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Bt-cotton–vegetable-based intercropping systems as influenced by crop establishment method and planting geometry of *Bt*-cotton in Indo-Gangetic plains region

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The present study was conducted at ICAR-Indian Agricultural Research Institute, New Delhi in a split-plot design replicated thrice with four main-plot treatments, i.e. four combinations of two cotton establishment methods (CEMs) and two planting geometries (PGMs) [M_1 – transplanted cotton (90 × 60 cm PGM); M_2 – transplanted cotton (120 × 45 cm PGM); M_3 – direct seeded cotton (DSC; 90 × 60 cm PGM); M_4 – DSC (120 × 45 cm PGM)]; while sub-plot treatments comprised three intercropping systems [S-Ct – sole cotton; Ct + Ok – cotton + okra (1 : 2 row ratio); Ct + Cp – cotton + cowpea (vegetable purpose; 1 : 2 row ratio)]. It can be inferred from the study that transplanted cotton (TPC) with 90 × 60 cm planting geometry in *Bt*-cotton + vegetable cowpea intercropping system exhibited maximum seed-cotton equivalent yield (SCEY) as well as gross and net returns and other economic indices, followed by Ct + Ok and sole cotton. DSC with 90 × 60 cm PGM in Ct + Ok intercropping system proved superior in terms of SCEY, and gross and net returns besides other economic indices. Based upon yield advantage indices, TPC in 90 × 60 cm PGM under Ct+Cp intercropping system and DSC in 90 × 60 cm PGM under both intercrops were found to be the best options. Crop competition indices also revealed that the inclusion of these intercrops is advantageous because of spatial and temporal complementarity, different rooting pattern and plant architecture to utilize natural resources more efficiently in *Bt*-cotton-based intercropping systems in the semi-arid Indo-Gangetic plains region.

Keywords: *Bt*-cotton, crop establishment methods, intercropping systems, planting geometry, vegetable cowpea.

GLOBALLY, cotton (*Gossypium* sp.) is an important commercial crop with India having the largest world acreage of 11.98 M ha, representing about one quarter of global area (35 M ha) under cotton[1]. The average productivity of cotton lint in India is far below the world average of 767 kg/ha, and it contributes only to 25% of global production of 26 million tonnes. In north India, cotton is grown in about 1.36 million ha area with a total production of 5.8 million bale and an average lint yield of 722 kg/ha. However, the cotton productivity and profitability are low despite 100% irrigated area, probably due to poor crop establishment and non-standardization of suitable intercrops. Intercropping is one of the highly promising approaches for enhancing agricultural productivity and profitability[2]. Similarly, crop establishment is another most important factor deciding crop performance in sustaining cotton productivity and profitability. At present, farmers are facing problems of shrinking land-holding size, degradation of natural resources, climatic vulnerabilities and low monetary returns due to escalating cost of cultivation and inefficient utilization of agro-inputs[3]. Thus, production per unit area of land, time and inputs needs to be improved by efficiently harvesting the solar energy and carbon dioxide for conversion into economic produce[4]. As *Bt*-cotton is a short-stature crop of relatively longer duration, its slow initial growth and wider spacing offer vast scope for cultivation of suitable legumes and vegetables as intercrops. Further, improvements in productivity and profitability of *Bt*-cotton-based cropping systems are possible through efficient agronomic management and crop diversification/intensification by intercrops.

At present, no information is available on the inclusion of vegetable intercrops under different crop establishment

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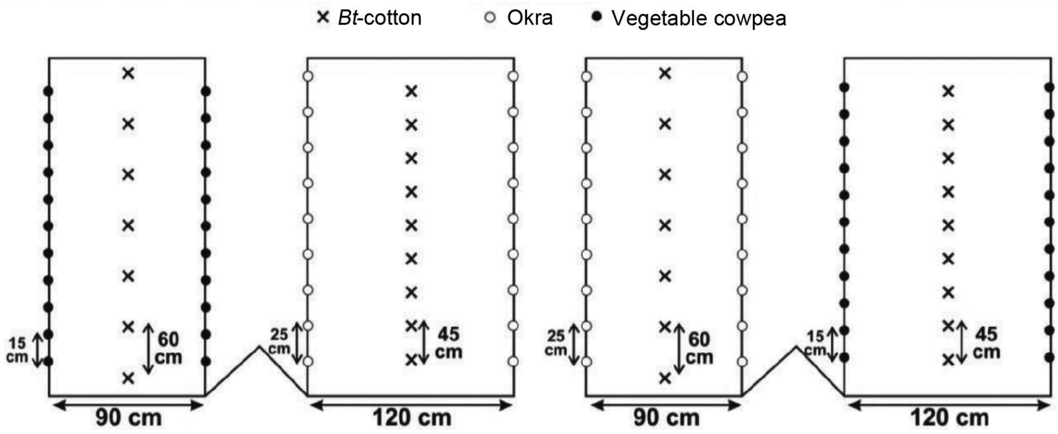

Figure 1. Planting plan in *Bt*-cotton-based intercropping systems.

methods (CEMs) of *Bt*-cotton as well as *Bt*-cotton-based intercropping systems with respect to productivity, profitability and crop competition indices. Hence, the present study was planned to explore the possibilities for inclusion of potential vegetable crops (both legumes and non-legumes) in *Bt*-cotton-based intercropping systems and examine the influence of CEMs, planting geometries (PGMs) and intercropping systems on crop productivity, profitability and crop competition indices so as to identify suitable vegetable intercrops for *Bt*-cotton-based intercropping systems under irrigated conditions of the Indo-Gangetic plains region (IGPR).

A field experiment was conducted at ICAR-Indian Agricultural Research Institute, New Delhi (28°37′N long.; 77°09′E lat.; 228.7 m altitude) during rainy season (*kharif*) of 2012 in a split-plot design and replicated thrice on sandy-loam soil, having pH 7.8, organic carbon 0.38%, electrical conductivity (EC) 0.31 dS/m, and available N, P and K in soil at 160, 14 and 268 kg/ha respectively. The main-plot treatments, viz. four combinations of two CEMs and two PGMs as follows: M_1 – transplanted cotton (90 × 60 cm PGM); M_2 – transplanted cotton (120 × 45 cm PGM); M_3 – direct seeded cotton (DSC; 90 × 60 cm PGM); M_4 – DSC (120 × 45 cm PGM); while sub-plot treatments, viz. three intercropping systems were: S-Ct – sole cotton; Ct + Ok – cotton + okra (1 : 2 row ratio); Ct + Cp – cotton + cowpea (vegetable purpose; 1 : 2 row ratio) respectively. For *Bt*-cotton nursery raising, poly-glasses of 15 cm height and 10 cm diameter were filled with soil and farmyard manure (FYM) in the ratio 3 : 1. Two *Bt*-cotton seeds were sown in each poly-glass on 5 June 2012, and watered on alternate days till the transplanting of one-month-old seedling (7 July 2012) in similar land configuration and spacing as followed in case of direct sowing method (M_1 and M_2).

According to row-to-row spacing of the two PGMs, broad-bed and furrow land configuration of 120 cm and 90 cm width having bed of 90 cm and 60 cm respectively, and furrow of 30 cm in each case were made before sowing/transplanting. Direct sowing of *Bt*-cotton was done on the same date (5 June 2012) as that followed for nursery raising for transplanted cotton (TPC) so as to ideally work out the productivity and crop competition indices in this study. In DSC, two seeds of *Bt*-cotton variety 'Bioseed 6588' were dibbled per hill using seed dibbler in the centre of broad-bed at 45 and 60 cm intra-row spacing according to the treatments (Figure 1). In intercrop also, two seeds were dibbled at the margin of broad-bed on both sides at an intra-row spacing of 15 and 25 cm for cowpea variety 'Pusa Komal' and okra variety 'Hybrid Ganga' respectively (Figure 1). Each intercrop was also raised as sole crop in the experiment for calculation of land equivalent ratios. Approximately one-month-old *Bt*-cotton seedlings were transplanted at the centre of the ridge by making a pit of desired dimension under M_1 and M_2. Intercrops according to the treatments were also sown at the time of *Bt*-cotton transplanting (7 July 2012) on both sides of the cotton row, i.e. at the margin of respective broad-beds (Figure 1).

Bt-cotton was fertilized with 180 : 60 : 50 kg N, P_2O_5 and K_2O/ha in sole and intercropped systems. N as urea was applied in two equal splits, i.e. first at sowing/transplanting and the remaining at the appearance of first flower in *Bt*-cotton. P as single super phosphate and K as muriate of potash were applied at transplanting time in TPC (M_1 and M_2) and at sowing time in DSC (M_3 and M_4). DSC received five irrigations before the onset of monsoon, besides one pre-sowing irrigation. Cotton transplanting was done during the onset of monsoon, without irrigation. Irrigation to cotton was provided to supplement the rainfall, so both TPC and DSC received one irrigation in the post-monsoon period. Total rainfall during the crop season was 502.8 mm. *Bt*-cotton was harvested in three pickings from the second fortnight of October to the first week of December. Finally the cotton sticks were harvested on 10 December 2012; while

Table 1. Seed cotton yield, yield of intercrops and seed cotton equivalent yield (SCEY) of intercrops as influenced by crop establishment methods, planting geometry and intercrops in *Bt*-cotton-based intercropping systems

Treatment	Seed cotton yield (t/ha)	Yield of intercrops (ha)	SCEY of intercrops (t/ha)
Crop establishment methods (CEMs)			
Transplanted cotton (TPC)	3.22	1.09	0.34
Direct seeded cotton (DSC)	3.06	1.50	0.52
SEm ±	0.03	0.04	0.01
CD (P = 0.05)	0.10	0.13	0.05
Planting geometry (PGM)			
90 × 60 cm	3.27	1.27	0.42
120 × 45 cm	3.01	1.32	0.44
SEm ±	0.03	0.04	0.01
CD (P = 0.05)	0.10	0.13	0.05
Intercropping systems (ICS)			
Sole cotton (S-Ct)	3.25		
Cotton + Okra (Ct + Ok)	3.06	0.99	0.41
Cotton + cowpea (Ct + Cp)	3.12	1.60	0.44
SEm ±	0.03	0.03	0.01
CD (P = 0.05)	0.10	0.09	0.03
Interactions (CEM × ICS)			
CD (P = 0.05)	NS	*	*

NS, Non-significant; *Significant.

pickings in the case of intercrops fruit (okra)/pod (cowpea) were done during mid-August to mid-September. Net plot of each treatment/crop was harvested at the appropriate stage, weighed for economic/biological yield and converted to per hectare basis using standard procedures. Economics of crop cultivation was calculated based on prevailing market prices of the inputs and outputs during the crop season. Net returns were calculated after subtracting cost of cultivation from gross returns. The data obtained from this study were statistically analysed following standard procedures using F-test. Least significant difference (LSD) values at $P = 0.05$ were used to determine the significant differences between treatment means.

For assessing the biological feasibility and economic viability of the intercropping systems, the land use and production efficiencies were computed using standard procedures as suggested by Ahlawat *et al.*[5]. Land equivalent ratios (LERs) were calculated using the formula proposed by Willey and Osiru[6]. The area–time equivalent ratios (ATERs) were calculated using the method of Hiebsch and McCollum[7]. Aggressivity was calculated using the formula proposed by McGilchrist[8]. Relative crowding coefficient (K) was calculated using the formula proposed by de Wit[9]. Competition ratio (CR) was calculated as suggested by Willey and Rao[10]. The land equivalent coefficient (LEC) as proposed by Adetiloye and Ezedinma[11] was calculated using the formula

$$\mathrm{LEC} = L_{\mathrm{a}} \times L_{\mathrm{b}},$$

where L_{a} and L_{b} are the partial LERs of component crops a and b respectively, in an intercropping system.

The relative value total (RVT) for each intercropping system was calculated using the formula suggested by Schultz *et al.* [12] as

$$\mathrm{RVR} = \frac{V_{\mathrm{c}} + V_{\mathrm{i}}}{V_{\mathrm{sc}}},$$

where V_{c} is the monetary value of cotton produce in intercropping; V_{i} the monetary value of intercrop produce; and V_{sc} is the monetary value of cotton produce in sole cropping.

The relative net returns (RNR) proposed for any intercropping system to be compared with the major sole crop was worked out following the method of Jain and Rao[13] as

$$\mathrm{RNR} = \frac{(P_i Y_i + P_j Y_j) \pm D_{ij}}{P_i Y_{ii}},$$

where Y_i and Y_j are the yield of ith major crop/ha and jth intercrop/ha respectively on i, jth crop combination, P_i and P_j the price of ith major crop and jth intercrop respectively, Y_{ii} the yield of ith sole crop/ha and D_{ij} is the differential cost of cultivation of i, jth crop combination in comparison to ith sole crop.

Table 1 shows that seed cotton yield is significantly higher (5.23%) under TPC than DSC due to higher plant stand and favourable climate in July during cotton transplanting under TPC-CEM, thus leading to extremely low mortality after transplanting (4.1%)[14]. However, in June-sown direct seeded cotton (DSC-CEM), the soil surface temperature is very high (sometime ~50°C) compared to

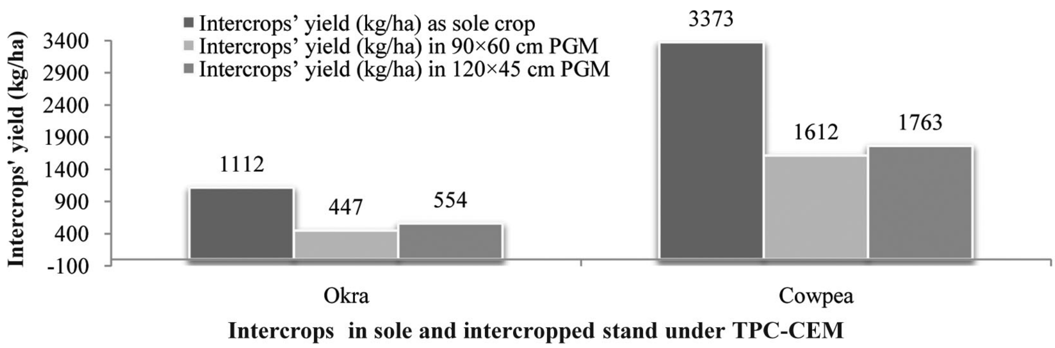

Figure 2. Yield of intercrops (kg/ha) in sole and intercropped stand as influenced by transplanted cotton crop establishment method (TPC-CEM), planting geometry and intercropping systems.

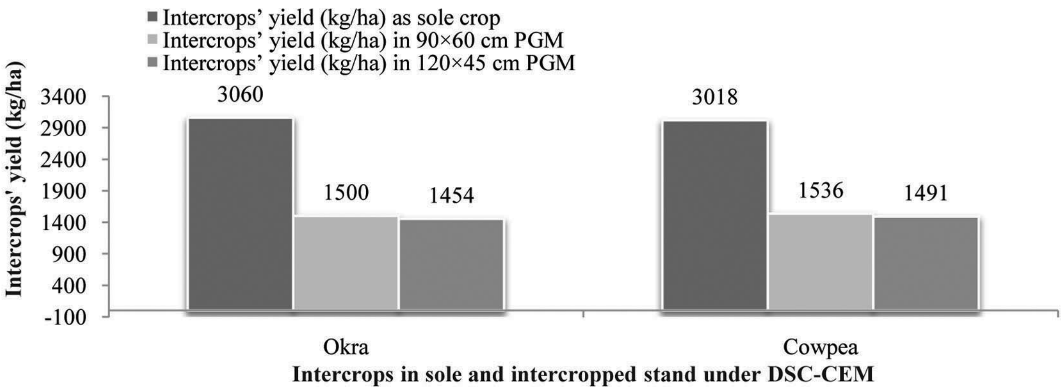

Figure 3. Yield of intercrops (kg/ha) in sole and intercropped stand as influenced by direct seeded cotton crop establishment method (DSC-CEM), planting geometry and intercropping systems.

ambient atmosphere temperature, which results in poor seed germination coupled with greater mortality of germinated seeds as well as relatively higher weed infestation[14]. PGM of 90 × 60 cm recorded marked improvement (8.63%) in SCY over 120 × 45 cm PGM, which may be ascribed to optimization of competition among the plants both under the ground for nutrients and water, and above the ground for light, CO_2 and space. Similar results were also reported by Bhalerao and Gaikwad[15]. In case of intercropping systems, sole cotton recorded marked increase by 6.2% and 4.2% in SCY over intercropping systems of Ct + Ok and Ct + Cp respectively. Both Ct + Ok and Ct + Cp recorded statistically similar SCY values. Between the intercrops, favourable effect of cowpea was observed on the growth, yield attributes and yield of *Bt*-cotton, which may be ascribed to its legume effect on soil health, specifically N availability to associated crop[16,17].

The variation in performance of intercrops w.r.t. intercrops' yield and seed cotton equivalent yield (SCEY) of intercrops was due to CEMs, PGMs and intercropping systems (Table 1). Among CEMs, yield of intercrops was higher (37.6%) over TPC due to less cotton plant stand in DSC and longer crop period availability for intercrop in DSC over TPC. Besides, intercrops got more space below and above the ground for their growth and development, which contributed to higher growth attributes and yield (Table 1). In PGMs, row-to-row spacing of 120 cm provided more favourable conditions in terms of physical, environmental, soil and water resource availability to intercrops which resulted in higher growth, yield attributes and yield of intercrops compared to the narrow-row spacing of 90 cm (ref. 4).

The results also showed that July-sown sole okra crop gave green fruit yield of 1112 kg/ha, while Ct + Ok in 90 × 60 cm and 120 × 45 cm PGMs could harvest only 40% and 49.8% of sole crop yield respectively (Figure 2). The June-sown sole okra crop gave green fruit yield of 3060 kg/ha, while Ct + Ok in 90 × 60 cm and 120 × 45 cm PGMs gave only 49% and 47.5% of sole crop yield respectively (Figure 3). Okra intercropped with cotton under DSC-CEM recorded significantly higher fruit yield than with TPC (Figures 2 and 3), which may be attributed to its early sowing in the first week of June, optimum moisture regime at the time of sowing and at vegetative phase (first week of June to first week of July) due to repeated irrigations and sufficient rainfall to meet the moisture requirement at the time of fruiting during active monsoons. On the contrary, okra intercropped with transplanted cotton was sown at the time of cotton

Table 2. Land equivalent ratio (LER), area–time equivalent ratio (ATER), aggressivity, relative crowding coefficient (RCC), competition ratio (CR) and land equivalent coefficient (LEC) as influenced by cotton establishment methods, planting geometry and intercropping systems

Treatment [CEM × PGM × ICS]	Intercrop yield (kg/ha)	Cotton yield (kg/ha)	LER			ATER	Aggressivity		Relative crowding coefficient (RCC)			Competition ratio (CR)		LEC
			Cotton	Intercrop	Total		A_c	A_i	K_c	K_i	Product of K	CR_c	CR_i	
TPC														
TPC; 90 × 60 cm PGM; Ct + Ok ICS	447	3364	0.96	0.40	1.36	1.15	2.28	–2.28	50.98	0.34	17.13	4.80	0.21	0.38
TPC; 120 × 45 cm PGM; Ct + Ok ICS	554	2875	0.92	0.49	1.41	1.15	2.04	–2.04	26.14	0.50	12.97	3.76	0.27	0.45
TPC; 90 × 60 cm PGM; Ct + Cp ICS	1612	3398	0.97	0.47	1.44	1.19	2.20	–2.20	69.36	0.46	31.74	4.13	0.24	0.46
TPC; 120 × 45 cm PGM; Ct + Cp ICS	1763	2830	0.91	0.52	1.43	1.15	1.96	–1.96	22.71	0.55	12.43	3.50	0.29	0.47
DSC														
DSC; 90 × 60 cm PGM; Ct + Ok ICS	1500	3210	0.95	0.49	1.44	1.20	2.12	–2.12	39.15	0.48	18.82	3.88	0.26	0.47
DSC; 120 × 45 cm PGM; Ct + Ok ICS	1454	2772	0.91	0.47	1.38	1.15	2.04	–2.04	21.92	0.45	9.92	3.87	0.26	0.43
DSC; 90 × 60 cm PGM; Ct + Cp ICS	1536	3195	0.94	0.50	1.44	1.19	2.08	–2.08	35.70	0.52	18.50	3.76	0.27	0.47
DSC; 120 × 45 cm PGM; Ct + Cp ICS	1491	2763	0.91	0.49	1.40	1.16	2.00	–2.00	21.09	0.49	10.30	3.71	0.27	0.45

A_c and A_i, Aggressivity of cotton on intercrops and intercrops on cotton respectively; K_c and K_i, RCC of cotton on intercrops and intercrops on cotton respectively; CR_c and CR_i, CR of cotton on intercrops and intercrops on cotton respectively. LER, Land equivalent ratio; ATER, Area-time equivalent ratio; LEC, Land equivalent coefficient.

Table 3. Economic indices as influenced by cotton establishment methods, planting geometry and intercropping systems under *Bt*-cotton-based intercropping systems

Treatment [CEM × PGM × ICS]	SCEY (kg/ha)	Gross returns (INR/ha)	Net returns (INR/ha)	Relative value total	Relative net returns	Income equivalent ratio
TPC						
TPC; 90 × 60 cm PGM; S–Ct ICS	3496	1,25,856	88,382	–	–	–
TPC; 120 × 45 cm PGM; S–Ct ICS	3095	111,420	73,946	–	–	–
TPC; 90 × 60 cm PGM; Ct + Ok ICS	3550	127,809	83,735	1.01	1.07	1.36
TPC; 120 × 45 cm PGM; Ct + Ok ICS	3106	111,810	67,736	1.00	1.06	1.43
TPC; 90 × 60 cm PGM; Ct + Cp ICS	3846	138,448	94,674	1.10	1.15	1.45
TPC; 120 × 45 cm PGM; Ct + Cp ICS	3320	119,510	75,736	1.07	1.13	1.44
DSC						
DSC; 90 × 60 cm PGM; S–Ct ICS	3374	121,464	83,396	–	–	–
DSC; 120 × 45 cm PGM; S–Ct ICS	3025	108,900	70,832	–	–	–
DSC; 90 × 60 cm PGM; Ct + Ok ICS	3835	138,060	93,392	1.14	1.19	1.44
DSC; 120 × 45 cm PGM; Ct + Ok ICS	3378	121,602	76,934	1.12	1.18	1.39
DSC; 90 × 60 cm PGM; Ct + Cp ICS	3622	130,380	86,012	1.07	1.13	1.46
DSC; 120 × 45 cm PGM; Ct + Cp ICS	3177	114,378	70,010	1.05	1.11	1.41

Selling price: Bt-cotton: INR 36,000/t; okra: INR 15/kg; vegetable cowpea: INR10/kg.

transplanting in the first week of July and thus faced more competition from the base crop as well as weeds due to regular rainfall at seedling stage.

In July-sown sole cowpea, green pod yield was 3373 kg/ha (Figure 2). Intercropping of cowpea with transplanted *Bt*-cotton in 90 × 60 cm and 120 × 45 cm PGMs gave about 47.8% and 52.2% green pod yield to that of sole crop yield respectively (Figure 2). While cowpea intercropped with direct seeded *Bt*-cotton in 90 × 60 cm and 120 × 45 cm PGMs gave 50.8% and 49.4% yield to that of sole crop yield respectively (Figure 3). In contrast to okra, intercropped stand of cowpea under TPC recorded slightly higher growth and yield attributes resulting in markedly higher pod yield (Figure 2), which may be attributed to its greater competitiveness due to rapid growth and spreading habit, and coincidence of the reproductive phase with high rainfall regime in the case of its intercropped stand under DSC-CEM (Figure 3), which affected pollination and pod-setting.

LER and ATER are important indices to measure the yield advantage in an intercropping system. Based upon the average yield of the intercrops and cotton (Table 2), LER and ATER were greater than unity for all the intercropping systems and CEMs, indicating advantage of intercropping over sole *Bt*-cotton. Maximum LER was recorded under TPC-CEM in 90 × 60 cm PGM under Ct + Cp ICP and DSC-CEM in 90 × 60 cm PGM under both intercrops (Table 2). Ganajaxi *et al.*[18] also reported higher LER under intercropping in *Bt*-cotton than sole cotton. The intercropping of vegetable cowpea under TPC-CEM in 90 × 60 cm PGM and okra in DSC-CEM with 90 × 60 cm PGM was found to be the best w.r.t. ATER values of 1.19 and 1.20 respectively. This implies that 19% and 20% additional yield can be realized per unit space and per unit time over the respective sole crops. These higher values could be due to better and efficient utilization of monetary and non-monetary resources resulting from temporal and spatial complementarity[4]. Likewise in transplanted cotton, the highest land the equivalent coefficient (LEC) was observed in Ct + Cp intercropping system at 120 × 45 cm PGM. While under DSC-CEM, the highest LEC was found under both Ct + Ok and Ct + Cp intercropping systems at 90 × 60 cm PGM in the present study.

Based upon average yield of the intercrops and *Bt*-cotton (Table 2), the aggressivity values indicated that *Bt*-cotton had positive values for all CEMs and intercropping systems, while more negative for intercrops. This shows that intercrops were dominated by cotton under all CEMs and intercropping systems. Dominating nature of cotton is due to its tall stature, higher leaf area, resource exhaustiveness, while it is reverse for intercrops. The relative crowding coefficient (RCC) is an index which is based on the planting density of each crop in the intercropping system. The product of RCC (K) should be more than unity for the system to be advantageous. All the intercropping systems under different CEMs recorded product of K more than unity, thus indicating that intercropping systems are advantageous because of spatial and temporal complementarity between both crops and also having different rooting pattern and plant architecture to utilize natural resources more efficiently[4]. In cotton, the highest competition ratio was observed in Ct + Ok intercropping system with 90 × 60 cm PGM under both TPC and DSC CEMs. In intercropping, highest CR was observed in Ct + Cp with 120 × 45 cm PGM under TPC and both 90 × 60 cm and 120 × 45 cm PGMs under DSC.

Overall, Ct + CP under TPC-CEM in 90 × 60 cm PGM exhibited highest SCEY of 8.33% and 10.1% over Ct + Ok under TPC-CEM in 90 × 60 cm PGM and sole cotton under TPC-CEM in 90 × 60 cm PGM respectively (Table 3). In DSC-CEM, Ct + Ok with 90 × 60 cm PGM recorded highest SCEY by 5.88% and 13.6% over Ct + Cp with 90 × 60 cm PGM and sole cotton with 90 × 60 cm PGM respectively. Likewise, TPC-CEM with 90 × 60 cm PGM under Ct + Cp and DSC-CEM with 90 × 60 cm PGM in Ct + Ok gave maximum gross and net returns (Table 3). In general, under both CEMs, the relative value total (RVT) and relative net returns (RNR) remained more than unity for both intercropping systems at both PGMs; however, Ct + Ok performed better under DSC method, while Ct + Cp gave relatively similar RVT and RNR under both CEMs (Table 3). The above results indicate that the performance of okra intercrop is good under June-sown DSC because okra is a warm-season vegetable requiring a long and warm growing season of 90–100 days. Among CEMs and intercropping systems, Ct + Cp with 90 × 60 cm PGM both under TPC and DSC CEMs accounted for maximum respective income equivalent ratio of 1.45 and 1.46 respectively, indicating superiority of this treatment over others which is attributed to increased proportion of net returns in relation to cost of cultivation[19].

Thus, it can be concluded that TPC with 90 × 60 cm PGM in *Bt*-cotton + vegetable cowpea intercropping exhibits maximum SCEY as well as gross and net returns and other economic indices followed by Ct + Ok and sole cotton respectively. DSC with 90 × 60 cm PGM in Ct + Ok intercropping system proved superior in terms of SCEY and gross and net returns besides other economic indices. Based upon yield advantage indices, TPC in 90 × 60 cm PGM under Ct + Cp intercropping system and DSC in 90 × 60 cm PGM under both intercrops are found to be the best options. Crop competition indices also revealed that inclusion of these intercrops is advantageous because of spatial and temporal complementarity, different rooting patterns and plant architecture to utilize natural resources more efficiently in *Bt*-cotton-based intercropping systems in the semi-arid IGPR.

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