Indian Journal of Agricultural Sciences **87** (11): 1528–34, November 2017/Article

Bamboo (*Dendrocalamus strictus*) + sesame (*Sesamum indicum*) based agroforestry model: A sustainable livelihood option for farmers of semi-arid region

INDER DEV[1], ASHA RAM[2], S P AHLAWAT[3], D R PALSANIYA[4], RAM NEWAJ[5], R K TEWARI[6], RAMESH SINGH[7], K B SRIDHAR[8], R P DWIVEDI[9], M SRIVASTAVA[10], O P CHATURVEDI[11], R V KUMAR[12] and R S YADAV[13]

ICAR-Central Agroforestry Research Institute, Jhansi, Uttar Pradesh 284 003

Received: 15 March 2017; Accepted: 18 July 2017

ABSTRACT

A study on *Dendrocalamus strictus* + *Sesamum indicum* based agroforestry was conducted at ICAR-Central Agroforestry Research Institute, Jhansi (Uttar Pradesh), India during 2007 to 2012 to find out the suitability of bamboo based agroforestry system (AFS) in the semi-arid region. Bamboo recorded survival of 62 to 77% (1st year), 86 to 96 (2nd year) and 100% thereafter. *D. strictus* culm (No.) varied in the range of 178-388 (1st year); 936 to 1439 (2nd year); 1507 to 2134 (3rd year); 2182 to 2901 (4th year) and 2422 to 3215 (5th year, i.e. at harvest stage). Bamboo did not influence the sesame yields during initial two years, however, yield level got reduced during subsequent years. During 5th year intercropped sesame yield got reduced 15.69 (10m × 10m bamboo) and 10.09% (10m × 12m bamboo) as compared to pure crop. Bamboo clump affected the sesame yield substantially and 16.3, 14.3, 7.5 and 0.3% sesame yield reduction was observed at a distance of 1.0, 2.0, 3.0 and 4.0m, respectively, during 5th year. Organic C increased from 3.92 to 6.24 g/kg soil over a period of five years in bamboo based AFS. At harvest stage of bamboo (5th year), highest B:C ratio of 2.83 was observed in 10m×10m bamboo + sesame followed by 2.59 (10m×12m bamboo + sesame) and 1.43 (pure sesame). Therefore, bamboo based AFS has economic and environmental advantages over the sole crop and due to this, the system could be one of best alternative livelihood options for farmers of semi-arid tropics.

Key words: Agroforestry system, Bundelkhand region, Productivity, Shade, Tree-Crop interaction

Bamboo is a very fast growing perennial plant and has the ability to produce culms every year and gives very high return in comparison of timber trees (Sandhu *et al.* 2010, Tewari *et al.* 2016). Bamboos have an about 1500 uses that includes food, construction, fuel, charcoal, medicinal products and the manufacture of paper, flooring, screens and clothing etc. (Filho *et al*. 2004, Chauhan and Kumar 2005, Pilliere 2008). Demand for bamboo was 26.9 million tonnes against the supply of 13.47 million tonnes (Mandal and Khanduri 2004) with almost 50% deficit. To meet the domestic demand, India imported bamboo worth US$ 5.62 million in 2012 (COMTRADE data 2013). The Government of India launched National Bamboo Mission in 2006-07 as a Centrally Sponsored Scheme to promote the bamboo in the country. In order to meet the present and future demand, expansion of bamboo in non-forest area through agroforestry will be viable approach for increasing bamboo area as well improving the livelihood of the marginal and small farmers (Rahangdale *et al*. 2014).

D. strictus (Roxb.) is the most commonly found bamboo species in India and occupies about 53% of total bamboo area in India (Seethalakshmi and Kumar 1998). It has a good tensile strength (28000 lb/inch^2), greater than the mild steel (23000 lb/inch^2) making it one of the world's best natural engineering materials, and an essential for earthquake resistant construction. Cultivation and maintenance cost of *D. strictus* is very low as compared to short rotation

[1]Principal Scientist (e mail: drinderdev@gmail.com), Agronomy; [2]Scientist (e mail: ashusirvi84@gmail.com), Agronomy, ICAR-Central Agroforestry Research Institute, Jhansi U.P. 284003; [3]Head (e mail: ahlawatsp@gmail.com), ICAR-National Bureau of Plant Genetic Resources, New Delhi 110012, India; [4]Senior Scientist (e mail: drpalsaniya@gmail.com), Agronomy, ICAR-Indian Grassland and Fodder Research Institute, Jhansi 284 003 (U.P); [5]Principal Scientist (e mail: ramnewaj@gmail.com), Agronomy; [6]Principal Scientist (e mail: rktserjam62@gmail.com), Horticulture; [7]Principal Scientist (e mail: rameshsinghnrcaf@gmail.com), SWE; [8]Scientist (e mail: sriaranya@gmail.com), Forestry; [9]Principal Scientist (e mail: raghudwivedi66@gmail.com), Agricultural Extension; [10]DST Women Scientist (e mail: madhulika.csir@gmail.com); [11]Director (e mail: chaturvediopc@gmail.com), ICAR-Central Agroforestry Research Institute, Jhansi 284003, U.P.; [12]Head (e mail: rvkumar4@rediffmail.com), ICAR-Indian Grassland and Fodder Research Institute, Jhansi 284003 (U.P); [13]Head (e mail: rsyadav@icar.org.in), ICAR-Indian Institute of Soil and Water Conservation, RC, Datia 475661 (M.P).

trees species like poplar, eucalyptus, leucaena etc. It starts yielding commercial culms after 4–5 years of establishment, which can be harvested annually till flowering occurs (35–50 years). Bamboo is also of ecological importance in providing various ecosystem services including carbon sequestration (Kaushik *et al.* 2015), preventing soil erosion by its strongly developed rhizomes and roots and is used in cultural rituals (Bystriakova *et al*. 2003). Because of its economic and ecological importance and wider adaptability and versatility, bamboos have the potential to be incorporated into agroforestry systems in the semi-arid tropics in place of conventional tree species. The semi-arid tropic (SAT) region of India in general and Bundelkhand region in particular is prone to severe droughts due to undulating topography, shallow soil depth, low water holding capacity and high evapo-transpiration owing to intense radiation. The *D. strictus* is very hardy and can thrive very well in the Bundelkhand region suffering from periodically excessive drought and poor agricultural productivity (<1.0 t/ha).

Fodder shortage, frequent drought and "*Anna Pratha*", a traditional system under which farmers leave their cattle unfettered to graze in the open or in the other's field making farmers less inclined to sow their land in *kharif* season. Sesame has the tremendous potential in Bundelkhand region, because cattle do not eat this crop. Furthermore, sesame is an ideal crop for rainfed area and may give good economic returns to the farmers. Recently, Government of Uttar Pradesh also stepped in with a policy announcement after recognizing the potential for sesame cultivation in Bundelkhand during *kharif* by giving subsidies on sesame seed (Prasad 2015). Bamboo and sesame have emerged as a new hope for the marginal and small farmers, however, no work has been done on bamboo + sesame based agroforestry in the Bundelkhand region. This study is a part of the coordinated research project on "Development of bamboo based agroforestry systems for six agro-climatic zones" with funds under R&D project of National Bamboo Mission, Ministry of Agriculture, New Delhi. The project was initiated at ICAR-Central Agroforestry Research Institute (CAFRI), Jhansi (UP) in 2007. The present study aims at to find out the suitability of bamboo + sesame agroforestry system suitable for semi-arid environment conditions.

MATERIALS AND METHODS

Field study on bamboo + sesame based agroforestry system was carried out at the research farm of ICAR-Central Agroforestry Research Institute, Jhansi (Uttar Pradesh), India during 2007 to 2012. The study site was situated at 25º 30′ - 25º 32′ N latitude and 78º 32′ - 78º 34′ E longitudes at an altitude of 272 m above msl. Soil of the experimental site was low in fertility and inter-mixed red and black soil group of Bundelkhand region of Uttar Pradesh covered under the order of Alfisol. The area received less than the average rainfall during 2007 and 2009 (mean annual rainfall is 867 mm), while during rest of the study period it was normal/above normal. The experiment was laid out in randomized block design (RBD) with three replications and five treatments {M_1: 10m ×10m bamboo + sesame; M_2: 10m × 12m bamboo + sesame; M_3: pure crop (sesame); M_4: 10m ×10m pure bamboo; M_5: 10m × 12m pure bamboo}. In the experiement, 12 clumps per plot (3 × 4: rows × clumps) having 100 clumps/ha (10m × 10m) and 84 clumps/ha (10m × 12m) were maintained. Sesame crop was grown during *kharif* season as intercrop as per treatments with standard package of practices. Observations in sesame were recorded at a distance of 1.0 (S_1), 2.0 (S_2), 3.0 (S_3) and 4.0 m (S_4) (considering as sub plot treatments) from bamboo clump and were analyzed under split plot design. Oil content in sesame seed was estimated by Soxhlet method (Soxhlet 1879). Five clumps were randomly selected in each treatment and identified with paint marking. The numbers of culm in these selected clumps were counted. Survival (%) was recorded over the years. The ANOVA test was performed using SPSS 17.0 statistical software to compare the treatment means. Treatment means were compared at the 5% level of significance ($P<0.05$) using least significant difference.

RESULTS AND DISCUSSION

Dendrocalamus strictus

Survival of bamboo varied in the range of 62 to 77% (first year), 86 to 96% (second year) and 100% (third year onwards). The mortality during the initial years was due to delayed planting (late September) (Bundelkhand region remained under severe drought during 2004-2007). On an average, there were 276, 1194, 1829, 2501 and 2814 number of culms/ha during 1st to 5th year, respectively. No. of culm varied in the range of 178-388 (1st year); 936 to 1439 (2nd year); 1507 to 2134 (3rd year); 2182 to 2901 (4th year) and 2422 to 3215 (5th year, i.e. at harvest stage). Significantly more number of culm were obtained in T_1 (bamboo–10m × 10m + sesame) over the years as compared to pure bamboo at both the spacing (Fig 1). Intercropping of sesame has no adverse effect on bamboo growth rather intercropping

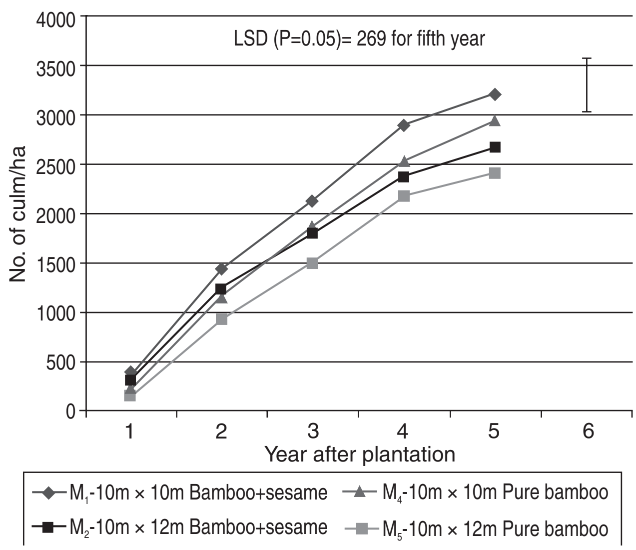

Fig 1 No. of bamboo culms/ha in sesame+bamboo based AFS

improved the no. of bamboo culm as compared to sole bamboo.

Influence on sesame crop

Growth

During initial two years, the bamboo plantation did not influence the sesame plant population significantly (Table 1), however, plant population (m^{-2}) of sesame was adversely affected in bamboo based AFS 3rd year onward and it was observed to be significantly lower as compared to pure crop. However, plant population (m^{-2}) of intercropped sesame in both the bamboo spacing (M_1: 10m × 10m, and M_2: 10m × 12m) were observed at par. No significant differences in plant population were found at various distances from bamboo clump upto two years of bamboo plantation. Sesame plant population during third year and subsequently upto fifth year of bamboo plantation, were observed significantly lower at 1.0 and 2.0 m than the plant population at 3.0 and 4.0 m distance from the bamboo clump. Lowest plant populations were found at 1.0 m distance from clump, while maximum population was observed at 4.0m. Lowest sesame population nearer to the bamboo clump could be attributed to high competition for various resources *viz.* light, water, space, nutrients etc.

Bamboo plantation did not affect the plant height of sesame during first two years of bamboo plantation, while during 3rd, 4th and 5th year of plantation, plant height in bamboo based AFS was significantly higher over the plant height of pure crop (Table 1). Likewise within in the AFS, during 3rd year onwards, the average plant height nearer to bamboo clump (at 1.0 and 2.0 m distance) was observed significantly higher as compared to plant height observed at 3.0 and 4.0 m distance from bamboo clump.

Data presented in Table 1 indicated that primary and secondary branches were not influenced during first two years of plantation, thereafter bamboo plants and density affected the primary and secondary branches substantially. During 3rd year onwards, pure crop of sesame produced significantly higher primary and secondary branches as compared to sesame in bamboo based AFS. The no. of primary branches/m varied in the range of 6.25 to 7.0 (M_1: 10m×10m-bamboo+sesame), 6.30 to 6.75 (M_2:10m×12m-bamboo+sesame) and 6.82 to 7.20 (M_3: pure sesame). Similarly the secondary branches/m varied in the range of 5.30 to 5.70 (M_1), 5.40 to 5.79 (M_2) and 5.30 to 6.05 (M_3). Observations recorded in sub plots indicated that number of primary and secondary branch were significantly higher at 3.0 and 4.0 m as compared to 1.0 and 2.0 m distance from the bamboo clump.

Yield contributing characters

Data on yield contributing characters (Table 2 and Fig 2) indicated that during initial growth period (first two years of establishment) bamboo offered by and large no competition to sesame intercrop in AFS. During the subsequent years, various yield contributing characters were influenced in the bamboo based AFS.

Table 1 Growth parameters of sesame under bamboo based agroforestry system

Treatment	Plant population (m^{-2})					Plant height (cm)					No. of primary branches/plant					No. of secondary branches/plant				
	2008	2009	2010	2011	2012	2008	2009	2010	2011	2012	2008	2009	2010	2011	2012	2008	2009	2010	2011	2012
Main plot (Bamboo spacing)																				
M_1: 10m × 10m	30.1^a	32.0^a	32.3^b	30.5^b	29.2^b	111.5^a	105.5^b	110.0^b	113.5^b	109.5^b	7.00^a	6.60^a	6.20^b	6.50^b	6.25^b	5.57^a	5.35^a	5.50^b	5.30^b	5.70^b
M_2: 10m × 12m	29.5^a	33.1^a	32.9^b	30.9^b	30.5^b	113.7^a	105.4^b	110.1^b	111.2^b	107.7^b	6.52^a	6.75^a	6.35^b	6.67^b	6.30^b	5.62^a	5.40^a	5.55^b	5.50^b	5.79^b
M_3: Pure crop	32.0^a	33.2^a	34.1^a	32.5^a	32.0^a	112.5^a	107.3^a	107.2^a	109.0^a	103.0^a	6.82^a	6.75^a	7.20^a	7.15^a	6.70^a	5.65^a	5.30^a	5.69^a	5.90^a	6.05^a
Sub plot (Distance from bamboo clump)																				
S_1: 1.0m	30.5^a	32.5^a	30.5^b	29.9^b	29.0^b	110.5^a	104.2^b	112.2^b	115.5^b	112.0^b	6.72^a	6.45^a	6.30^b	6.48^b	6.18^b	5.49^a	5.29^a	5.48^b	5.25^b	5.55^b
S_2: 2.0m	31.7^a	33.7^a	31.2^b	31.5^b	30.1^b	112.0^a	105.5^b	111.2^b	112.0^b	108.5^b	6.77^a	6.66^a	6.25^b	6.62^b	6.33^b	5.58^a	5.41^a	5.57^b	5.42^b	5.68^b
S_3: 3.0m	30.9^a	31.2^a	32.8^b	32.5^a	31.7^a	111.8^a	104.9^b	107.5^a	109.1^a	104.5^a	6.95^a	6.58^a	6.75^b	6.93^a	6.51^a	5.48^a	5.37^a	5.67^a	5.77^a	5.89^a
S_4: 4.0m	32.2^a	32.8^a	33.5^a	33.1^a	32.5^a	114.0^a	106.0^a	108.0^a	108.7^a	103.5^a	6.80^a	6.40^a	7.10^a	6.90^a	6.67^a	5.62^a	5.33^a	5.75^a	5.93^a	6.01^a

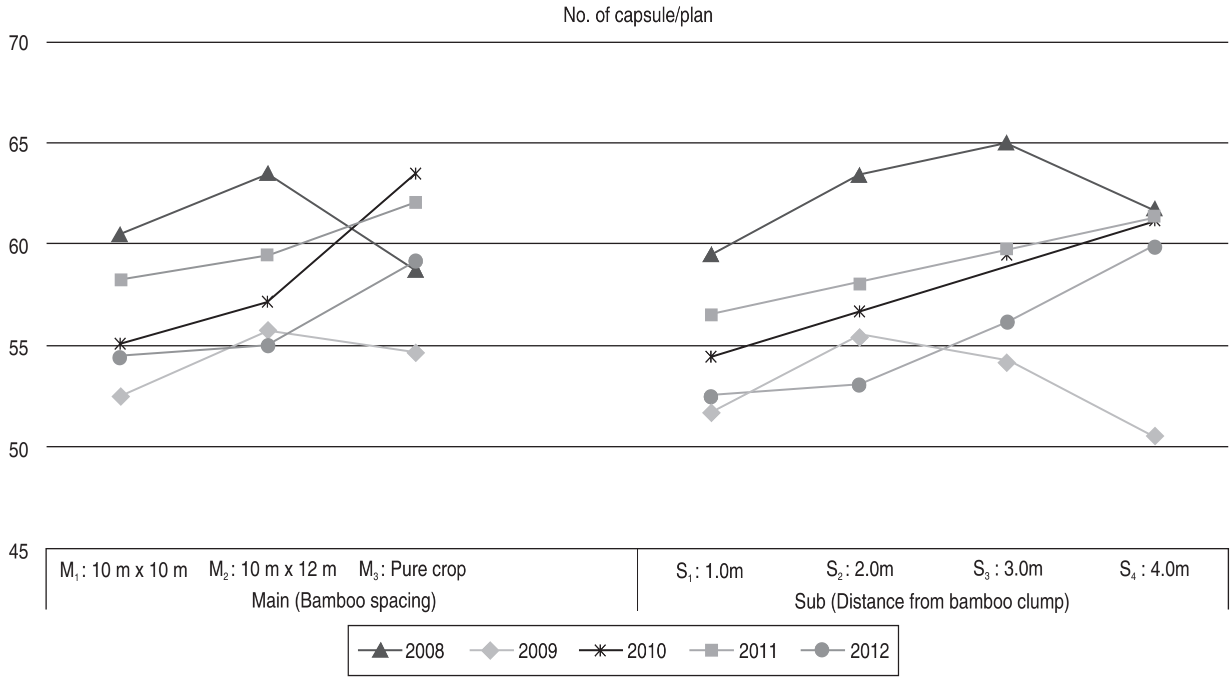

Fig 2 No. of capsules/plant in sesame under bamboo based AFS

Table 2 Yields contributing characters and oil content of sesame under bamboo based agroforestry system

Treatment	No. of seed/capsule					Test weight (g)					Oil content (%)				
	2008	2009	2010	2011	2012	2008	2009	2010	2011	2012	2008	2009	2010	2011	2012
Main plot (Bamboo spacing)															
M_1: 10m × 10m	43.5[a]	41.2[a]	44.2[b]	42.0[b]	43.7[b]	3.15[a]	3.25[a]	3.10[a]	3.15[a]	3.15[a]	32.5[a]	32.7[a]	32.2[a]	33.7[a]	34.0[a]
M_2: 10m × 12m	42.2[a]	40.5[a]	45.2[b]	42.1[b]	45.5[b]	3.05[a]	3.18[a]	3.12[a]	3.20[a]	3.20[a]	33.1[a]	33.5[a]	33.0[a]	32.8[a]	33.7[a]
M_3: Pure crop	40.0[a]	42.1[a]	47.0[a]	46.2[a]	47.2[a]	3.11[a]	3.17[a]	3.18[a]	3.22[a]	3.22[a]	34.1[a]	32.7[a]	32.8[a]	33.5[a]	33.5[a]
Sub plot (Distance from bamboo clump)															
S_1: 1.0 m	41.2[a]	43.2[a]	44.5[b]	41.5[b]	42.7[b]	3.20[a]	3.18[a]	3.17[a]	3.20[a]	3.17[a]	33.5[a]	34.0[a]	33.5[a]	32.1[a]	33.5[a]
S_2: 2.0 m	44.5[a]	45.2[a]	43.7[b]	43.5[b]	43.0[b]	3.10[a]	3.23[a]	3.15a	3.18[a]	3.18[a]	35.0[a]	33.7[a]	32.7[a]	33.2[a]	33.6[a]
S_3: 3.0 m	45.0[a]	44.7[a]	46.3[a]	45.9[a]	46.8[a]	3.11[a]	3.18[a]	3.20[a]	3.23[a]	3.25[a]	34.1[a]	33.8[a]	31.8[a]	32.7[a]	34.1[a]
S_4: 4.0 m	43.5[a]	42.5[a]	47.8[a]	46.2[a]	48.1[a]	3.17[a]	3.15a	3.15[a]	3.25[a]	3.30[a]	35.2[a]	32.7[a]	33.0[a]	32.5[a]	32.1[a]

A perusal of the fig 2 reveals that No. of capsules/plant were not affected by bamboo plantation during initial two years. However, during 3rd, 4th and 5th year, no. of capsules/plant were observed to be significantly lower in bamboo based AFS (M_1: 10m × 10m, and M_2: 10m × 12m) as compared to pure crop. No. of capsules/plant at different distance from bamboo clump were statistically at par during initial two years of plantation, while during 3rd year onward the capsules were observed significantly lower at 1.0 and 2.0 m distance as compared to 3.0 and 4.0 m distance from bamboo clump. During 5th year of plantation, 12.6, 11.6, 6.48 and 0.3% reduction in no. of capsules/plant were observed at a distance of 1.0, 2.0, 3.0 and 4.0 m, respectively from the clump in both the spacing of bamboo (M_1: 10m × 10m, and M_2: 10m × 12m) as compared to pure crop.

During initial two years of bamboo plantation, the no. of seeds/capsule were not affected significantly in bamboo based AFS and pure crop (Table 2). However, no. of seeds/capsule were observed significantly lower in both the bamboo spacing as compared to pure crop during third year onwards. During fifth year of bamboo plantation, no. of seeds/capsule were 7.41 and 3.6% less in intercropped sesame between bamboo spacing M_1: 10m × 10m, and M_2: 10m × 12m, respectively as compared to sole crop. During third year onwards, no. of seeds/capsule were reduced significantly nearer to bamboo clump (at 1.0 and 2.0 m) as compared to plants at 3.0 and 4.0 m distance from the bamboo clump. However, no. of seeds/capsule at 3.0 and 4.0m distance and in pure crop was statistically at par during 3rd, 4th and 5th year of bamboo establishment.

Oil content (%)

Data presented in Table 2 indicated that oil content (%) varied in the range of 31.8 to 34.0% in different treatments

Table 3 Yields and harvest index of sesame under bamboo based agroforestry system

Treatment	Seed yield (kg/ha)					Stover yield (kg/ha)					Harvest index (%)				
	2008	2009	2010	2011	2012	2008	2009	2010	2011	2012	2008	2009	2010	2011	2012
Main plot (Bamboo spacing)															
M_1: 10m × 10m	557.7[a]	540.5[a]	510.7[b]	528.5[b]	502.1[b]	1109[a]	1101[a]	1036[b]	1045[b]	1012[b]	33.46[a]	32.93[a]	33.02[a]	33.59[a]	33.16[a]
M_2: 10m × 12m	537.6[a]	547.4[a]	518.5[b]	537.5[b]	535.5[b]	1041[a]	1109[a]	1024[b]	1089[b]	1092[b]	34.06[a]	33.05[a]	33.61[a]	33.05[a]	32.90[a]
M_3: Pure crop	550.7[a]	535.1[a]	570.5[a]	561.5[a]	595.6[a]	1068[a]	1062[a]	1113[a]	1102[a]	1165[a]	34.02[a]	33.50[a]	33.89[a]	33.75[a]	33.83[a]
Sub plot (Distance from bamboo clump)															
S_1: 1.0 m	545.0[a]	560.2[a]	507.2[b]	515.2[b]	498.2[b]	1101[a]	1110[a]	1025[b]	1045[b]	995[b]	33.11[a]	33.54[a]	33.10[a]	33.02[a]	33.36[a]
S_2: 2.0 m	562.7[a]	550.3[a]	522.9[b]	529.5[b]	510.2[b]	1109[a]	1108[a]	1059[b]	1031[b]	1035[b]	33.66[a]	33.18[a]	33.06[a]	33.93[a]	33.02[a]
S_3: 3.0 m	550.0[a]	538.8[a]	555.6[a]	547.5[a]	550.8[a]	1091[a]	1062[a]	1095[a]	1089[a]	1089[a]	33.52[a]	33.66[a]	33.66[a]	33.46[a]	33.59[a]
S_4: 4.0 m	567.2[a]	562.5[a]	565.8[a]	556.9[a]	593.5[a]	1154[a]	1107[a]	1105[a]	1125[a]	1156[a]	32.95[a]	33.69[a]	33.86[a]	33.11[a]	33.92[a]

in bamboo based AFS. No significant differences were observed in oil content (%) due to bamboo plantation as well as due to distance from the bamboo culm, however, significant differences were observed in total oil yield as influenced by different treatments.

Yields (seed and stover) and harvest index

During initial two years of bamboo establishment, no significant differences were observed in yields in bamboo based AFS and in pure crop (Table 3). However, during 3rd year onwards, seed yield in both the bamboo spacing (M_1: 10m × 10m, and M_2: 10m × 12m) were observed significantly lower as compared pure crop. Yield reduced with age of bamboo plantation. During fifth year of plantation 15.69 and 10.09% yield got reduced in sesame intercropped between M_1: 10m × 10m, and M_2: 10m × 12m bamboo spacing, respectively as compared to pure crop. No influence was observed in sesame yield in both the bamboo spacing at different distances upto two year of bamboo establishment. During 3rd year onwards, sesame yield nearer to bamboo clump was reduced significantly as compared to yield at 3.0 and 4.0 m distances. During 5th year, 16.3, 14.3, 7.5 and 0.3% yield reduction was observed at 1.0, 2.0 3.0 and 4.0 m, respectively. Similar trend was observed in stover yield and corresponding values for stover yield reduction were 14.5, 11.1, 6.52 and 0.8%, respectively. No significant differences were observed in harvest index in sesame crop in bamboo based AFS as well as in pure crop.

Economic returns

Cost of cultivation was higher in bamboo+ sesame as compared to bamboo and sesame alone during 2008. During initial four years, net returns in pure crop were 94.1, 0.7, 43.2 and 29.2% higher during 1st, 2nd, 3rd and 4th, respectively over the bamboo spaced at 10m × 10m in sesame (Table 4). However, during 5th year highest net return (₹ 34.76 thousand/ha) was recorded in (M_1:10m × 10m bamboo spacing) followed by in M_2:10m × 12m bamboo spacing (₹ 31.82 thousand/ha) and in pure sesame crop (₹ 14.72 thousand/ha). Harvesting of bamboo culm was started in fifth year and 1/3rd of bamboo stand was harvested with net return of ₹ 19.84, 16.15, 21.04 and 16.94 thousand/ha in M_1, M_2, 10m × 10m pure bamboo and 10m × 12m pure bamboo, respectively. After fifth year, harvesting of 1/3rd bamboo culms were expected every year. During fifth year, among the bamboo + sesame agroforestry systems and pure sesame crop, highest B: C ratio observed as 2.83(M_1) followed by 2.59 (M_2) and minimum was recorded as 1.43 (pure crop).

Soil fertility

The soil had 6.54 (pH), 0.180 dS/m (EC), 3.92/kg (soil O.C.), 213 kg/ha (available N), 5.28 kg/ha (available P) and 185 kg/ha (available K) at initial stage of experimentation. After five years pH was observed more or less same but organic carbon, N, P and K content increased in all the landuse treatments (Table 5). Increase in organic carbon from 3.92 to 6.24 g/kg soil, N from 213 to 275 kg/

Table 4 Financial analysis of bamboo + sesame agroforestry system

Treatment	Cost of cultivation (₹'000)					Net return (₹'000)					B: C ratio				
	2008	2009	2010	2011	2012	2008	2009	2010	2011	2012	2008	2009	2010	2011	2012
M_1: 10m × 10m	11.51	8.72	9.35	10.05	12.30	3.83	6.69	5.20	7.23	34.76	0.33	0.77	0.56	0.72	2.83
M_2: 10m × 12m	10.88	8.72	9.35	10.05	12.30	3.91	6.89	5.40	7.89	31.82	0.36	0.79	0.58	0.78	2.59
M_3: Pure crop	7.71	8.52	9.10	9.75	10.30	7.44	6.74	7.44	9.34	14.72	0.97	0.79	0.82	0.96	1.43
M_4: 10m × 10m pure bamboo	3.80	0.20	0.25	0.30	2.00	-3.80	-0.20	-0.25	-0.30	21.04					3.52
M_5: 12m × 10m pure bamboo	3.17	0.20	0.25	0.30	2.00	-3.17	-0.20	-0.25	-0.30	16.94					3.20

Table 5 Changes in soil fertility in sesame + bamboo based AFS

Treatment	pH	OC (g/kg soil)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
Initial status	6.54	3.92	213.0	5.28	185.0
Final status (after 5 years)					
M_1: 10m × 10m	6.49	6.24	275.0	5.75	195.0
M_2: 10m × 12m	6.51	6.20	258.0	5.68	193.0
M_3: Pure crop	6.60	5.43	229.0	5.38	182.0
M_4: 10m × 10m pure bamboo	6.58	6.10	244.0	5.50	199.0
M_5: 12m × 10m pure bamboo	6.57	6.08	240.0	5.46	196.0

ha and available P from 5.28 to 5.75 kg/ha were observed in M_1, followed by M_2 and pure bamboo treatments.

Higher growth and production of trees when cultivated in agroforestry systems might be due to benefits drawn by tree plantations from various agricultural inputs, *viz.* irrigation, tillage, fertilizers etc. (Singh *et al.* 1998, Chaturvedi 1992, Verma 2008, Chauhan *et al.* 2012). The allelopathic effect of bamboo as well as shade, besides more competition for various resources might have resulted in reduced plant population of sesame under AFS and nearer to the bamboo clump. Reduction in various growth parameters and yield attributing parameters of various crops under different AFS were reported by several studies in India (Sharma and Chauhan 2003, Dey *et al.* 2007, Chauhan *et al.* 2010, Pandey *et al.* 2010, Chauhan *et al.* 2012, Rahangdale *et al.* 2014). Plants in shade conditions are generally taller than plants in open conditions. This may be due to long and thinner stem of the crop plants (Thangam and Thamburaj 2008). The competition between trees and understorey crops not only exist for aboveground resources (i.e. light) but also for below ground resources (i.e. nutrients, moisture) resulting poor growth and yields of the plants (Gao *et al.* 2013). Kaushal and Verma (2003) also reported that negative effects of trees were more on growth and yield of the crop, which were grown in its close vicinity. Dev *et al.* (2016) observed that chickpea seed yield was 25.95 (10m × 10m bamboo spacing) and 21.08% (10m × 12m bamboo spacing) lower as compared to sole chickpea during 3rd year in *D. strictus* based AFS and it was also observed that distance from the clump had also significant influence on the seed yield. During 3rd year seed yield recorded at a distance of 4.0 m from the bamboo clump was significantly higher as compared to 1.0, 2.0 and 3.0 m distance. The reduction in seed yield of sesame may be attributed to reduced Photosynthetic Active Radiation (Gao *et al.* 2013) under bamboo canopy in comparison to sole crop of sesame. Agroforestry species including bamboo become more competitive with age and consequently decrease the crop yields (Shanmughavel and Francis 2001, Ahlawat *et al.* 2008, Chauhan *et al.* 2010, Behari 2013, Dev *et al.* 2015).

Net returns were higher in pure sesame upto four years as compared to bamboo based AFS, however, during 5th year, bamboo based AFS (when 1/3rd bamboo culms were harvested) recorded higher net returns. Higher return in pure sesame during 1st year could be attributed to lower cost of cultivation as compared to cost involved in bamboo establishment. Bamboo leaf litter and fine root decomposition might have enhanced the soil organic matter and other nutrients (N, P and K) in bamboo based AFS as compared to pure crop (Nath and Das 2012, Mehta *et al.* 2012).

D. strictus based AFS produced bamboo stock as well as sustained crop yields over the years. Increased bamboo stock during subsequent years, resulted in gradual reduction of crop yields, however, yield reduction was compensated through bamboo stock harvesting. Organic C content increased over the years in the bamboo based AFS. Similarly, the economic returns were also higher in bamboo based AFS during 5th year. *D. strictus* intercropping with sesame is therefore economically and environmentally advantageous.

ACKNOWLEDGEMENTS

Authors are thankful to the National Bamboo Mission for providing the funds for the study and Director, ICAR-CAFRI for providing necessary facilities and guidance for executing the study.

REFERENCES

Ahlawat S P, Kumar R V, Gupta V K and Dhyani S K. 2008. Scope of bamboo based agroforestry system in India. (*In*) *Proceeding of national conference on Bamboo management, conservation, value addition and promotion* held at TFRI Jabalpur (India) from 12-14th March, 2008. p 89.

Behari B. 2013. Agroforestry model of bamboo cultivation on degraded agricultural land. PhD thesis, Guru Ghasidas University, Bilaspur.

Bystriakova N, Kapos V, Lysenko I and Stapleton C M A. 2003. Distribution and conservation status of forest bamboo diversity in the Asia-Pacific Region. *Biodiversity and Conservation* **12:** 183–4.

Chaturvedi A N.1992. Optimum rotation of harvest for poplars in farmlands under agroforestry. *Indian Forester* **118**(2): 81–8.

Chauhan S K and Kumar L. 2005. Bamboo: an ideal species for agroforestry in India. *Asia-Pacific Agroforestry News* **27**: 14.

Chauhan S K, Sharma R, Sharma S C, Gupta N and Ritu. 2012. Evaluation of poplar (*Populus deltoides* Bartr. Ex Marsh.) boundary plantation based agri-silvicultural system for wheat-paddy yield and carbon storage. *International Journal of Agroforestry and Silviculture* **2**(5): 239–46.

Chauhan S K, Sharma S C, Beri V, Ritu, Yadav S and Gupta N. 2010. Yield and carbon sequestration potential of wheat (*Triticum aestivum*) and poplar (*Populus deltoides*) based agri-silvicultural system. *Indian Journal Agricultural Sciences* **80**(2): 129–35.

COMTRADE data, accessed from the INBAR Bamboo and Rattan Trade Database on July 19, 2013.

Dev I, Ahlawat S P, Palsania D R, Ram A, Newaj Ram, Tewari R K, Singh R, Sridhar K B, Dwivedi R P, Srivastava M, Chaturvedi O P, Kumar R V and Yadav R S. 2016. A sustainable livelihood option for farmers' of semi-arid region: Bamboo + Chickpea based Agroforestry model. *Indian Journal of Agroforestry* **18**(1): 84–9.

Dev I, Dhyani S K, Ram A, Sridhar K B, Tiwari R, Srivastava M, Singh R and Ahlawat S P. 2015. Weed dynamics under bamboo-based agroforestry system in semi-arid region. (*In*) *25th Asian-Pacific Weed Science Society Conference on Weed Science for Sustainable Agriculture, Environment and Biodiversity*, Hyderabad, India during 13-16 October 2015, p 370.

Dey A N, Mohanty T L and Patra S N. 2007. Economics of bamboo based agroforestry system in Eastern and South-Eastern coastal plain of Orrisa. *Indian Journal of Forestry* **30**(3): 179–282.

FAO. 2005. World Bamboo Resources- A Thematic Study Prepared in the Framework of the Global Forest Resources Assessment, 2005.

Filho A P and Badr O. 2004. Biomass resources for energy in North-Easter Brazil. *Applied Energy* **77:** 51–67.

Gao L, Xu H, Bi H, Xi W, Bao B, Wang X, Bi C and Chang Y. 2013. Intercropping competition between apple trees and crops in agroforestry systems on the Loess Plateau of China. *PLoS ONE* **8**(7): e70739. doi:10.1371/journal.pone.0070739.

Kaushal R and Verma K S. 2003. Tree-Crop interaction studies in natural agroforestry system: A case study from Western Himalayas in India. (*In*) *Proceedings of XII World Forestry Congress*, Quebec City, Canada.

Kaushik S, Singh Y P, Kumar D, Thapliyal M and Barthwal S. 2015. Bamboos in India, ENVIS Centre on Forestry, National Forest Library and Information Centre. Forest Research Institute, Dehradun, p 326.

Mandal R and Khanduri S K. 2004. Product diversification in bamboo- opportunities for sustainable development. Souvenir, 7 World Congress, 27 Feb. to 4 March 2004, held in Delhi.

Mehta R, Dinakaran J, Patel S, Laskar A H, Yadava M G, Ramesh R and Krishnayya N S R. 2012. Changes in litter decomposition and soil organic carbon in a reforested tropical deciduous cover (India). *Ecology Research* DOI 10.1007/s11284-012-1011-z.

Nath A J and Das A K. 2012. Carbon pool and sequestration potential of village bamboos in agroforestry systems in Northeast India. *Tropical Ecology* **53**(3): 287–93.

Pandey A K, Gupta V K and Solanki K R. 2010. Productivity of neem-based agroforestry system in semi-arid region of India. *Range Management Agroforestry* **31**(2):144–9.

Pilliere E. 2008. Communicating Science through a dynamic website concerning the multiple uses of bamboo. Biosciences Horizons. https://www.nottingham.ac.uk/ biosciences/ documents/ burn/2008/communicating-science-through-a-dynamic-website-elizabeth-pilliere, 2008, pdf. 1–14.

Prasad A M. 2015. Indigenous oilseed may change fortunes of Bundelkhand's farmers. http://indianexpress.com/article/india/india-news-india/indigenous-oilseed-may-change-fortunes-of-bundelkhands-farmers/

Rahangdale C P, Pathak N N and Koshta L D. 2014. Impact of bamboo species on growth and yield attributes of Kharif crops under agroforestry system in wasteland condition of the Central India. *International Journal of Agroforestry and Silviculture* **1**(3): 31–6.

Sandhu M K, Chauhan S K, Sharma R and Gosal S S. 2010. Micro-propagation of three bamboo species from nodal explants of mature culms. *Journal of Agricultural Science and Technology* **4**(2): 1–7.

Seethalakshmi K K and Kumar M S M. 1998. Bamboos of India. A Compendium, Kerala Forest Research Institute. Kerala and International Network for Bamboo and Rattan, p. 342.

Shanmughavel P and Francis K. 2001. Intercropping trials of four crops in plantation. *Journal of Bamboo and Rattan* **1**(1): 3–9.

Sharma S K and Chauhan S K. 2003. Performance of soybean crop under tree species. *Indian Journal of Agroforestry* **5**(1&2): 137–9.

Singh K, Ram P, Singh A K and Hussain A. 1998. Poplar (*Populus deltoides* Bartram ex Marshall) in forest and agroforestry systems. *Indian Forester* **114**(11): 814–8.

Soxhlet F. 1879. Die gewichtsanalytische Bestimmung des Milchfettes. *Polytechnisches J. (Dingler's)* **232**: 461–5.

Tewari R K, Ram A, Dev I, Sridhar K B and Singh R. 2016. Farmers' friendly technique for multiplication of bamboo (*Bambusa vulgaris*). *Current Science* **111**(5): 886–9.

Thangam M and Thamburaj S. 2008. Comparative performance of tomato varieties and hybrids under shade and open conditions. *Indian Journal of Horticulture* **65**(4): 429–33.

Verma A. 2008. Evaluation of growth behaviour of *Populus deltoides* Marsh. clones under farm forestry. M Sc thesis, PAU, Ludhiana.