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Research Paper

Sustainability assessment of cotton based intercropping systems for productivity and profitability using different quantitative indices under semi-arid vertisols

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ABSTRACT

Field experiments were conducted to evaluate cotton (*Gossypium* spp.)-based intercropping systems with greengram [*Vigna radiata* (L.) Wilezek], blackgram [*Vigna mungo* (L.) Hepper], pigeonpea [*Cajanus cajan* (L.) Millsp.] maize (*Zea mays* L.) and soybean [*Glycine max* (L.) Merrill.] as intercrops in semi-arid (moist) Vertisols at Khedbrahma (Gujarat) and soybean and pigeonpea as intercrops in semi-arid (moist) Vertisols at Akola during rainy seasons of 2008–09, 2009–10 and 2010–11. The intercropping systems were evaluated for superiority based on cotton equivalent yield (CEY), rainwater use efficiency (RWUE), monetary returns, sustainability yield index (SYI) and three competition indices, viz. land equivalent ratio (LER), relative crowding coefficient (RCC) and competition ratio (CR). At Khedbrahma, cotton + blackgram (1:1) was found to be an efficient system with significantly higher mean CEY (983 kg/ha), net returns (₹18,893/ha), benefit: cost ratio (2.68), RWUE (2.23 kg/ha-mm), higher SYI (70.4) and LER (1.44) and lower total CR (2.17). At Akola, cotton + soybean (1:1) was found to be efficient with significantly higher mean CEY (1,609 kg/ha) besides higher net returns (₹35,177/ha), benefit: cost ratio (2.94), RWUE (3.68 kg/ha-mm), higher SYI (34.1) and LER (1.31) and lower total CR (2.19). Further, the multi-tier system of cotton + soybean + pigeonpea + soybean (3:2:2:2) was the second best with higher productivity, benefit: cost ratio and RWUE. Cotton + blackgram (1:1) at Khedbrahma and cotton + soybean (1:1) at Akola were identified as efficient intercropping systems and could be adopted under similar agro-ecological settings in the respective domains.

Key words **:** Competition indices, Cotton-based intercropping systems, Rainwater use efficiency, Sustainability Yield Index, Semi-arid Vertisols

In rainfed agriculture, the production risks are high due to weather aberrations i.e. delayed onset of monsoon, early, midseason and terminal droughts during various phenological stages of the crops. Therefore, the dry spells occurring at various phenological stages of the crop would reduce the yield by about 25 to 50% under different soil and agro climatic conditions. Though, mixed/intercropping is an old and widespread practice to minimize the production risks in rainfed agriculture, the changing cropping patterns, cultivars and management practices necessitates to evaluate the performance of existing intercropping systems or to identify new intercropping systems. In the long duration cotton crop, mixed/intercropping is practiced under rainfed condition with plethora of intercrops, row ratios etc. across diverse agro-ecologies such as semi-arid black soils (Vertisols) of Vidarbha in Maharashtra and north Gujarat. However, it is always aimed to grow a suitable short duration intercrop in cotton for attaining maximum productivity per unit area in a sustainable manner with higher monetary returns apart from efficiently utilizing the rainwater and other inputs (Rao *et al.* 2003, Vittal *et al*., 2003).This information is lacking for most of the rainfed crops. The focused research on intercropping in different research centers of the All India Coordinated Research Project for Dryland Agriculture (AICRPDA) network aims to identify an efficient intercropping systems that would give higher productivity and stability of intercropping versus mono-cropping in agro-climatic regions

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where only a single crop was feasible in a year (Ravindra Chary *et al*., 2012). In the present study, in order to identify efficient cotton based intercropping systems in respect of yield advantage, resource use efficiency, optimal competition, sustainability and profitability, field experiments were conducted across diverse agro-ecologies (climate and soil types) at two AICRPDA centres representing semi-arid Vertisols at Khedbrahma in Gujarat and Akola in Maharashtra states.

MATERIALS AND METHODS

Field experiments were conducted under rainfed condition for 3 years during rainy (*kharif*) seasons of 2008–09, 2009–10 and 2010–11 at the centres of All India Coordinated Research Project for Dryland Agriculture at Khedbrahma (Cotton Research Station Farm), (73° 03' E, 24° 02' N and 205 m above mean sea level) Sabarkantha district, Gujarat) and Akola (75°57' E, 17°57' N and 295 m above mean sea level, Akola district, Maharashtra). Khedbraham represents semi-arid moist climate with mean annual rainfall of 830 mm, while Akola represents semi-arid (moist) climate with mean annual rainfall of 805 mm. At Khedbrahma, the experimental site was a Vertisol characterized with clayey texture, water holding capacity of 30.1%, pH of 7.45, electrical conductivity of 0.15 dS/m, and low in soil organic carbon, low in available nitrogen, medium in available phosphorus and high in available potassium. At Akola, the experimental site was a Vertisol characterized with clayey texture, water holding capacity of 37.5%, pH of 7.8, electrical conductivity of 0.20 dS/m, and low in soil organic carbon, low in available nitrogen, medium in available phosphorus and medium in available potassium. The field experiments were conducted with cotton as base crop at both the locations. At Khedbrahma, the intercrops included greengram, blackgram, pigeonpea, maize and soybean in additive series with row, proportion of 1:1. The cultivar and fertilizer dose adopted in sole crops were: cotton-'Gujarat hybrid 10', and 150:0:0 kg N: P_2O_5: K_2O/ha and 50 kg N/ha each at basal and 2 top dressings at 45 and 70 days after sowing (DAS); for pigeonpea-'GTH-1' and 25:50:0 kg NPK/ha; for soybean–'GS-1' and 30:60:0 kg NPK/ha; for green gram-'GM 4' and 20:40:0 kg N: P_2O_5: K_2O/ha; for blackgram-'T 9' and 20:40:0 kg P_2O_5: K_2O/ha; for maize-'HQPM' and 100:50:0 kg N: P_2O_5: K_2O/ha. In cotton, the inter-row spacing was 120 cm and plant to spacing was 90 cm. In between 2 cotton rows, the intercrops were sown. The plant to plant spacing in greengram and blackgram was 15 cm, in maize and soybean was 20 cm and in pigeonpea, it was 30 cm. Two interculture and weedings were done at 25 and 45 DAS in all the intercropping systems and sole crops except in sole pigeonpea and sole cotton i.e. at 25 and 60 DAS. At Akola, the intercrops included soybean and pigeonpea. Cotton + soybean (1:1) was grown under additive series, while cotton + pigeonpea in 4:2 and 6:2 row ratios were in replacement series and cotton + soybean + pigeonpea + soybean (3:2:2:2) was also in replacement series. The cultivar, spacing and fertilizer dose adopted in sole crops were: cotton – 'AKH 8828', 60 cm × 30 cm and 25:25:0 kg N: P_2O_5: K_2O/ha as basal dose and 25 kg N/ha as top dressing at 30 DAS; for pigeonpea-'C 11', 60 cm × 20 cm and 25:50:0 kg N: P_2O_5: K_2O/ha as basal; for soybean-'TAMS 38', 30 cm × 8 cm and 30:75:0 kg N: P_2O_5: K_2O/ha. In intercropping systems, same cultivars were adopted as in sole crops. However, the spacing adopted were: in cotton + soybean (1:1), 30 cm inter-row and 30 cm and 8 cm intra-row spacing in cotton and soybean respectively; in cotton + pigeonpea, both in 4:2 and 6:2 systems - 60 cm inter-row and 30 cm and 20 cm intra-row spacing in cotton and pigeonpea respectively; and in cotton + soybean + pigeonpea + soybean (3:2:2:2) system - 45 cm inter-row and 30 cm, 8 cm and 20 cm intra-row spacing in cotton, soybean and pigeonpea, respectively. The fertilizer dose of cotton was given to all the intercropping systems. In sole soybean and cotton + soybean (1:1), 2 hoeings and in rest of the sole and intercropping systems 3 hoeings were done. In sole pigeonpea and sole soybean, 2 weedings and in sole cotton and all intercropping systems 3 weedings were done. At both locations, the experiments were conducted in a randomized block design with 3 replications. The details of date of sowing, date of harvest, crop duration, crop seasonal rainfall and rainy days pertaining to all the sole crops and intercropping systems were recorded both at Khedbrahma and Akola and are presented in Table 1 and 2, respectively.

Cotton equivalent yield (CEY) was determined by taking into account the actual yields (kg/ha) attained by crops along with the prices or value (per kg) of the crops. The rainwater use efficiency (kg/ha-mm) (Rockstrom *et al*., 2003) of a crop or cropping system could be determined by considering the cotton equivalent yield (kg/ha) attained by the system and crop seasonal rainfall (mm) received from sowing to harvest of a given crop or the long duration crop in the cropping system. It is given as a ratio of the cotton equivalent yield and the crop seasonal rainfall of a crop or a cropping system in each year and averaged over years. The superiority of intercropping systems over the sole crops was assessed based on three standard competition indices, *viz.* land equivalent ratio (Willey, 1979), relative crowding coefficient (De Wit, 1960) and competition ratio (Willey, 1979). The land equivalent ratio (LER) could be measured to assess an intercropping system for its superiority based on the yield attained under sole and intercrops in a given season. The component crop with

higher relative crowding coefficient (RCC (K)) value is the dominant and that with low K value is the dominated. Higher the RCC, lower would be the performance of the intercropping system and vice-versa. The competition ratio (CR) is an important tool to know the degree with which one crop competes with the other. Lower the CR value better is the intercropping system and vice-versa. These competition indices were derived for multi-tier intercropping systems i.e., with three crops tested at Akola. The economic analysis was done based on net monetary returns (₹/ha) and benefit: cost ratio.

The sustainability of intercropping systems was examined based on cotton equivalent yield (CEY) attained by different cropping systems, crop seasonal rainfall (CRF) at each location. A regression model of CEY could be derived as a function of crop seasonal rainfall (CRF) and its quadratic term as

$$CEY = \pm \alpha \pm \beta 1\ (CRF) \pm \beta 2\ (CRF)^2 \quad \ldots\ldots\ldots\ldots\ (1)$$

where, α is the intercept; β_1, and β_2 are regression coefficients measuring the effect of crop seasonal rainfall on cotton equivalent yield of different crops over years.

The sustainability yield index (SYI) (Maruthi Sankar *et al*., 2012) of a cropping system could be measured as a ratio of the "difference between mean yield and prediction error" and "maximum yield" attained by any cropping system in any year in the 3-year study period. The regression model could be assessed based on coefficient of determination (R^2) and is tested by F-test. The SYI 'h' of a cropping system 'i' could be derived as

$$\eta_i = [(A_i - \Phi)/ (Y_{max})]^* 100 \quad \ldots (2)$$

where,

A_i is mean yield of a cropping system over years;

Φ is the prediction error derived based on a regression model;

Y_{max} is the maximum yield attained by any cropping system in the study period.

Based on SYI, a cropping system with maximum SYI could be preferred as most efficient system for attaining sustainable maximum yield and profit in a given soil and agro-climatic condition. Analysis of variance (ANOVA) was carried out to test the treatment differences in each year and also for the data pooled over years at Khedbrahma and Akola. The treatments were assessed based on the Least Significant Difference (LSD) criteria at $p < 0.05$ level of significance (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Cotton equivalent yield and Rainwater use efficiency

At Khedbrahma under semi-arid Vertisols, the different cropping systems gave cotton equivalent yield (kg/ha)

Table 1. Dates of sowing and harvest of crops, crop seasonal rainfall and rainy days at Khedbrahma

Crop/Year	Date of sowing (DOS)	Date of harvest (DOH)	Crop duration (days)	Crop seasonal rainfall (mm)	Rainy days
Cotton					
2008–09	04 August, 2008	12 February, 2009	193	323	20
2009–10	21 July, 2009	31 January, 2010	195	460	20
2010–11	07 July, 2010	25 January, 2011	203	783.2	41
Greengram					
2008–09	04 August, 2008	24 October, 2008	82	323	20
2009–10	21 July, 2009	05 October, 2009	77	447	7
2010–11	07 July, 2010	25 September, 2010	81	783.2	41
Blackgram					
2008–09	04 August, 2008	28 October, 2008	86	323	20
2009–10	21 July, 2009	15 October, 2009	87	447	7
2010–11	07 July, 2010	05 October, 2010	91	783.2	41
Pigeonpea					
2008–09	04 August, 2008	12 January, 2009	162	323	20
2009–10	21 July, 2009	08 January, 2010	161	460	20
2010–11	07 July, 2010	06 January, 2011	184	783.2	41
Maize					
2008–09	04 August, 2008	10 November, 2008	99	323	20
2009–10	21 July, 2009	25 October, 2009	86	447	7
2010–11	07 July, 2010	15 October, 2010	101	783.2	41
Soybean					
2008–09	04 August, 2008	04 November, 2008	93	323	20
2009–10	21 July, 2009	23 October, 2009	84	447	7
2010–11	07 July, 2010	17 October, 2010	103	783.2	41

with lowest variation of 17.1% in 2010–11 compared to maximum of 26.8% in 2009–10 with mean of 15.6% over years (Table 3). Rainwater use efficiency (RWUE) (kg/ha-mm) had a higher coefficient of variation in the range of 17.2% in 2010–11 to 27.3% in 2009–10 with mean of 16.6% over years. Among cotton based intercropping systems, maximum cotton equivalent yield of 1262 kg/ha with RWUE of 3.91 kg/ha-mm was attained under cotton + soybean (1:1) in 2008-09 and 955 kg/ha with RWUE of 1.22 kg/ha-mm by cotton + blackgram (1:1) in 2010–11. However, cotton + blackgram (1:1) gave maximum mean cotton equivalent yield of 983 kg/ha with mean RWUE of 2.23 kg/ha-mm over three years (Table 3). This indicated that the cotton in combination with soybean and blackgram crops have best utilized the normal crop seasonal rain fall of 323 mm received during 2008–09, a low rainfall of 447 mm in 2009–10 and a high rainfall of 783 mm in 2010–11. Although the rainfall was below normal in 2009–10 and above normal in 2010–11, still the cropping system has best utilized the crop seasonal rainfall and performed efficiently compared to all other cropping systems evaluated in the study. Further, these crops due to short stature and good canopy serve as live mulch in the space between interrows during initial stages of the crop, thus conserve moisture and efficient utilization by the component crops and also might be due to the absence of competition between cotton and blackgram for growth resources such as nutrients, moisture, and solar radiation. Rana *et al.* (2006) too observed higher crop productivity and RWUE in maize based intercropping systems compared to sole crops under rainfed condition. Mohammed *et al.* (1994) while discussing on cotton + cowpea intercrop-

Table 2. Dates of sowing and harvest of crops, crop seasonal rainfall and evaporation at Akola

Crop/Year	Date of sowing (DOS)	Date of harvest (DOH)	Crop duration (days)	Crop seasonal rainfall (mm)	Rainy days
Cotton					
2008–09	27 June, 2008	21 January, 2009	209	461.0	37
2009–10	29 June, 2009	11 December, 2009	166	499.2	30
2010–11	19 June, 2010	19 January, 2011	215	879.6	40
Soybean					
2008–09	27 June, 2008	14 October, 2008	110	455.5	36
2009–10	29 June, 2009	14 October, 2009	108	396.4	27
2010–11	19 June, 2010	08 October, 2010	112	799.6	35
Pigeonpea					
2008–09	27 June, 2008	30 October, 2008	187	461.0	37
2009–10	29 June, 2009	07 October, 2010	193	513.9	31
2010–11	19 June, 2010	30 December, 2010	195	879.6	40

Table 3. Cotton equivalent yield and rainwater use efficiency in cotton based intercropping systems at Khedbrahma (mean of 3 years)

Treatments	Cotton equivalent yield (kg/ha)				RWUE (kg/ha-mm)			
	2008–09	2009–10	2010–11	Mean	2008–09	2009–10	2010–11	Mean
Sole cotton	924	424	617	655	2.86	0.92	0.79	1.52
Sole greengram	824	1007	758	863	2.55	2.25	0.97	1.92
Sole blackgram	892	627	517	679	2.76	1.40	0.66	1.61
Sole pigeonpea	977	743	646	789	3.02	1.62	0.82	1.82
Sole maize	589	412	784	595	1.82	0.92	1.00	1.25
Sole soybean	1,093	741	643	826	3.38	1.66	0.82	1.95
Cotton + greengram (1:1)	1,145	933	780	953	3.54	2.09	1.00	2.21
Cotton + blackgram (1:1)	1,175	819	955	983	3.64	1.83	1.22	2.23
Cotton + pigeonpea (1:1)	1,171	682	737	863	3.63	1.48	0.94	2.02
Cotton + maize (1:1)	1,204	564	882	883	3.73	1.26	1.13	2.04
Cotton + soybean (1:1)	1,262	727	820	936	3.91	1.63	1.05	2.19
Mean	1,023	698	740	820	3.17	1.55	0.94	1.89
SD	203	187	126	128	0.63	0.42	0.16	0.31
SEm±	53	69	25	49	0.16	0.15	0.03	0.09
CD (P=0.05)	155	204	74	144	0.42	0.40	0.08	0.24
CV (%)	19.8	26.8	17.1	15.6	19.9	27.3	17.2	16.6

ping systems indicated that higher cotton equivalent yield could be achieved with short duration intercrops like cowpea.

At Akola under semi-arid Vertisols, different intercropping systems gave cotton equivalent yield with coefficient of variation in the range of 8.7% in 2009–10 to 17.1% in 2010–11 with mean of 12.6%; while they gave RWUE of 24.0% in 2010–11 to 46.8% in 2008–09 with mean of 21.4% over years (Table 4). Cotton + soybean (1:1) gave significantly higher cotton equivalent yield of 1803 kg/ha in 2008–09 with RWUE of 3.91 kg/ha-mm and 1,479 kg/ha with RWUE of 1.68 kg/ha-mm in 2010–11, while cotton + soybean + pigeonpea + soybean (3:2:2:2) was superior in 2009–10 with cotton equivalent yield of 2,040 kg/ha with RWUE of 4.09 kg/ha-mm (Table 4). However, cotton + soybean (1:1) was superior with maximum mean cotton equivalent yield of 1609 kg/ha with RWUE of 2.90 kg/ha-mm, while cotton + soybean + pigeonpea + soybean (3:2:2:2) was at par with the superior system with mean cotton equivalent yield of 1573 kg/ha with RWUE of 2.85 kg/ha-mm over 3 years. Further, cotton + soybean (1:1) being in additive series with short duration soybean interspaced adequately in between cotton rows was found to be highly resource use-efficient system with respect to utilization of seasonal rainfall of 461 mm received in 2008–09, 499.2 mm in 2009–10 and a high rainfall of 879.6 mm in 2010–11 as indicated by significantly higher RWUE of 3.91, 3.09 and 1.68 kg/ha-mm during 2008–09, 2009–10 and 2010–11 respectively with overall mean of 2.90 kg/ha-mm over years. Cotton + pigeonpea either in 4:2 or 6:2 row ratio found to be less efficient with respect to CEY and RWUE when compared to other intercropping systems and this might be due to competition for resources below and above ground during critical stages of pigeonpea and cotton. Higher base crop equivalent yields were observed by Aal (1991) in a study on cotton + soybean intercropping, Ghosh *et al*. (2006) in groundnut + cereals and soybean + pigeonpea intercropping systems and Khan *et al*. (2001) in cotton based intercropping systems compared to sole crops due to yield advantage resulted with higher resource use-efficiency.

Competition indices

Under semi-arid Vertisols at Khedbrahma, the partial LER of intercropped cotton was more than intercrops with maximum LER (0.93) when cotton was intercropped with

Table 4. Cotton equivalent yield and rainwater use efficiency in cotton based intercropping systems at Akola (mean of 3 years)

Treatments	Cotton equivalent yield (kg/ha)				RWUE (kg/ha-mm)			
	2008–09	2009–10	2010–11	Mean	2008–09	2009–10	2010–11	Mean
Sole cotton	1,069	996	965	1,010	2.32	2.00	1.10	1.80
Sole soybean	1,648	1,024	1,392	1,355	3.62	2.58	1.74	2.65
Sole pigeonpea	370	3,096	823	1,430	0.80	6.02	0.94	2.59
*C+S+P+S (3:2:2:2)	1,384	2,040	1,295	1,573	3.00	4.09	1.47	2.85
Cotton + soybean (1:1)	1,803	1,544	1,479	1,609	3.91	3.09	1.68	2.90
Cotton + pigeonpea (4:2)	723	1,833	999	1,185	1.57	3.67	1.14	2.13
Cotton + pigeonpea (6:2)	819	1,016	1,001	945	1.78	2.04	1.14	1.65
Mean	1,117	1650	1,136	1,301	2.40	3.40	1.30	2.40
SEm±	78	90	112	93	0.17	0.18	0.13	0.15
CD (P=0.05)	241	279	346	289	0.52	0.57	0.40	0.48
CV (%)	12.1	8.7	17.1	12.6	46.8	42.2	24.0	21.4

*C, cotton; S, soybean; P, pigeonpea

Table 5. Performance of cotton based intercropping systems as measured by competition indices at Khedbrahma

Treatments	LER			RCC			CR	
	L_a	L_b	Total	K_a	K_b	K	CR_a	CR_b
Cotton + greengram (1:1)	0.86	0.47	1.33	6.08	0.89	5.43	1.82	0.55
Cotton + blackgram (1:1)	0.86	0.57	1.44	6.35	1.34	8.51	1.51	0.66
Cotton + pigeonpea (1:1)	0.82	0.48	1.30	4.66	0.92	4.31	1.71	0.58
Cotton + maize (1:1)	0.93	0.50	1.43	12.48	1.04	13.00	1.81	0.55
Cotton + soybean (1:1)	0.84	0.46	1.29	5.18	0.84	4.34	1.84	0.54

L_a and L_b - partial LERs of cotton and green gram/black gram/maize/soybean, respectively. K_a and K_b are the RCC values of cotton and green gram/black gram/maize/soybean, respectively CR_a and CR_b are the CR values of cotton and green gram/black gram/maize/soybean respectively.

maize. The yield advantage in terms of LER was higher with cotton + blackgram (1.44) (Table 5) indicating that 44% more area would be required by a sole crop to equal the yield of intercropping system (Midya *et al.,* 2005). This also showed an advantage from intercropping over pure stands in terms of efficient use of land or environmental resources for plant growth (Mead and Willey, 1980, Dhima, *et al.,* 2007). Cotton + blackgram (1:1) and cotton + maize (1:1) were superior with maximum land equivalent ratio (LER) of 1.44 compared to cotton + greengram (1:1), cotton + pigeonpea (1:1) and cotton + soybean (1:1) systems. Higher yield advantage in cotton based intercropping systems with higher LER was also recorded by Aasim *et al.* (2008). The RCC was found to be 8.51 in cotton + blackgram (1:1) compared to the highest of 13.0 in cotton + maize (1:1) and lowest of 4.31 in cotton + pigeonpea (1:1) (Table 5). The values of partial K for cotton (K_a = 4.66 to 12.48) were more than one and also more (K_b = 0.84 to 1.34) than intercrops which indicated cotton as a dominant crop and more competitive than intercrops. Khan *et al.,* (2001) also reported higher K values for cotton intercropped with legumes (Banik *et al*., 2000). The CR values of cotton were more compared to intercrops under all the intercropping systems studied which indicated that cotton was more competitive than the intercrops (Khan *et al*. 2001). In respect of an efficient intercropping as assessed by CR, cotton + blackgram (1:1) was superior, since the system recorded lower CR (2.17) compared to other systems (ranged between 2.29 to 2.38) and also indicated that the competition in the growth of two species was best managed by choosing cotton and black gram for less competition for resources and attain maximum productivity. Although, cotton + black gram (1:1) had a higher RCC of 8.51 compared to cotton + pigeonpea (1:1) (4.31), cotton + soybean (1:1) (4.34), cotton + green gram (1:1) (5.43), the RCC coefficient of cotton (Ka) was marginally higher compared to other crops. In blackgram also, same was the situation based on RCC (Kb). Based on CR, cotton + blackgram (1:1) had the lowest CR value for cotton (1.51), while it was the highest for blackgram (0.66) based on the system. The maximum CR value of 1.84 in cotton with 0.54 for soybean was observed under cotton + soybean (1:1) system. Thus, cotton + blackgram (1:1) was more efficient in respect of yield attained in less area and less time period (Khan *et al.,* 2001) with efficient coefficients of LER, RCC and CR for the system in the three year study under Vertisols.

At Akola under semi-arid Vertisols, the LER obtained in all the intercropping systems was more than one indicating yield advantage. Maximum LER of 1.31 (Table 6) was obtained with cotton + soybean (1:1) which indicated that 31% more area would be required by a sole crop to equal the yield attained under intercropping system (Midya *et al*., 2005). There was a further advantage from intercropping over pure stands in terms of efficient use of land or environmental resources for plant growth (Mead and Willey, 1980, Dhima, *et al.,* 2007). In a multi-tier cotton + soybean + pigeonpea + soybean (3:2:2:2) intercropping system, though two intercrops were included, the LER was observed to be 1.25 which was lower than the maximum LER of 1.31 obtained from cotton + soybean (1:1). This indicated less utilization of land resources or more competition by the component crops for the limited resources. In all the intercropping systems, cotton had lower partial K_a values (0.75 to 1.58) than intercrops (1.19 to 3.89) in the respective intercropping systems indicating that cotton was a dominated crop and less competitive than the respective intercrops. In cotton + soybean (1:1) intercropping system, soybean had partial K_b value (3.89) which indicated that soybean was highly competitive and a dominant crop. The product of the coefficients of component crops was greater than one in all the intercropping systems except cotton + pigeonpea (6:2) where K value was 0.98. Therefore, all other intercropping systems had definite yield advantage except cotton + pigeonpea (6:2) indicating that this system has no advantage and the component crops were highly competitive for the limited resources (Banik *et al*., 2000). In all the intercropping systems, the CR values of cotton (0.64 to 1.09) were less than the intercrops (1.31 to 1.57) in the respective intercropping systems (Table 8) which indicated that cotton had a higher competition from the component crops. Based on CR values, cotton + soybean + pigeonpea + soybean (3:2:2:2) was less efficient with higher CR (3.15) compared to other

Table 6. Performance of cotton based intercropping systems as measured by competition indices at Akola

Treatments	LER				RCC				CR		
	L_a	L_b	L_c	Total	K_a	K_b	K_c	K	CR_a	CR_b	CR_c
Cotton + soybean + pigeonpea + soybean (3:2:2:2)	0.44	0.47	0.34	1.25	1.58	1.10	1.81	3.15	1.09	0.75	1.31
Cotton + soybean (1:1)	0.52	0.80	-	1.31	1.07	3.89	-	4.17	0.65	1.54	-
Cotton + pigeonpea (4:2)	0.60	0.42	-	1.01	0.75	2.13	-	1.59	0.72	1.38	-
Cotton + pigeonpea (6:2)	0.71	0.37	-	1.09	0.83	1.19	-	0.98	0.64	1.57	-

intercropping systems, while cotton + soybean (1:1) and cotton + pigeonpea with row ratios of 4:2 / 6:2 were more efficient with CR values of 2.19 and 2.10/2.21 respectively. Cotton + soybean (1:1) with higher LER and efficient CR and RCC values were found to be more efficient intercropping system as the competition in the growth of two crop species was best managed with less competition resulting in higher productivity.

Profitability and Sustainability

At Khedbrahma, due to higher cost of cultivation in cotton, the lower net returns and lower benefit: cost ratios were observed as compared to other sole crops. However, higher net returns (₹13,489 to ₹18,893/ha and benefit: cost ratios (2.08 to 2.68) were reported with all intercropping systems as compared to sole cotton (₹ 9,610/ha and 2.06, respectively). Among intercropping systems, cotton + black gram (1:1) was superior with maximum net returns of ₹18,893/ha with benefit: cost ratio of 2.68. Under semi-arid Vertisols at Akola, among different intercropping systems, mean maximum net returns of ₹35,177/ha with benefit: cost ratio of 2.94 were attained by cotton + soybean (1:1) system followed by cotton + soybean + pigeonpea + soybean (3:2:2:2) with mean net returns of ₹34,184/ha and benefit: cost ratio of 2.95. The cotton based intercropping systems were found to be remunerative (Khan *et al*., 2001) and also increased income by 30 to 40% with different cotton based intercropping systems (Sayeed *et al*. 1991).

Sustainability yield index

Based on multiple regression model of cotton equivalent yield through crop seasonal rainfall, the regression model of CEY through crop seasonal rainfall were calibrated for each location and are given below:

Akola : $CEY = -13736 + 49.080\ (CRF) - 0.037\ (CRF^2)$

Khedbrahma : $CEY = 3100^{**} - 9.985^{**}\ (CRF) + 0.008^{**}\ (CRF)^2$

The cotton equivalent yield had a predictability (R^2) value of 0.88 under Vertisols at Khedbrahma, while it had a lower predictability of 0.19 under Vertisols at Akola. The prediction error was found to be minimum of 94 kg/ha at Khedbrahma, while it was maximum of 553 kg/ha at Akola based on the multiple regression model calibrated for each location over years. The difference of the mean cotton equivalent yield of a cropping system and the prediction error of yield based on regression model was compared with the maximum potential yield attained at a location. Maximum potential cotton equivalent yield (Y_{max}) of 1262 kg/ha attained at Khedbrahma and 3096 kg/ha attained at Akola were considered for deriving the sustainability yield index of different cropping systems

Table 7. Net returns, BC ratio and sustainability yield index of cotton based intercropping systems at Khedbrahma (mean of 3 years)

Treatments	Net returns (₹/ha)	Benefit: cost ratio	SYI (%)
Sole cotton	9,610	2.06	44.5
Sole greengram	22,073	5.45	60.9
Sole blackgram	15,600	4.16	46.4
Sole pigeonpea	17,177	3.51	55.1
Sole maize	12,349	2.60	39.7
Sole soybean	18,770	3.71	58.0
Cotton + greengram (1:1)	17,883	2.59	68.1
Cotton + blackgram (1:1)	18,893	2.68	70.4
Cotton + pigeonpea (1:1)	13,489	2.08	60.9
Cotton + maize (1:1)	14,454	2.21	62.5
Cotton + soybean (1:1)	16,917	2.49	66.7
Mean	16,110	3.05	57.6
SEm±	1,051	0.32	13.9
LSD (P=0.05)	2,061	0.62	28.0
CV (%)	21.6	34.6	17.6

over 3 years. Based on the SYI, cotton + black gram (1:1) was superior with SYI of 70.4% at Khedbrahma, while sole maize attained lowest SYI of 39.7% among different cropping systems. Cotton + green gram (1:1) was the second best system with SYI of 68.1% under semi-arid Vertisols (Table 7). At Akola, cotton + soybean (1:1) was superior with maximum sustainability yield index of 34.1%, while cotton + pigeonpea (6:2) attained lowest SYI of 12.7% in the study period (Table 8). Cotton + soybean + pigeonpea + soybean (3:2:2:2) was the second best intercropping system with SYI of 32.9% under semi-arid Vertisols. The regression models of cotton equivalent yield through crop seasonal rainfall indicated that better yield prediction could be made at Khedbrahma (R^2 of 0.88) compared to Akola (R^2 of 0.19). The maximum potential yield of 1262 kg/ha was found to be sustainable with SYI of 70.4% by adopting cotton + blackgram (1:1) system under Vertisols at Khedbrahma. This was closely followed by cotton + greengram (1:1) system with SYI of 68.1% for attaining maximum cotton equivalent yield. However, under semi-arid Vertisols at Akola, cotton + soybean (1:1) was efficient with maximum SYI of 34.1% for attaining cotton equivalent yield of 3096 kg/ha, and was closely followed by cotton + soybean + pigeonpea + soybean (3:2:2:2) multi-tier intercropping system with SYI of 32.9% over years. It is observed that the most inferior system of growing sole maize had lowest SYI of 33.3%, while the best system of cotton + soybean (1:1) had an almost equal SYI of 34.1% at Akola. Thus the intercropping systems were best suited for attaining maximum sustainable cotton equivalent yield with significantly lower prediction in different rainfall conditions as observed in

Table 8. Net returns, benefit: cost ratio and sustainability yield index of cotton based intercropping systems at Akola (mean of 3 years)

Treatments	Net returns (₹/ha)	B C : ratio	SYI (%)
Sole cotton	16,972	2.03	14.8
Sole soybean	29,285	2.90	25.9
Sole pigeonpea	33,983	3.36	28.3
*C + S + P + S (3:2:2:2)	34,184	2.95	32.9
Cotton + soybean (1:1)	35,177	2.94	34.1
Cotton + pigeonpea (4:2)	22,966	2.38	20.4
Cotton + pigeonpea (6:2)	24,887	2.42	12.7
Mean	28,208	2.71	24.2
SEm±	2,598	0.17	3.2
CD (P=0.05)	5,093	0.33	6.3
CV (%)	24.4	16.7	35.0

*C, cotton; S, soybean; P, pigeonpea

the study period.

Efficient cotton based intercropping system based on productivity, resource use efficiency competition indices, profitability and sustainability

At Khedbrahma, cotton + black gram (1:1) was superior with maximum mean cotton equivalent yield of 983 kg/ha and RWUE of 2.23 kg/ha-mm over 3 years. It also gave maximum net returns of ₹18,893/ha with BC ratio of 2.68 compared to other systems. Cotton + black gram (1:1) was superior with maximum land equivalent ratio (LER) of 1.44. The relative crowding coefficient (RCC) was found to be 8.51 in cotton + black gram (1:1). It had lowest CR value for cotton (1.51). Maximum CR value of 1.84 in cotton with 0.54 for soybean was observed under cotton + soybean (1:1) system. The maximum potential yield of 1262 kg/ha was found to be sustainable with SYI of 66.7% by adopting cotton + black gram (1:1) system under Vertisols at Khedbrahma. This was closely followed by cotton + green gram (1:1) system with SYI of 61.6% for attaining maximum cotton equivalent yield.

At Akola, cotton + soybean (1:1) was superior with maximum mean cotton equivalent yield of 1609 kg/ha and RWUE of 2.90 kg/ha-mm, while cotton + soybean + pigeonpea + soybean (3:2:2:2) was at par with the superior system with mean cotton equivalent yield of 1573 kg/ha and RWUE of 2.85 kg/ha-mm over three years. Maximum net returns of ₹35,177/ha with BC ratio of 2.94 was attained by cotton + soybean (1:1). It was also superior with maximum LER of 1.31 and RCC value of cotton + soybean (1:1) 4.17. The CR index indicated the superiority of cotton + soybean (1:1) with value of 0.65 and 1.54, respectively. Thus cotton + soybean (1:1) was superior based on all the quantitative indices under semi-arid Vertisols. Cotton + soybean (1:1) was efficient with maximum SYI of 34.1% for attaining cotton equivalent yield of 3096 kg/ha, and was closely followed by cotton + soybean + pigeonpea + soybean (3:2:2:2) multi-tier intercropping system with SYI of 32.9% over years.

Under semi-arid (moist) Vertisols, cotton + blackgram (1:1) at Khedbrahma and cotton + soybean (1:1) at Akola were found to be superior with respect to higher productivity, profitability and resource use efficiency with best competition indices. Hence, these two intercropping systems could be adopted under similar rainfed agro-ecological situations in the respective recommendation domains.

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