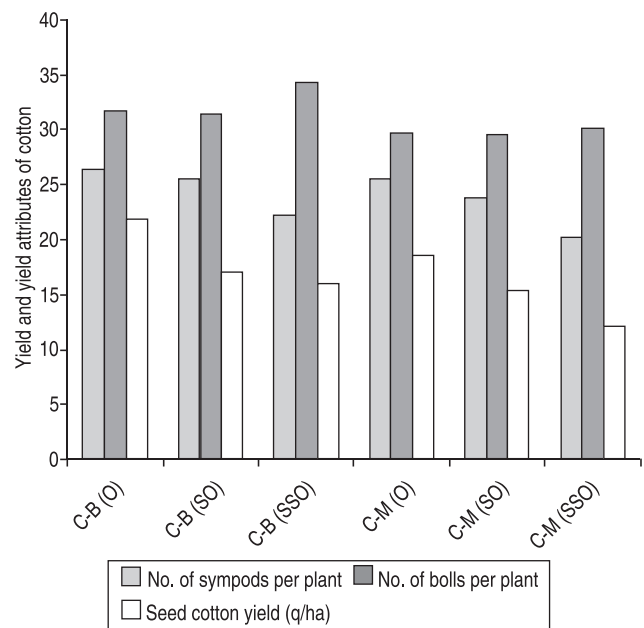


Fig 5 Seed cotton yield (q/ha) and yield attributes of cotton (C) under various treatments.

in the schedule 0.6 than 0.8 and 1.0 IW: CPE ratios due to lesser total water expense in the former.

Soil fertility status

The soil fertility status was analyzed after completion of the experiment on 3rd year (2012-13). The data revealed that the pH was maintained under various crop sequences, whereas electric conductivity (EC) was maintained under cluster bean and green gram based crop sequences. The increase in EC was observed in cotton based cropping sequences. Which may be attributed to application of higher doses of inorganic fertilizers particularly nitrogen to cotton. Highest EC was found under cotton-mustard

Table 6 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
Barley-Cotton	3.20	2.60	2.32
Barley-Green gram	1.78	1.71	1.55
Barley-Cluster bean	2.68	2.60	2.40
Mustard-Cotton	3.07	2.57	2.09
Mustard-Greengram	1.96	1.80	1.61
Mustard-Clusterbean	2.77	2.60	2.48
CD (P=0.05)		0.17	

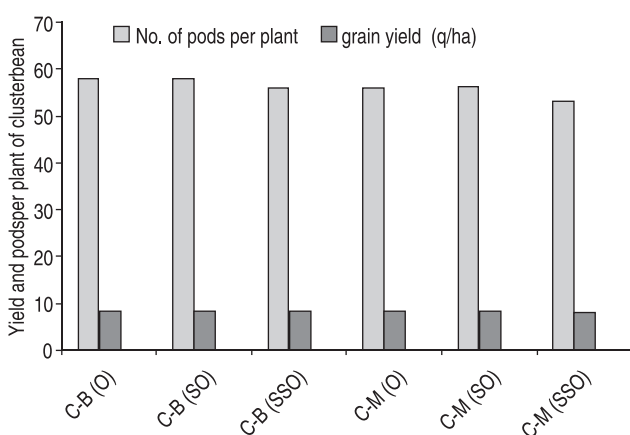


Fig 6 Grain yield (q/ha) and pods per plant (no.) of clusterbean (CB) under various treatments.

crop sequence. The highest organic carbon was obtained under cluster bean-barley (0.38%) followed by cluster bean-mustard (0.35%) cropping system and lowest organic carbon (OC) was found in cotton- mustard system. The nitrogen fixing behavior of clusterbean, lesser nutrient requirement or removal and addition of litter fall (leaves) during senescence may have contributed to the improvement in organic status. Moreover clusterbean-barley is relatively lesser feeder than clusterbean-mustard cropping sequence. Lowest organic carbon content in surface layer of soil of cotton-mustard sequence might be due to excessive mining of nutrients of both the crops coupled with meager addition of crop residues during their growing season. The potassium content decreased in cotton based crop sequence (315 kg/ha and 312 kg/ha) from initial status (326 kg/ha) but, slender increase in available K was noticed in cluster bean-barley (339) and greengram-mustard (334 kg/ha) and greengram-barley (337 kg/ha) cropping system. There was increase in available P under all the crop sequences.

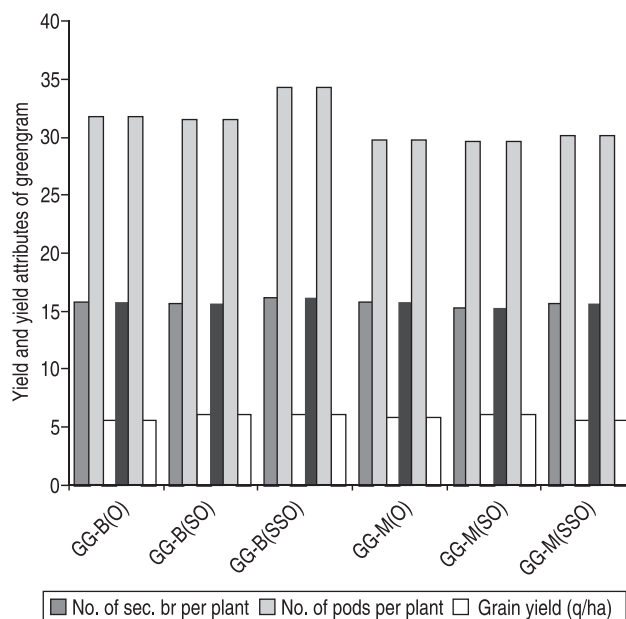


Fig 7 Grain yield (q ha⁻¹) and yield attributes of greengram (GG) under various treatments.

The increase in 0.5 N NaHCO₃ extractable P may be due to the application of phosphorous in every year and its subsequent fixation which may be made available in soil to the plants under favourable temperature and moisture conditions. But higher increase was found under cluster bean based sequence than initial status, while available N also showed similar trend. 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 the entire crop sequences. Adequate soil moisture is required for the movement, uptake and assimilation of nutrients by the plants. It might be the reason that nutrient extraction pattern from soil may be different for various nutrients under differential water supplies. Whereas, contrasting results were found in available potassium in which the highest values were

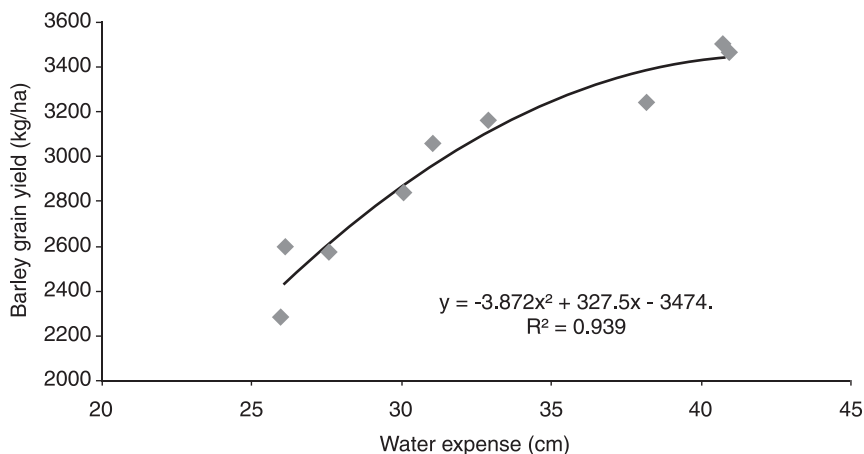


Fig 8 Relationship of water expense with barley grain yield.

recorded in SSO and lowest in optimum irrigation regime in all the crop sequences.

Economics

As the various crop sequences were evaluated consisting of crops of diverse nature, it was vital to compare the crop sequences on the basis of economics. The economic analysis given in Table 5 revealed that the highest cost of cultivation (₹ 62819 and ₹ 62427) was obtained in cotton-mustard and cotton-barley cropping sequences followed by greengram-mustard and greengram-barley sequences (₹ 39695 and ₹ 39303) and lowest was obtained under clusterbean-barley (₹ 29297) and clusterbean-mustard (₹ 29690) cropping sequences. The higher cost of cultivation in cotton may be attributed to higher cost of *Bt* seed, added fertilizers and more number of insecticides sprays, labour for cotton picking etc. The highest gross returns (₹ 80298) were obtained under cotton-barley cropping system but net returns (₹ 17871) were lower than clusterbean-mustard (₹ 47900) and clusterbean-barley (₹ 46586) systems. Undoubtedly higher net returns in clusterbean based cropping systems are the outcome of lower input costs. Rathore *et al.* (2015) also reported maximum net returns under clusterbean-mustard cropping system and lowest gross returns under cotton-mustard cropping system compared to fallow-mustard, soybean-mustard, groundnut-mustard and sesame-mustard crop sequences. Lowest net returns (₹ 10545) were realized in greengram-barley cropping system. Consequently the benefit cost ratio was also highest in cluster bean based cropping systems, which came out to be 2.61 and 2.59 under mustard-clusterbean and clusterbean-barley system, respectively. The optimum water regime showed highest gross returns, net returns and benefit cost ratio than sub- optimum and sub-sub-optimum irrigation regimes. Higher economic returns under optimum regime might be due to more grain yields.

From the above, it can be inferred that equally clusterbean-mustard and clusterbean-barley are best suited cropping systems under limited but assured irrigation facilities in light textured soils and semi-arid conditions of south-western Punjab. These cropping systems enhanced water productivity to strengthen our initiative to grow more crops per drop of water. In addition these cropping systems helped in sustaining the soil health too.

REFERENCES

AICRP-RM. 1998. National Research Centre on Rapeseed-mustard,

Annual Progress Report 1997-98, pp 8–18.

FAO. 2002. Food barley improvement. <http://www.fao.org/ag/AGP/AGPC/doc/field/other/act.htm>

Grestaa Fabio, Orazio Sortino, Carmelo Santonoceto, Luca Issi, Cristina Formantici and Yves M G. 2013. Effects of sowing time on seed yield, protein and galactomannans content of four varieties of guar (*Cyamopsis tetragonoloba* L.) in a Mediterranean environment. *Industrial Crops and Products* **41**: 46–52.

Hirwe N A and Jadhav A S. 2010. Productivity and economics of cropping sequences under different irrigation methods. *Agriculture update* **5**(1&2): 132–5.

Pal D, Kumar S and Verma R P S. 2012. Pusa Losar (BHS 380)- the first dual-purpose variety for northern hills of India. *Indian Journal of Agricultural Sciences* **82**:164–5.

Kaur J and Mahal S S. 2016. Effect of sowing methods, paddy straw mulch and irrigation schedules on crop performance, water productivity and monetary returns of barley (*Hordeum vulgare*). *Indian Journal of Agronomy* **61**(3): 366–71.

Kumar V, Khippal A, Singh J, Selvakumar R, Malik R, Kumar D, Kharub AS, Verma R P S and Sharma I. 2014. Barley research in India: Retrospect and prospects. *Journal of Wheat Research* **6**(1): 1–20.

Piri I. 2008. Effect of irrigation on yield, quality and water-use-efficiency of Indian mustard. *Proceedings of the 14th Australian Society of Agronomy Conference*, Adelaide, Australia.

Piri I, Nik M, Tavassoli A and Rastegaripour F. 2011. Effect of irrigation intervals and sulphur fertilization on growth analyses and yield of *Brassica juncea*. *African Journal of Microbiology Research* **5**: 3640–6.

Rathore S S, Shekhawat K, Meena A and Singh D. 2015. Growth, productivity and economics of coral-432 (Indian mustard hybrid) under different cropping systems. *Journal of Oilseed Brassica* **6**(1): 202–8.

Ray K, Sengupta K, Pal A K and Banerjee H. 2015. Effects of sulphur fertilization on yield, S uptake and quality of Indian mustard under varied irrigation regimes. *Plant Soil Environment* **61**(1): 6–10

Robert Kelby, Imel B S. 2015. Agronomic and economic analysis of guar (*Cyamopsis Tetragonoloba* L.) in comparison to drought tolerant crops adapted to the Texas high plains. Thesis submitted to Texas Technical University.

Singh A and Shivay Y S. 2013. Residual effect of summer green manure crop and zinc applied wheat (*Triticum durum*) under basmati rice-wheat cropping sequence. *Indian Journal of Agronomy* **58**(3): 327–33.

Tomar J, Kumar P, Kumar A, Sandhya, Kumar S and Kushwaha S R. 2016. Influence of irrigation schedules and fertilizer levels on barley (*Hordeum vulgare*) in western Uttar Pradesh. *Indian Journal of Agronomy* **61**(4): 515–8.