Research Article

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Effect of spacing and pruning regimes on photosynthetic characteristics and yield of cocoa in mixed cropping with arecanut

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Abstract

The experiment was laid out with cocoa (*Theobroma cacao* L.) as a mixed crop with arecanut (*Areca catechu* L) in 1994 at the Regional Station, Vittal. There were two spacing (S1 - 2.7 x 2.7 m; S2 - 2.7 x 5.4 m) and three canopy size (P1 - small, P2 - medium and P3 - large) treatments. The photosynthetically active radiation (PAR) and light interception varied significantly during the years. The differences in photosynthesis of spacing treatments were significant and showed increasing trend with years of growth. Similar results were noticed in transpiration rate and stomatal conductance. There was no significant difference in intercellular CO_2. Chlorophyll fluorescence indices viz., Fo, Fm, Fv and Fv/Fm were lower in S2 treatment as compared to S1. There were significant differences with regard to year and pruning regimes on bean yield of cocoa. Maximum yield was obtained in S1P3 and S2P3 treatments.

Keywords: Chlorophyll fluorescence, photosynthesis, pruning, *Theobroma cacao* L, yield

Introduction

Cocoa plants, which are grown under arecanut as mixed crop (Shama Bhat, 1988) need proper regulation of the canopy. This can be done by proper pruning methods. The light environment within crop canopies is characterized by temporal and spatial variability. The rate of photosynthesis (Pn) is also related to changes in chlorophyll fluorescence emission (Walker *et al.*, 1983; Ireland *et al.*, 1984). These are affected by the canopy architecture in trees. Proper canopy management is required to maintain shape and size. Optimization of leaf area is essential for productivity of cocoa. Pruning trials in Ghana showed that during early years pruned trees showed higher yield, but in later years unpruned trees gave higher yields (Bonaparte, 1966). Discretionary pruning showed higher yield (Martin and Prasad, 1983). Pruning showed non-significant negative effect in five years old trees (Ampofo, 1986). In a trial with five canopy treatments, it was found that big spreading canopy gave the highest yields (Thomas and Balasimha, 1992). A spacing and pruning trial with seedling progenies have shown that significant interaction existed between spacing and pruning treatments with reference to bean yields (Balasimha, 2001). Growth and canopy characteristics have been studied in cocoa grafts in relation to spacing and pruning regimes (Balasimha, 2006). Proper, systematic and timely pruning is essential in cocoa cultivation to ventilation, tree height and agronomic practices (Lik and Hussein, 2001). Pruning for maintenance and rehabilitation are performed during cocoa life cycle (Mohd Yusoff, 1996).

Maximum leaf areas should be maintained with pruning practices to avoid self-shading and interference with main crop. Photosynthetic characteristics in cocoa seedling progenies with different plant density and canopy architecture were studied earlier (Balasimha, 2001). Similar effect of plant density and pruning has also been reported in cashew (Balasimha and Yadukumar, 1993). In this paper photosynthesis and chlorophyll fluorescence parameters in relation to spacing and pruning regimes are reported.

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Materials and Methods

The experiment was laid out with cocoa (*Theobroma cacao* L.) grafts as a mixed crop with arecanut in 1994 at the Regional Station, Vittal. The arecanut was planted at 2.7 x 2.7 m spacing which works out to be 1350 trees/ha. There were two spacing (S1 - 2.7 x 2.7 m and S2 - 2.7 x 5.4 m) and three canopy size (P1 – small, 10 m^3, P2 – medium, 10-15 m^3 and P3 – large, 16-20 m^3) treatments for cocoa. The plants were fertilized with 100:40:140 g of NPK per plant annually and irrigated regularly during summer months. The arecanut palms were four years old at the time of planting of cocoa. For cocoa, the plant density in these spacings works out to be 1350 and 675 per ha in S1 and S2 treatments, respectively. The trial was laid out in a split-plot design with four replications and statistical analysis done accordingly. The plot size was 6 trees. The canopies of cocoa were pruned from 4th year onwards annually during August by removing required quantity of branches and foliage to maintain the pruning regimes.

Field measurements were taken during December each year from 10.00h to 12.00h. The photosynthetic measurements were done from 3rd to 8th years, while light interception was recorded from 3rd to 10th years of growth of cocoa. Yield was collected from 4th to 10th years. Photosynthetic parameters were measured using portable photosynthetic system LI-6200 (Balasimha *et al.*, 1991). Photosynthetically active radiation (PAR), temperature, vapour pressure deficit (VPD), photosynthesis (Pn), transpiration (E) and stomatal conductance (gs) were recorded on 3-5 mature leaves of outer canopy using a 1-liter chamber. In each case, fully expanded, healthy 3rd to 4th leaf from distal portion of hardened flush (approximately 1-month old) were used. About 30 cm^2 leaf area was enclosed and equilibrated for 1-2 min before taking the measurements. Water use efficiency was computed from Pn and E values. Two observations for each leaf were recorded and atleast four leaves sampled per tree. Chlorophyll fluorescence was measured using Hansatech Plant Efficiency Analyzer (Balasimha, 1992). A leaf clip was attached to the leaf and shutter closed for 30 min to dark adaptation. The measurements were done and data were later transferred to computer. Pods were harvested every year during harvesting season and dry bean yield estimated.

Results and Discussion

The microclimatic variables were recorded during the years with respect to treatments are given in Tables 1-4. The photosynthetically active radiation (PAR) was significantly higher during early years of growth (Table 1). There was significant difference in treatments P3. This is mainly due to the fact that the canopy of cocoa had not developed considerably during early years. Other parameters like temperature (Table 2), relative humidity (RH) (Table 3) and vapour pressure deficit (VPD) (Table 4) showed significant differences with respect to pruning and years. There was also significant interaction between spacing and pruning regimes. This is due to the higher PAR during early years of growth that causes higher VPD. The light interception was increased with growth of cocoa plants over the years (Table 5). Once the canopies developed full, more than 90 % of light interception was recorded. In cashew there was significant higher photosynthesis in wider spacing trees, which was parallel with higher PAR levels (Balasimha and Yadukumar, 1993).

Table 1. PAR ($\mu mol\ m^{-2}s^{-1}$) in cocoa

Years (Y)	Spacing (S)	Pruning (P)			
		P1	P2	P3	Mean
3	S1	734	594	638	655
	S2	628	754	554	646
	Mean	681	674	596	
4	S1	441	479	583	501
	S2	457	424	462	448
	Mean	449	451	522	
5	S1	200	423	392	338
	S2	454	420	421	432
	Mean	327	421	407	
6	S1	559	487	622	556
	S2	542	474	542	519
	Mean	551	480	582	
7	S1	111	215	161	162
	S2	332	360	139	277
	Mean	221	288	150	
8	S1	173	345	164	227
	S2	426	372	302	367
	Mean	300	358	233	
CD (P=0.05)	Y	137			
	S	NS			
	P	NS			
	S x P	NS			

NS - Not Significant

The differences in Pn of different treatments were significant with reference to spacing and years (Table 6) but not with pruning treatments. The Pn was higher during early years as compared to later years which may be mainly because the PAR was also higher during the period. The results of transpiration rate (Table 7) and stomatal conductance (Table 8) showed slightly different responses. There were significant differences with respect to pruning and years. Stomata of intact leaves generally open in response to increased PAR and is directly related to transpiration rate (Burrows and Milthorpe, 1976).

Table 2. Changes in temperature (°C)

Years (Y)	Spacing (S)	Pruning (P)			
		P1	P2	P3	Mean
3	S1	34.05	34.54	34.85	34.48
	S2	34.77	34.12	34.83	30.06
	Mean	34.41	34.37	34.84	
4	S1	31.53	31.52	32.44	31.83
	S2	32.21	31.40	31.61	31.74
	Mean	31.87	31.46	32.02	
5	S1	30.03	30.74	31.27	30.68
	S2	31.75	30.70	30.96	31.14
	Mean	30.89	30.72	31.11	
6	S1	33.69	34.83	35.83	34.63
	S2	35.77	35.18	34.85	35.27
	Mean	34.73	35.01	35.12	
7	S1	29.84	29.74	30.01	29.86
	S2	30.80	30.12	30.00	33.65
	Mean	35.32	29.94	30.01	
8	S1	30.21	30.56	30.81	30.53
	S2	31.51	30.81	28.70	30.34
	Mean	30.86	30.69	29.75	
CD (P = 0.05)	Y	2.31			
	S	NS			
	P	NS			
	S x P	1.96			

NS - Not Significant

Table 3. Changes in relative humidity (%)

Years (Y)	Spacing (S)	Pruning (P)			
		P1	P2	P3	Mean
3	S1	40.52	38.59	39.37	39.49
	S2	37.12	40.46	41.13	39.57
	Mean	38.82	39.52	40.25	
4	S1	51.24	48.77	46.06	48.68
	S2	47.88	49.61	45.53	47.64
	Mean	49.56	49.19	45.78	
5	S1	51.06	49.52	44.54	48.37
	S2	46.14	48.39	46.52	47.01
	Mean	48.60	48.98	45.49	
6	S1	36.81	38.06	33.12	36.05
	S2	34.53	36.96	36.26	35.91
	Mean	36.65	37.49	34.78	
7	S1	53.29	52.77	50.00	52.02
	S2	49.90	52.03	51.03	50.98
	Mean	51.59	52.39	50.51	
8	S1	51.59	48.29	49.06	49.64
	S2	46.92	49.42	49.74	48.69
	Mean	49.52	48.85	49.40	
CD (P = 0.05)	Y	2.92			
	S	NS			
	P	1.20			
	S x P	1.70			

NS - Not Significant

Table 4. Changes in vapour pressure deficit (kPa)

Years (Y)	Spacing (S)	Pruning (P)			
		P1	P2	P3	Mean
3	S1	32.13	33.80	34.38	33.43
	S2	35.11	32.46	32.17	33.24
	Mean	33.62	33.13	33.27	
4	S1	22.80	23.89	26.15	24.40
	S2	25.27	23.27	25.54	24.67
	Mean	24.01	23.58	26.02	
5	S1	21.21	2.49	25.66	23.12
	S2	25.47	23.00	24.25	24.24
	Mean	23.34	22.75	24.95	
6	S1	36.04	35.29	38.69	36.67
	S2	38.62	36.01	35.75	36.79
	Mean	37.33	35.65	37.22	
7	S1	19.76	19.83	21.39	20.33
	S2	22.40	20.71	20.99	21.37
	Mean	21.08	20.27	21.19	
8	S1	20.06	23.08	22.91	22.35
	S2	24.71	22.77	22.75	23.41
	Mean	22.89	22.93	22.83	
CD (P = 0.05)	Y	2.98			
	S	NS			
	P	0.84			
	S x P	1.19			

NS - Not Significant

Table 5. Changes in light interception by cocoa canopy (%)

Years (Y)	Spacing (S)	Pruning (P)			
		P1	P2	P3	Mean
3	S1	83.73	64.12	81.16	76.34
	S2	75.22	81.35	75.11	77.23
	Mean	79.47	72.74	78.14	
4	S1	85.62	87.03	88.63	87.09
	S2	75.58	87.03	88.26	83.62
	Mean	80.60	87.03	88.45	
5	S1	67.12	93.76	90.07	83.65
	S2	88.46	86.66	83.10	86.07
	Mean	77.79	90.12	86.58	
6	S1	91.82	88.46	92.90	91.06
	S2	91.95	91.66	93.34	92.32
	Mean	91.88	90.06	93.12	
7	S1	96.14	97.47	96.40	96.67
	S2	93.37	94.28	95.07	94.24
	Mean	94.76	95.88	95.73	
8	S1	98.47	97.46	96.35	97.43
	S2	91.33	96.22	93.80	93.78
	Mean	94.90	96.84	95.06	
9	S1	97.81	97.21	96.33	97.12
	S2	94.17	96.66	90.88	93.74
	Mean	95.99	96.69	93.60	
10	S1	98.85	98.75	96.19	97.93
	S2	94.90	98.62	93.64	95.66
	Mean	96.87	98.68	94.82	
CD (P=0.05)	Y	6.31			
	S	NS			
	P	NS			
	S x P	NS			

NS - Not Significant

Table 6. Photosynthesis in cocoa (µmol $m^{-2}s^{-1}$)

Years (Y)	Spacing (S)	Pruning (P)			
		P1	P2	P3	Mean
3	S1	5.25	3.75	4.24	4.41
	S2	4.32	5.02	4.79	4.71
	Mean	4.78	4.39	4.52	
4	S1	3.30	4.05	4.41	3.92
	S2	4.05	4.06	4.02	4.04
	Mean	3.67	4.05	4.21	
5	S1	2.92	4.62	3.33	3.63
	S2	5.18	4.12	3.73	4.35
	Mean	4.05	4.37	3.53	
6	S1	3.33	3.45	2.43	3.07
	S2	3.00	3.66	2.42	3.03
	Mean	3.16	3.56	2.42	
7	S1	2.58	2.15	2.25	2.32
	S2	3.41	4.05	2.44	2.30
	Mean	2.99	3.10	2.34	
8	S1	2.30	2.81	2.91	2.67
	S2	3.62	4.04	3.15	3.60
	Mean	2.96	3.42	3.03	
CD (P=0.05)	Y	0.64			
	S	0.37			
	P	NS			
	S x P	NS			

NS - Not Significant

Table 7. Transpiration rate in cocoa (mmol m^{-2} s^{-1})

Years (Y)	Spacing (S)	Pruning (P)			
		P1	P2	P3	Mean
3	S1	4.26	4.44	3.90	4.20
	S2	4.15	4.73	4.90	4.59
	Mean	4.21	4.58	4.40	
4	S1	5.49	5.24	5.08	5.27
	S2	5.38	5.38	3.96	4.91
	Mean	5.44	5.31	4.52	
5	S1	5.17	4.83	3.50	4.50
	S2	4.45	4.20	4.14	4.26
	Mean	4.81	4.52	3.82	
6	S1	5.05	5.70	5.08	5.28
	S2	5.56	6.18	4.86	5.54
	Mean	5.30	5.94	4.97	
7	S1	3.64	3.54	3.31	3.50
	S2	3.72	3.47	3.37	3.52
	Mean	3.68	3.51	3.34	
8	S1	3.74	3.21	3.26	3.40
	S2	3.65	3.55	3.13	3.44
	Mean	3.69	3.38	3.20	
CD (P=0.05)	Y	0.48			
	S	NS			
	P	0.42			
	S x P	NS			

NS - Not Significant

Table 8. Stomatal conductance in cocoa (mol m^{-2} s^{-1})

Years (Y)	Spacing (S)	Pruning (P)			
		P1	P2	P3	Mean
3	S1	0.183	0.197	0.188	0.189
	S2	0.176	0.221	0.237	0.211
	Mean	0.179	0.209	0.212	
4	S1	0.303	0.202	0.227	0.244
	S2	0.279	0.282	0.186	0.249
	Mean	0.291	0.242	0.206	
5	S1	0.296	0.253	0.169	0.237
	S2	0.199	0.218	0.209	0.209
	Mean	0.248	0.236	0.185	
6	S1	0.165	0.204	0.140	0.170
	S2	0.173	0.204	0.148	0.175
	Mean	0.169	0.204	0.144	
7	S1	0.225	0.207	0.184	0.206
	S2	0.197	0.187	0.191	0.192
	Mean	0.211	0.197	0.188	
8	S1	0.223	0.194	0.167	0.195
	S2	0.166	0.179	0.154	0.166
	Mean	0.194	0.187	0.161	
CD (P=0.05)	Y	0.042			
	S	NS			
	P	0.026			
	S x P	NS			

NS - Not Significant

Table 9. CO_2 intercellular (ppm)

Years (Y)	Spacing (S)	Pruning (P)			
		P1	P2	P3	Mean
3	S1	274	289	274	279
	S2	277	282	290	283
	Mean	276	285	282	
4	S1	314	310	297	307
	S2	301	307	289	299
	Mean	308	308	293	
5	S1	313	298	284	299
	S2	278	295	292	288
	Mean	295	297	288	
6	S1	295	296	297	296
	S2	298	325	299	307
	Mean	296	310	298	
7	S1	324	327	322	324
	S2	306	304	319	310
	Mean	315	315	321	
8	S1	317	303	300	307
	S2	297	285	289	290
	Mean	307	294	294	
CD (P=0.05)	Y	10.8			
	S	NS			
	P	NS			
	S x P	NS			

NS - Not Significant

This is the reason for increased transpiration and conductance in initial years, which had higher incident PAR. There was also no significant difference in intercellular CO_2 in spacing and pruning treatments (Table 9). Water use efficiency (Table10) showed significant variation with respect to years and spacing that was closely similar to variations in Pn. Chlorophyll fluorescence indices viz., Fo, Fm, Fv and Fv/Fm showed lower values in S2 as compared to S1 (Table 11).

Table 10. Water use efficiency in cocoa (Pn/E)

Years (Y)	Spacing (S)	Pruning (P)			
		P1	P2	P3	Mean
3	S1	1.24	0.89	1.15	1.09
	S2	1.14	1.11	0.95	1.07
	Mean	1.19	1.00	1.05	
4	S1	0.60	0.79	0.86	0.75
	S2	0.80	0.77	1.06	0.88
	Mean	0.70	0.78	0.96	
5	S1	0.56	0.99	0.97	0.84
	S2	1.14	1.04	0.91	1.03
	Mean	0.85	1.01	0.94	
6	S1	0.63	0.59	0.51	0.58
	S2	0.59	0.58	0.56	0.58
	Mean	0.61	0.59	0.54	
7	S1	0.71	0.54	0.68	0.64
	S2	0.92	1.21	0.72	0.95
	Mean	0.81	0.88	0.70	
8	S1	0.61	0.88	0.89	0.78
	S2	1.01	1.13	1.00	1.05
	Mean	0.81	1.00	0.94	
CD (P=0.05)	Y	0.13			
	S	0.07			
	P	NS			
	S x P	NS			

NS - Not Significant

Table 11. Mean chlorophyll fluorescence parameters in cocoa (units)

Treatment Spacing	Pruning	F_o	F_m	F_v	F_v/F_m
S1	P1	541	3088	2541	0.821
	P2	544	3118	2571	0.818
	P3	533	2883	2329	0.797
Mean		546	3028	2480	0.812
S2	P1	594	2706	2116	0.776
	P2	587	2682	2094	0.778
	P3	552	2882	2344	0.803
Mean		578	2759	2184	0.785
CD (P=0.05)	Spacing	6.1	76.0	75.0	0.005
	Pruning	NS	NS	NS	NS

NS - Not Significant

Interaction of spacing and pruning treatments on bean yield is presented (Table 12). There were significant differences with regard to pruning regimes. Yield increased significantly with years and there was a significant interaction effect between spacing and pruning regimes. There was an increasing trend in yield with pruning treatments from P1 to P3. Maximum yield was recorded in S1P3 and S2P3 treatments. It is, thus, clear that canopy area is an important determinant of yield in cocoa. No study on the interaction with main crop arecanut was done in this trial, but earlier study in seedling progenies has shown that there was no effect due to various spacing and pruning treatments on arecanut trees (Balasimha, 2001). The leaf area and canopy photosynthesis are important factors of productivity as reported earlier (Thomas and Balasimha, 1992; Balasimha, 2001). From this study it is concluded that a spacing of S2P3 i.e. a spacing of 2.7 x 5.4 m and pruning regime of 16-20 m^3 canopy is recommended both from the yield point of view and agronomic advantage.

Table 12. Bean dry weight (kg ha^{-1}) in cocoa

Years (Y)	Spacing (S)	Pruning (P)			
		P1	P2	P3	Mean
4	S1	271	574	882	576
	S2	346	317	318	327
	Mean	308	446	600	
5	S1	75	479	312	288
	S2	216	258	133	202
	Mean	145	368	222	
6	S1	664	668	878	737
	S2	559	574	837	656
	Mean	611	621	858	
7	S1	554	516	932	667
	S2	377	586	783	582
	Mean	465	551	858	
8	S1	828	965	1382	1058
	S2	1260	1026	1215	1167
	Mean	1044	996	1298	
9	S1	438	625	1105	722
	S2	422	950	1264	875
	Mean	430	787	1184	
10	S1	594	1261	1336	1063
	S2	530	1227	1247	1002
	Mean	562	1244	1292	
CD (P=0.05)	Y	201			
	S	NS			
	P	97			
	S x P	257			

NS - Not Significant

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