CANOPY ARCHITECTURE, PHOTOSYNTHESIS AND YIELD OF IRRIGATED COCOA

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By

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CERTIFICATE

This is to certify that this dissertation entitled "CANOPY ARCHITECTURE, PHOTOSYNTHESIS AND YIELD OF IRRIGATED COCOA" submitted in partial fulfilment for the Degree of Master of Philosophy, of the Mangalore University embodies the results of bonafide research work done by George Thomas under my guidance and supervision. I further certify that this thesis or part of it has not previously formed the basis for the award of any degree, diploma or other similar titles.

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CONTENTS

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GEORGE THOMAS. 28/8/90.

LIST OF TABLES

Note: Significant at $P > 0.05$ (*) or $P > 0.01$ (**)

LIST OF FIGURES

1. INTRODUCTION

Cocoa (*Theobroma cacao.*Linn.) belongs to the family Sterculiaceae and its centre of origin believed to be the head waters of the Amazon basin (Alvim 1984) was introduced in India as an intercrop of arecanut (*Areca catechu*) and coconut (*Cocos nucifera*). The main uses of cocoa products are in beverages, confectionary, cosmetic and pharmaceutical industries.

Botanically cocoa is considered to be shade loving, since it has evolved as an understorey plant of Amazon forests. Field plantations of cocoa are therefore usually interplanted with shade providing species (Alvim and Alvim 1980). Other functions of shade trees are to act as a wind-break and also to counteract unfavourable ecological factors such as low soil fertility, high transpiration leading to moisture stresses (Alvim and Alvim 1980) and excessive leaf temperature (Okali and Owusu 1975). Among plantation crops cocoa is highly susceptible to drought (Balasimha 1987). Considering these factors the environmental conditions required for large scale cultivation of cocoa as a monocrop are very limited. Since arecanut is being raised as an irrigated crop in South India and since agrometeorological conditions existing in these gardens seem to compare well with the requirements of cocoa, it is widely grown as an intercrop of arecanut in South India (Bhat 1988). Under arecanut palms where the exploitation of interspace is feasible, different combinations of several shade loving species like coffee, clove, nutmeg etc are possible in addition to cocoa. Light use efficiency in arecanut based high density multispecies cropping system is an important factor determining the performance and yield of plants. An optimum canopy area, density and architecture of cocoa should be maintained to be accommodated in the available light and air space of the arecanut garden. If the optimum canopy level of cocoa is known, other shade tolerant species can be cultivated in the available space to increase the productivity per unit area.

Two major determinants of a crop are its ability to produce high photosynthates over a wide range of enviornmental conditions and to effectively transport and partition the assimilates into economically important organs (Daie 1985). As far as the cocoa physiology is concerned enhancement of the former is seriously limited because the photosynthesis of cocoa leaves is saturated at 1/5th of the full day light (RajaHarun and Hardwick 1988 a; Balasimha et al. 1989 a) and further increase of light can inhibit net photosynthesis (RajaHarun and Hardwick 1988 a). Arecanut crown transmits about 29% of the full day light and is considered to be optimum for cocoa (Balasimha 1989). Since cocoa is a plant having shade adaptation with large horizontally inclined leaves, majority of the leaves in the plant may be far below the light compensation point. The lower shaded leaves - 'parasitic leaves' - surviving below the light compensation point may import assimilate from actively photosynthesising upper leaves to maintain normal respirations (Gifford and Jenkins 1982). This unprofitable partition of assimilates to meet the maintenance, growth and respiration of shaded leaves require attention when a plant with comparatively very low net photosynthesis like cocoa comes into the picture. If a crop is not able to allocate a major portion of the fixed carbon into yields, high photosynthetic rates would not translate into increased food production (Daie 1985). An enhanced shifting of assimilates to economic produce and hence increased yield could be realised if the tissues not serving any useful function like, the leaves exposed to light intensities below the photosynthetic compensation point are removed.

An appropriate pruning can facilitate several agronomic practices such as weeding, spraying and harvesting. The interior of the tree is made more accessible and this greatly facilitates harvesting and spraying not only saving labour costs but also reducing losses caused by the leaving of ripe pods on the tree. A high incidence of black pod disease has been reported in the unpruned plant (Martin and Prasad 1983).

Foregoing discussions converge to the importance of the elucidation of an optimum canopy shape, structure and density of cocoa. Though farmers do the pruning once in an year, normally during the month of October, a well designed study to evolve optimum canopy architecture for better yield in cocoa has not been conducted so far. Therefore this endeavour was to design an optimum canopy level by giving different extents of pruning. Physiological and biochemical responses, yield and light interception efficiency of mature cocoa trees at different levels of prunings were studied.

2 REVIEW OF LITERATURE

Light is the most important environment of a plant which is required not only for photosynthesis but also as a modulator of complex developmental and regulatory mechanisms. Plants can be broadly classified into sun adapted/tolerant plants and shade adapted/tolerant plants depending on the response of a plants to sun/shade conditions (Boardman 1977; Givnish 1988). Cocoa being shade adapted, it is grown under the shade of taller plants (Alvim and Alvim 1980).

2.1. Leaf characteristics of cocoa in relation to light

Leaf characteristics of cocoa in relation to light indicate the limited adaptation of cocoa in open area. Significantly higher specific leaf weight, chl a/chl b ratio, light saturation irradiance, light saturated rate of photosynthesis and leaf nitrogen content are the characteristics of a sun adapted plant when compared with a shade adapted plant (Boardman 1977; Givnish 1988). In cocoa light saturated photosynthetic rate is very low (about 3-4 micro mol co_2 m^{-2} s^{-1}) with a low light saturation point between 350 to 400 micro mol m^{-2} s^{-1} i.e., about 1/5th of the full day light (Balasimha et al. 1989a). A slight increase in net photosynthesis and light saturation irradiance was observed from cocoa leaves grown in open area (Balasimha et al. 1989a; Guers 1974; Okali and Owusu 1975). Increase of specific leaf weight has been reported in cocoa during sun adaptation. However, chl a/chl b ratio was found to be unaltered during sun adaptation in cocoa (Balasimha 1989). Raja Harun and Hardwick (1988a) reported the performance of cocoa seedlings under various levels of irradiation at different durations. Seedlings exhibited increasing net photosynthesis (PN) upto approximately 350 to 400 micro E m^{-2} s^{-1}. Increase of irradiance upto 750 micro E m^{-2} s^{-1} had no further effect on photosynthetic rate. About 95% of maximum photosynthesis was obtained at 50% saturating intensity. When leaves were continuously exposed to light intensities exceeding 50% of that giving maximum photosynthesis, rates began to decline after four hours of exposure. A rapid decline in photosynthesis was observed when leaves of seedlings were exposed to light intensities exceeding 100% saturating intensity. A linear increase in leaf stomatal resistance with saturating intensity values above 50% was also observed. This increase in leaf resistance is an indication of biochemical malfunction of the photosynthetic mechanism and is likely to result from the inability of the photosynthetic pigments to dissipate cell excitation energy by radiationless transition to reach the ground state. Therefore photooxidation of photosynthetic pigments and photoinhibition of photosynthesis can be expected at high light intensities above those which can be safely utilized by the plant (RajaHarun and Hardwick 1988a). Photobleaching seemed to occur in the leaves of outer canopy leading to decreased chlorophyll content during the months of high solar irradiation (Balasimha 1982). In an arecanut garden where 29% of the full day light percolates through arecanut canopy (Balasimha 1989) an inhibition of photosynthesis could be expected at midday (Balasimha et al. 1989a).

None of the workers have estimated the photorespiratory dry matter loss in cocoa. Since cocoa is a typical C_3 plant with a CO_2 compensation concentration of about 100 ppm (Balasimha et al. 1989a) a 20-25% of gross photosynthesis can be wasted due to photorespiration (Tolbert 1980). Huctheon (1976) attributed 40% loss of gross photosynthesis due to photorespiration.

2.2. Stomatal behaviour in cocoa

Relative humidity (RH) followed by leaf temperature are the two important factors regulating stomatal action and hence transpiration rate (Tr) and PN in cocoa. (Balasimha and Rajagopal 1988; RajaHarun and Hardwick 1988b; Balasimha et al. 1989a). A negative correlation was observed between RH and stomatal conductance (Balasimha and Rajagopal 1988). RajaHarun and Hardwick (1988b) reported sudden decline of PN above 10 mbars of vapour pressure deficit (VPD), but Balasimha et al. 1989a observed maximum PN upto 18 mbars. A strong positive correlation exists between leaf temperature and stomatal conductance (Balasimha and Rajagopal 1988) and therefore high leaf temperature can bring about high rate of transpiration despite high stomatal resistance (RajaHarun and Hardwick 1988b). Stomata of inact leaves generally open in response to increase in photosynthetically active radiation (PAR) (Burrows and Milthorpe 1976). But in cocoa, the effect of RH is stronger than light on stomatal action and the RH can nullify the effect of light (Balasimha and Rajagopal 1988). Temperature optima of photosynthesis was observed to be 32°C (Balasimha et al. 1989a).

2.3. Carbohydrate status of the plant and crop productivity

Carbohydrate status of the cocoa plant plays an important role in the growth and productivity of cocoa. Taylor and Hadley (1988) concluded that onset of vegetative growth in cocoa takes place only if the carbohydrate in the storage pool especially in stem is higher than a set threshold, and once it is started its rate is largely determined by the level of available carbohydrate within the plant. Cocoa has an unusual development of photosynthetic apparatus. The photosynthetic pigments and enzymes do not develop until after the termination of leaf expansion (Baker and Hardwick 1973; 1976; Baker et al. 1975). With the development of chloroplast lamellae and chlorophyll synthesis, the level of ribulose bis-phosphate carboxylase activity and the photosynthetic rate increase. As a result of such pattern in photosynthetic machinery, the soluble sugar concentration rises only after leaf expansion is complete (Baker and Hardwick 1975). Due to this peculiar leaf development, developing flushes are powerful sinks of carbohydrates and they import photoassimilate from mature leaves (Bird and Hardwick 1982; Machado and Hardwick 1988; Taylor and Hadley 1988). On the contrary to other species (Thorne and Koller 1974; Ho 1979; Harold 1980), photosynthesis of mature cocoa leaves do decline at the time of peak flush development, probably due to the immobilization of dark reaction enzymes of photosynthesis (Machado and

Hardwick 1988). Decline in protein content of mature leaves has been reported (Santana and Igue 1979). Another feature of cocoa leaf is the gradual decline of photosynthetic efficiency during its life span (Machado and Hardwick 1988). Hence the current photoassimilate of a mature leaf cannot be a good contributor of carbohydrate on sink demand due to the cumulative effect of self-shading and decline of the photosynthesis. Therefore, the cessation of flushing is attributed to the depletion of stored carbohydrate (Bird and Hardwick 1982; Machado and Hardwick 1988). The physiological reason of the phenomenon called cherelle wilt is also attributed to the shortage of carbohydrate supply (Alvim 1954).

2.4. Canopy size and crop productivity

For optimum productivity a comparatively big canopy with spreading nature seems to be ideal for cocoa. Balasimha et al. (1989b) observed a positive correlation between yield and leaf area while a negative corelation between yield and leaf area index. Therefore it can be inferred that for better crop production, maximum leaf area should be maintained with least self shading of leaves. High harvest index was observed in drought tolerant accessions of cocoa accompanied by high water use efficiency, canopy photosynthesis, low leaf area index, high leaf area and high biomass production. A significantly high PN was not observed in drought tolerant high yielding accessions which showed high HI as compared to drought susceptible accessions. Thus, there is need of a high leaf area and high canopy photosynthesis to get better yield. Stem girth and number of bearing branches are also positively correlated to yield (Balasimha et al. 1989b). However such correlation cannot be expected between yield and stem diameter after the full bearing stage of plant (Glendinning 1966).

2.5. Pruning experiments on cocoa

So far three pruning experiments have been reported on cocoa

(Ampofo 1986; Bonaparte 1966; Martin and Prasad 1983). But in all these experiments a detailed physiology of pruned cocoa had not been carried out.

Martin and Prasad (1983) reported a pruning experiment with three types of pruning viz, discretionary pruning where 2-3 basal chupons were allowed to grow in addition to the main stem, strict pruning and no pruning. Discretionary pruning showed higher yield. But no pruning had higher yield than the strict pruning. This experiment was carried out on 16 year old plants which had undergone strict pruning during the first 10 years period. In a 16 years old plant the leaf area index might be higher than the optimum of 9-10 (Balasimha et al. 1989b). Therefore the discretionary pruning might have helped in maintaining the optimum leaf area index with minimum shock to plant.

Bonaparte (1966) reported a pruning experiment where during the early years the pruned trees yielded slightly more than the unpruned trees, but after ten years from planting, the unpruned trees started to yield more heavily than pruned trees. The third experiment (Ampofo 1986) included two treatments viz, restriction of the trees to the first jorquette and no pruning. This was done on five years old cocoa plants. Four years data were collected after pruning treatment. In three out of four years yield data, pruning showed negative effect on yield, but was not significant except in one season. But the cumulative yield of four years data showed significantly higher yield in unpruned over pruned trees. Besides these reports, Ramadasan et al. (1980) have demonstrated a pruning procedure to shape the cocoa plants derived from fan shoots.

3 MATERIALS AND METHODS

3.1. Location

The Central Plantation Crops Research Institute, Regional station is located at Vittal (12.25°N and 75.42°E) in Dakshina Kannada district of Karnataka, above 91 m mean sea level. The soil is typically lateritic in nature. The nutrient status of soil is as follows: pH 5.3-5.6, organic carbon 0.70-1.1%, total nitrogen 0.05-0.09% available P_2O_5 3.8-7.1ppm and available K_2O 35-85ppm. The mean rainfall over the last four years ranged from 2110.8 to 3683.4mm, annually distributed over a period of one hundred and five days. Usually a long dry period prevails from December to April. Temperature ranges between 32-33°c (maximum) and 22.0-22.6°c (minimum).

3.2. Layout

The cocoa (*Theobroma cacao* .Linn.) variety, Forestero Landas 351 was used in the present study. Planting was done in 1982 at a spacing of 2.7 x 2.7 m under the shade of 18 year old arecanut palms (*Areca catechu*,Linn.). The spacing of arecanut was 2.7 x 2.7m. However before the starting of pruning experiments, cocoa plants of the alternate rows were removed and therefore the spacing of cocoa was changed to 2.7 x 5.4 m during this trial. The fertilizer dosage per tree per year was 100g N_2, 40g P_2O_5 and 140 K_2O. Twenty rows of cocoa plants with 5 trees per row were selected from this plot and divided into five blocks, each block comprising four rows.

Five types of prunings, one to each block were given during the last week of September 1988. The types of prunings were unpruned single storied (T_1), unpruned double storied (T_2), minimal pruned cone shaped (T_3), severely pruned (T_4) and pruned flat spreading canopy (T_5). Photographs of the different tree shapes are shown in Figure 1-5. The T_1 and T_2 trees were allowed to remain as such without prun-

Fig. 1. Unpruned single storied canopy

Fig. 2. Unpruned double storied canopy

Fig. 3. Pruned cone shaped canopy

Fig. 4. Severely pruned canopy

Fig. 5. Flat spreading canopy

ing. Trees of the T_2 had a second jorquette branching after the first one whereas the T_1 had only the first jorquette branches. In T_3 all the small unbearing tertiary branches grown towards the basal portion of the primary bearing branches were cut without removing primary bearing branches. Therefore the canopy had a good aeration inside the canopy with a belt of sun-exposed apex leaves. All the primary branches except two or three were removed from the trees of the T_4 treatment irrespective of its size or position. Hence the trees of the T_4 treatment had undergone the most heavy pruning. T_4 also had no special size or shape in the canopy. The flat canopy of the T_5 was created by removing the upright branches without cutting the fan branches as far as possible. But to provide flat nature, major branches had also been removed whenever it was found necessary. Considering the extent of pruning, the T_4 had the maximum and T_3 the minimum pruning.

Measurements were taken for physiological parameters during October/November 1988 (S_1), March/April 1989 (S_2) and September 1989 (S_3). These seasons are important when crop productivity is concerned because of the onset of flowering at October/November, peak pod load at March/April and the completion of harvest by September. Growth measurements were recorded twice during the experimental period, once at the beginning (October/November 1988, S_1) and the other at the end of the experimental period (September 1989, S_3).

3.3. Sampling

One representative tree from each row was selected and all the observations except growth characters, yield and estimation of starch, sugar and nitrogen were carried out on this tree. Yield and growth characters of all the trees were noted. But for estimating starch, sugar and nitrogen, one year old twigs along with mature leaves were collected from all the trees and pooled together in row wise manner.

Leaves and stems of these pooled samples were analysed separately for starch, sugar and nitrogen after drying. Whenever a leaf had to be used for observations, an open mature leaf of a flush, preferably from third to fifth from the tip of the shoot was used. Moreover it was sampled during morning hours i.e. between 10 and 11 h or otherwise specified.

3.4. Photosynthetic characters

Photosynthetic characters viz, photosynthetically active radiation (PAR), net photosynthesis (PN), air temperature (Tair), transpiration rate (Tr), vapour pressure deficit (VPD), leaf temperature (LT), stomatal conductance (CS), internal CO_2 concentration (Ci) and ambient CO_2 (Co) concentration were measured using a Portable Photosynthesis system LI 6200 (LI - COR Inc 1987). Three leaves from outer canopy were studied enclosing upto 30 cm^2 leaf area in a one litre chamber. The sampling was usually done between 10 and 12 h and two values were recorded from each leaf. Therefore a single character from a tree was a mean of 6 values. Water use efficiency (WUE) (ratio of PN to Tr) and the ratio of internal to external CO_2 concentration (Ci/Co ratio) were calculated. Quantum flux distribution above the cocoa canopy (Li) i.e., below the arecanut crown and below the cocoa canopy (Lo) was noted, and from this light interception efficiency

$$\frac{Li - Lo}{Li} \times 100,$$ was calculated.

3.5. Estimation of sugar from phloem leaching

Total sugar from phloem leaching was estimated employing the method proposed by King and Zeivaent (1974) with necessary modifications. Three leaves were randomly sampled and dipped in 5 ml each of 20 mM EDTA solution after making a oblique cut at the tip of the petiole. These leaves were kept in a humid chamber for a period of 6hr to allow phloem leaching. After six hours leaves were removed and the leaf length noted for calculation of leaf area (Leaf area, $\log \bar{y} = -0.632 + 1.983\, x$ where $\bar{y}$ = leaf area, x = leaf length) (Reynolds 1971). Insoluble PVP (20 mg) was added to each of these samples to clear the phenolic content of the phloem leaching. The solution was shaken well and kept for sometime. Samples were filtered through Whatman No.1 filter paper and the total souble sugars of the filtrate was estimated by phenol - sulphuric acid method (Dubois et al. 1956). Sugar content was expressed in mg/cm^2 and the mean of the values obtained from the three leaves was considered.

3.6. Estimation of chlorophyll and specific leaf weight

Five leaves were sampled from all parts of the canopy and a thin ribbon of 3 mm width was cut from the central portion of each of the leaf. These ribbons were sliced and mixed well. 100 mg of tissue from this sample was extracted with 85% aqueous cold acetone and made upto 25 ml after filtering through Whatman No.1 filter paper. The samples were read at 663 nm, 646 nm and 420 nm and pigments (chlorophyll a, b and carotenoids) were quantified according to Lichtenthaler and Wellburn (1983).

Five leaves were sampled and a known area of leaf from each leaf was dried, weighed and the specific leaf weight determined.

3.7. Starch, Sugar and total nitrogen from dried leaf and stem samples

3.7.1. Soluble Sugars

Dried tissue (100 mg) was extracted thrice, each for a duration of 15 min with 20 ml of 80% aqueous alcohol at boiling temperature. After third extraction, solution along with residual portion was filtered through Whatman No, 1 filter paper. The residual portion along with the filter paper was dried in the oven at 80°C for 24 hr for starch estimation from the residue. The extract was concentrated in evaporating dishes at 80°C on a water bath and resuspended in 10 ml of distilled water. Saturated lead acetate (1 ml) was added to the resuspended samples to precipitate the phenols. The samples were shaken well and kept for 30 min. After 30 min the samples were filtered through Whatman No. 1 filter paper and the excess of lead in the filterate was removed by adding 0.6 to 0.8 ml of saturated potassium oxalate. The samples were again filtered and made upto 25 ml. An aliquot was taken and the total sugar was estimated by the phenol-sulphuric acid method (Dubois et al. 1956).

3.7.2. Starch

Starch content of the residue obtained after the removal of soluble sugars was estimated by the perchloric acid digestion method of Clegg (1956), with modifications. The residue (50 mg) was digested twice, each for a duration of 2 hr with 36% perchloric acid at room temperature. Finally the filtrates were mixed and made upto 50 ml. Estimation of starch was done by the phenol - sulphuric acid method (Dubois et al. 1956) against starch standard in perchloric acid (Whelan 1955).

3.7.3. Nitrogen

The sample (100 mg) was analysed for total nitrogen by the method described by Jackson (1967). Samples were digested with 2 ml of conc. H_2SO_4 in a digestion chamber till the colour of the solution disappeared. The cleared solution was distilled in a micro - Kjeldal unit with 15 ml of 40% NaOH for 7 min and the released ammonia was collected in 10 ml of 4% boric acid. Ammonia containing boric acid was titrated against N/50 H_2SO_4 and the titre value noted. Titre value of the blank was found to be negligible. Percentage of nitrogen was calculated from the formula,

$$N\% = T - B \times \frac{N \times 1.4}{5} \quad \text{where}$$

T = Sample titre in ml,
B = Blank titre in ml,
N = Normality of the acid,
S = Sample weight, and converted to mg/g dry weight of tissue.

3.8. Growth measurements and yield

Measurements on growth characters viz, stem girth, stem height, canopy diameter (North-south and East-west diameter), canopy height and number of bearing branches were noted. Radius of the canopy was calculated from the canopy diameter [(NS + EW)/4]. From these observations canopy area was calculated using the following formula (Balasimha and Nair 1989).

$$\text{Canopy area} = \pi r l$$
$$\text{Where } l = \sqrt{h^2 + r^2}$$

However instead of πrl, $2\pi hr$ was used for calculating the canopy area of T_5.

Harvesting of ripe pods started during the first week of May 1989 and completed during August last week. Number of pods per tree was noted.

3.9. Statistical analysis

The data of three seasons in the case of physiological and biochemical characters and of two seasons in the case of growth characters except yield were compiled and statistically analysed on a computer. Significance due to treatment, season and treatment x season interaction were worked out. But in the case of yield where the data collected was only once, significance due to treatment was worked out. Correlation matrix of 13 characters as shown in Table 28 was taken. Correlation matrix of Cs, PN, PAR and Tr was also determined.

4. RESULTS AND DISCUSSION

Concisely speaking the effects of pruning are three viz, (1) percolation of more light through cocoa canopy due to the thinning of the canopy area (2) pruning induced flushing which depends on the extent of pruning, being minimum in less pruned and maximum in severely pruned treatments. Since a large quantity of carbohydrate is required for flushing; flushing and carbohydrate budget of the plant are closely associated. (3) reduction of canopy area and number of branches. If these consequences of pruning could bring positive effects like increased photoassimilation or enhanced partition of photoassimilate to economically important parts, higher yield could be obtained.

In the light of available data, the response of the pruned plant to the above mentioned consequences of pruning and the relevance of these responses in controlling the productivity of plants are discussed below. Finally the key factor, namely, yield in the form of number of pods per tree will be taken into account. In all instances, the performance of pruned treatments are compared with that of control (T_1) or otherwise mentioned. T_1 and T_2 will be considered as unpruned treatments while T_3, T_4 and T_5 as pruned treatments.

4.1. Growth characters

The initial (S_1) and final (S_3) growth characters of cocoa due to the five pruning treatments are given in Tables 1 and 2. After the pruning treatments the canopy area of the T_2 was significantly higher than all other treatments (Table 1) followed by T_1 and T_3. T_1 had a significantly higher value from T_4 and T_5 and a remarkably high value from T_3 . T_2 showed the highest number of branches followed by significantly less numbers in T_1, T_3, T_5 and T_4. (Table 2). T_1 had significantly higher numbers from T_3, T_4 and T_5.

Table 1 Character - Canopy Area (m²)

	Seasons		
Treatments	S_1	S_3	Mean
T_1	19.29	23.75	21.52
T_2	28.47	25.09	26.78
T_3	15.40	21.80	18.60
T_4	13.12	12.30	12.71
T_5	10.17	16.43	13.30
Mean	17.29	19.87	

S.E/plot - 3.08

C.V. (%) - 16.58

C.D. for Treatments - 3.160 **

C.D. for Seasons - 1.999 *

C.D. for TxS - 4.469 *

Table 2 Character - No. of Branches

	Seasons		
Treatments	S_1	S_3	Mean
T_1	32.13	55.63	43.88
T_2	45.94	61.44	53.69
T_3	15.77	35.73	25.75
T_4	12.84	23.97	18.41
T_5	21.41	25.44	23.43
Mean	25.62	40.44	

S.E/plot - 4.70

C.V (%) - 14.22

C.D. for Treatments - 4.818 **

C.D. for Seasons - 3.047 **

C.D. TxS - 6.813 **

Balasimha et al. (1989b) observed significant positive correlations among harvest index, canopy photosynthesis, total biomass, number of pods and number of bearing branches. A crop like cocoa where the light saturated photosynthesis is less (Balasimha et al.1989a) with severe adverse effect of increase of light exceeding saturating intensity (RajaHarun and Hardwick 1988a) on PN, the only alternative to increase the yield is to increase canopy area and hence leaf area, total biomass and canopy photosynthesis. Since the yield was negatively correlated to leaf area index and positively correlated to leaf area, it could be inferred that a big spreading canopy with minimum self-shading of leaves should be maintained in cocoa for better yield. In accordance with the report of Balasimha et al. (1989b) a positive correlation of yield to number of branches and canopy area was observed during the present study (Table 28).

4.2. Light penetration through cocoa canopy and photosynthetic characters

The PAR of the pruned treatments showed significantly higher values (Table 3). Light interception efficiency of the pruned treatments has been significantly reduced (Table 4), implicating the percolation of more light through cocoa canopy and the exposure of more leaves to light. In both instances the unpruned treatments did not show significant differences between them. The lowest light interception efficiency and the highest PAR was noted in T_4. In response to the increased quantum flux distributions, the leaves of T_4 and T_5 treated trees started to show light adaptation by investing more photoassimilate to increase specific leaf weight (Table 5) and nitrogen content of the leaves (Table 26). Significantly high specific leaf weight was observed in T_4 and T_5 when compared to T_2. Nitrogen content of the leaves increased significantly in T_4 and T_5 whereas among T_1, T_2 and T_3 the difference was not significant. The PN difference between treatments were not significant though higher levels were recorded in T_4 and T_5 (Table 6). Enhanced PN associated with high SLW

Table 3 Character - Photosynthetically Active Radiation (PAR) (micro mol $m^{-2}s^{-1}$)

Treatments	Seasons S1	S2	S3	Mean
T_1	472.89	626.57	509.04	536.17
T_2	621.73	919.15	504.12	681.67
T_3	827.03	903.71	863.37	864.71
T_4	958.30	946.45	1116.92	1007.22
T_5	940.16	848.43	890.42	893.00
Mean	764.02	848.86	776.77	

S.E/plot - 337.01	C.D. for Treatments - 277.777 *
C.V (%) - 42.31	C.D. for Season - 215.165
	C.D. for TxS - 481.125

Table 4 Character - Light Interception (%)

Treatments	Seasons S1	S2	S3	Mean
T_1	96.88	96.63	96.87	96.79
T_2	98.35	96.49	95.71	96.85
T_3	69.00	80.82	91.71	80.51
T_4	69.76	68.14	86.97	74.96
T_5	91.72	88.65	84.37	88.25
Mean	85.14	86.15	91.13	

S.E/plot - 10.04	C.D. for Treatments - 8.274 **
C.V (%) - 11.48	C.D. for Season - 6.409
	C.D. for TxS - 14.330

Table 5 Character - Specific Leaf Weight (SLW) (mg/cm^2)

	Seasons			
Treatments	S_1	S_2	S_3	Mean
T_1	6.52	7.13	5.94	6.53
T_2	5.84	6.44	5.53	5.94
T_3	6.43	6.76	6.04	6.41
T_4	6.90	6.63	6.97	6.83
T_5	6.94	6.84	6.96	6.91
Mean	6.53	6.76	6.29	

S.E/plot - 0.67 C.D. for Treatments - 0.555 **

C.V (%) - 10.32 C.D. for Seasons - 0.430

C.D. for TxS - 0.961

Table 6 Character - Net Photosynthesis (PN) (micro mol CO_2 m^{-2} s^{-1})

	Seasons			
Treatments	S_1	S_2	S_3	Mean
T_1	3.24	4.15	3.34	3.58
T_2	3.01	3.29	3.71	3.34
T_3	3.62	3.64	3.76	3.68
T_4	4.82	3.75	4.57	4.38
T_5	3.78	4.71	4.48	4.32
Mean	3.69	3.91	3.97	

S.E/plot - 1.08 C.D. for Treatments - 0.887

C.V (%) - 27.88 C.D. for Season - 0.687

C.D. for TxS - 1.536

(Barden 1977) and nitrogen content (Boardman 1977; Givnish 1988) is not observed in cocoa. On the contrary, transpiration rate (Tr) increased (Table 7) with a reduction in water use efficiency (Table 8) in T_4 and T_5. A positive correlation was also noted between Tr and PN (Fig 6). Stomatal conductance was enhanced in T_4 and T_5(Table 9). Stomata of inact leaves generally open in response to increase in PAR (Burrows and Milthorpe 1976). A strong positive correlation between leaf temperature and stomatal conductance (Balasimha and Rajagopal 1988) and between transpiration rate and leaf temperature and a negative correlation between stomatal resistance and leaf temperature (RajaHarun and Hardwick 1988b) have been reported in cocoa. Cumulative effect of PAR and leaf temperature (Table 10) would have enhanced stomatal conductance and transpiration rate in $T_4$and T_5. A strong positive correlation was observed between Tr and Cs (Fig 7). Balasimha and Rajagopal (1988) and RajaHarun and Hardwick (1988b) demonstrated stronger effect of RH and WVPD respectively on stomatal action in cocoa. Since the VPD increased only marginally (Table 11) in exposed conditions of pruned treatments, the PAR had to play an important role in stomatal action. A significant difference in Tair (Table 12) between T_1 and T_4 was also noted.

A Ci/Co ratio of 0.80 - 0.88, characteristic value of C_3 species has been ealier observed in cocoa. Moreover it has been proposed that due to the linear relationship of PN and stomatal conductance relatively constant Ci/Co can be expected in cocoa. There was also no significant difference in Ci in different light acclimatized plants (Balasimha et al. 1989a). In accordance with these observations, exactly the same performance (Table 13,14) was noted during the present study. There was a significant correlation between Cs and PN also (Fig 8). Chl a (Table 15) chl b (Table 16) chl a/chl b ratio (Table 17) and carotenoids (Table 18) remained unchanged during sun adaptations. However T_5 had a significantly less chl a/chl b ratio.

Table 7 Character - Transpiration Rate (Tr) (millimol $m^{-2}s^{-1}$)

Treatments	Seasons S₁	S₂	S₃	Mean
T_1	2.88	5.38	3.64	3.97
T_2	3.11	2.54	7.04	4.23
T_3	3.45	3.05	4.34	3.61
T_4	6.36	3.99	5.41	5.25
T_5	3.36	6.49	6.34	5.40
Mean	3.83	4.29	5.35	

S.E/plot - 1.66

C.V (%) - 36.88

C.D. for Treatments - 1.366 *

C.D. for Seasons - 1.058 *

C.D. for TxS - 2.366 *

Table 8 Character - Water Use Efficiency (WUE) (micro mol CO_2/millimol H_2O)

Treatments	Seasons S₁	S₂	S₃	Mean
T_1	1.14	1.06	0.91	1.03
T_2	0.98	1.30	0.56	0.95
T_3	1.06	1.29	0.89	1.08
T_4	0.74	0.93	0.81	0.83
T_5	1.18	0.89	0.74	0.94
Mean	1.02	1.09	0.78	

S.E/plot - 0.31

C.V (%) - 32.32

C.D. for Treatments - 0.257

C.D. for Seasons - 0.199 **

C.D. for TxS - 0.445

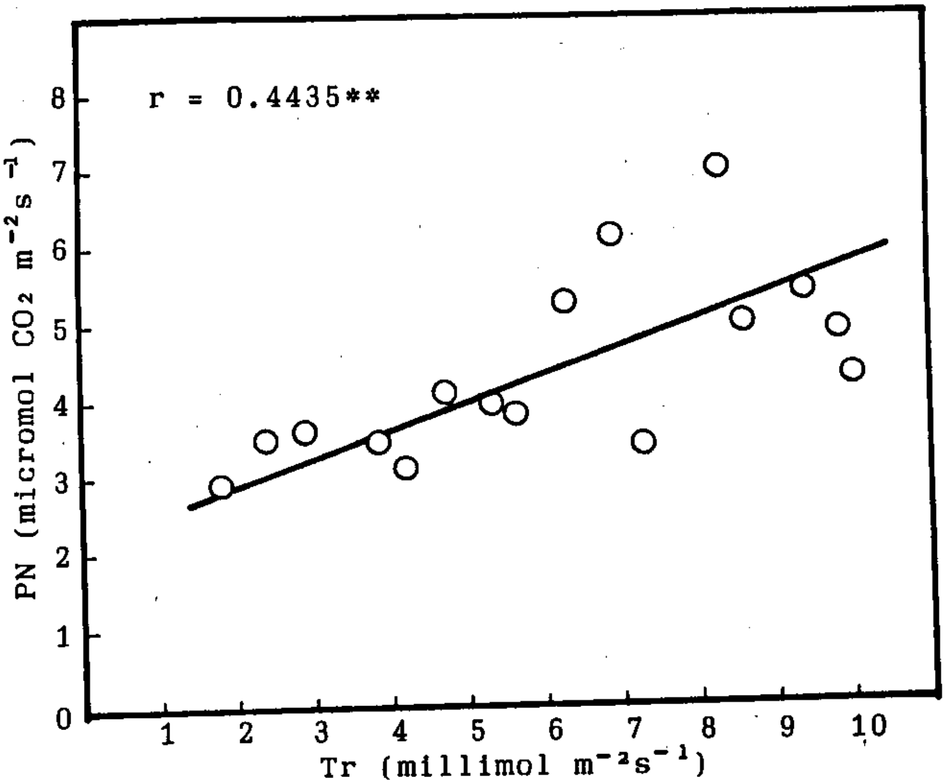

Fig. 6. Relationship between Transpiration Rate and Net Photosynthesis .

Table 9 Character - Stomatal Conductance (CS) (cm s^{-1})

	Seasons			
Treatments	S_1	S_2	S_3	Mean
T_1	0.28	0.57	0.57	0.48
T_2	0.26	0.20	1.08	0.51
T_3	0.48	0.25	0.88	0.54
T_4	0.66	0.34	0.76	0.59
T_5	0.32	0.62	1.13	0.69
Mean	0.40	0.40	0.89	

S.E/plot - 0.24

C.V (%) - 42.78

C.D. for Treatments - 0.198

C.D. for Seasons - 0.153 **

C.D. for TxS - 0.343 **

Table 10 Character - Leaf Temperature (LT) (°C)

	Seasons			
Treatments	S_1	S_2	S_3	Mean
T_1	33.87	34.69	34.52	34.36
T_2	34.88	36.60	35.93	35.80
T_3	33.18	35.97	34.28	34.48
T_4	36.48	36.37	35.90	36.25
T_5	34.48	35.83	35.11	35.14
Mean	34.58	35.89	35.15	

S.E/plot - 1.79

C.V (%) - 5.10

C.D. for Treatments - 1.479

C.D. for Seasons - 1.146

C.D. for TxS - 2.562

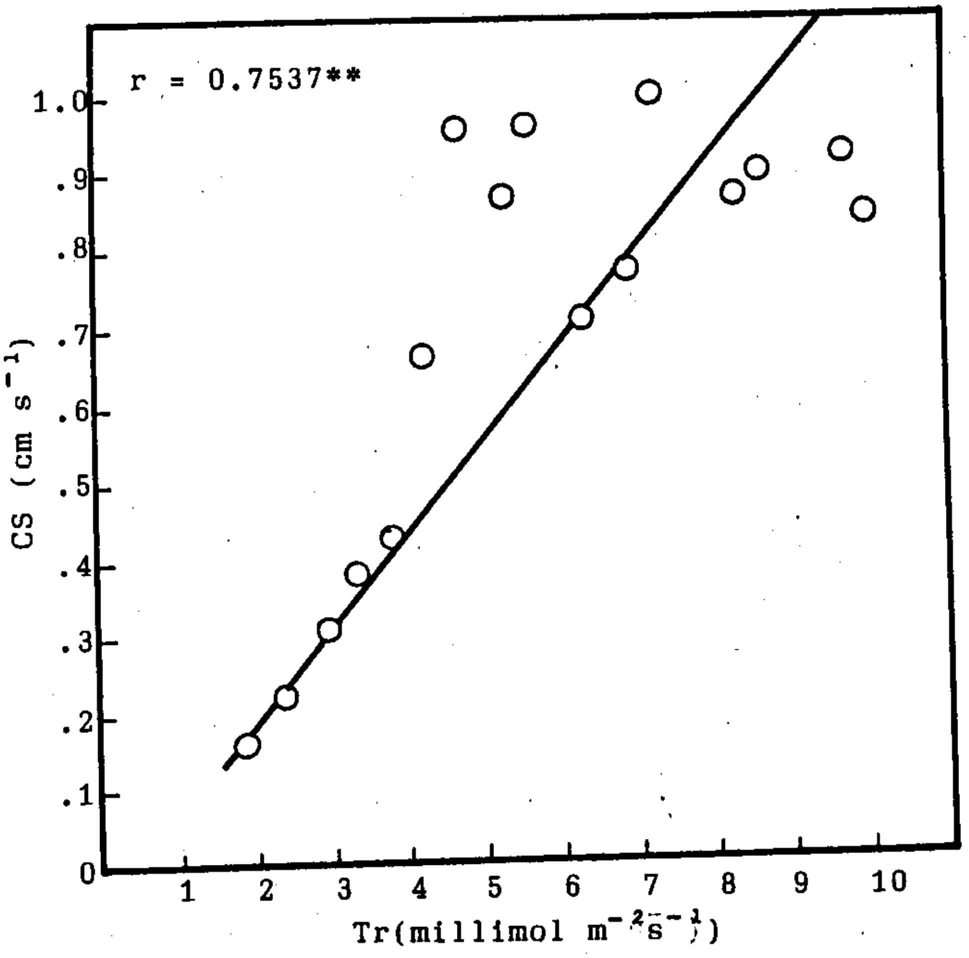

Fig.7. Relationship between Transpiration rate and Stomatal Conductance

Table 11 Character - Vapour Pressure Deficit (VPD) (m bar)

Treatments	Seasons S_1	 S_2	 S_3	 Mean
T_1	29.25	28.21	20.47	25.98
T_2	33.28	34.44	21.93	29.88
T_3	21.64	34.42	20.07	25.38
T_4	30.71	33.81	23.58	29.37
T_5	31.24	30.37	20.51	27.37
Mean	29.22	32.25	21.31	

S.E/plot - 5.95
C.V (%) - 21.55

C.D. for Treatments - 4.901
C.D. for Seasons - 3.797 **
C.D. for TxS - 8.489

Table 12 Character - Air Temperature (Tair) (°C)

Treatments	Seasons S_1	 S_2	 S_3	 Mean
T_1	33.50	34.10	34.51	34.04
T_2	34.13	35.55	35.76	35.15
T_3	32.48	34.80	34.05	33.78
T_4	35.84	35.31	35.78	35.64
T_5	33.46	35.14	35.30	34.63
Mean	33.88	34.98	35.08	

S.E/plot - 1.44
C.V (%) - 4.17

C.D. for Treatments - 1.191 *
C.D. for Seasons - 0.922 *
C.D. for TxS - 2.063

Table 13 Character - Ci/Co ratio

	Seasons			
Treatments	S_1	S_2	S_3	Mean
T_1	0.78	0.82	0.87	0.82
T_2	0.77	0.72	0.91	0.80
T_3	0.85	0.75	0.90	0.83
T_4	0.84	0.79	0.86	0.83
T_5	0.75	0.83	0.89	0.82
Mean	0.80	0.78	0.88	

S.E/plot - 0.04

C.V (%) - 4.83

C.D. for Treatments - 0.033

C.D. for Seasons - 0.025 **

C.D. for TxS - 0.057 **

Table 14 Character - Internal Carbondioxide Concentration (Ci) (ppm)

	Seasons			
Treatments	S_1	S_2	S_3	Mean
T_1	251.73	263.75	276.25	263.91
T_2	246.20	230.86	292.83	256.63
T_3	274.00	241.02	284.50	266.51
T_4	268.09	255.51	272.52	265.37
T_5	239.76	266.33	284.17	263.42
Mean	255.96	251.49	282.05	

S.E/plot - 12.77

C.V (%) - 4.85

C.D. for Treatments - 10.525

C.D. for Seasons - 8.153 **

C.D. for TxS - 18.23 **

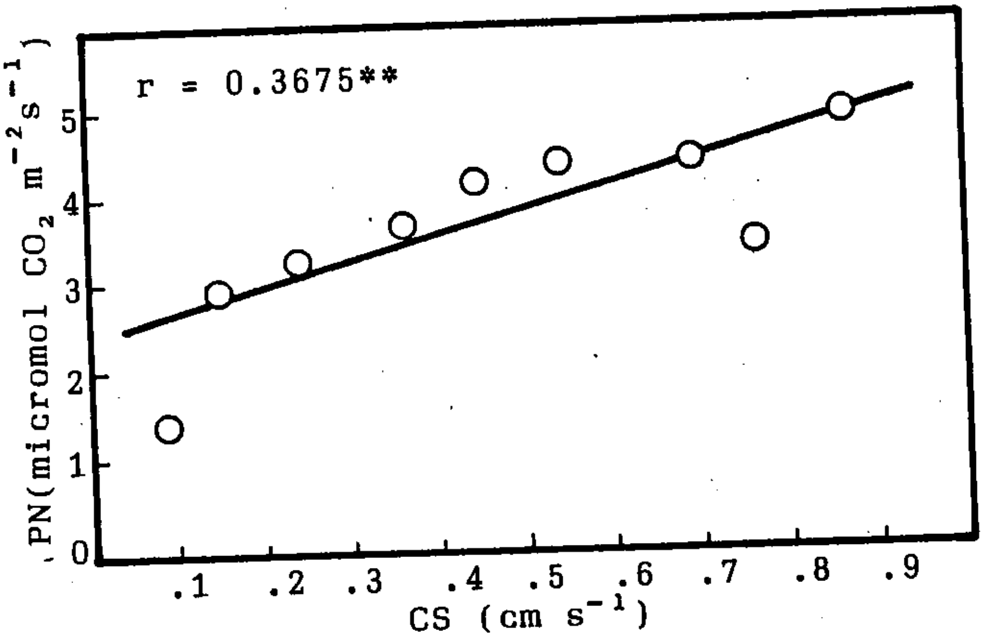

Fig. 8. Relationship between Stomatal Conductance and Net Photosynthesis

Table 15 Character - Chlorophyll a (mg g^{-1} Fresh weight)

	Seasons			
Treatments	S_1	S_2	S_3	Mean
T_1	1.80	1.81	1.48	1.70
T_2	2.09	1.61	1.67	1.79
T_3	1.56	1.67	1.58	1.60
T_4	2.02	1.63	1.48	1.71
T_5	1.98	1.69	1.38	1.69
Mean	1.89	1.68	1.52	

S.E/plot - 0.27

C.V (%) - 16.13

C.D. for Treatments - 0.226

C.D. for Seasons - 0.175 **

C.D. for TxS - 0.391

Table 16 Character - Chlorophyll b (mg g^{-1} Fresh weight)

	Seasons			
Treatments	S_1	S_2	S_3	Mean
T_1	0.58	0.68	0.65	0.64
T_2	0.67	0.56	0.77	0.67
T_3	0.51	0.65	0.69	0.62
T_4	0.65	0.63	0.62	0.63
T_5	0.65	0.60	0.60	0.62
Mean	0.61	0.63	0.67	

S.E/plot - 0.12

C.V (%) - 18.28

C.D. for Treatments - 0.096

C.D. for Seasons - 0.074

C.D. for TxS - 0.166

Table 17 Character - Chl a / Chl b Ratio

	Seasons			
Treatments	S_1	S_2	S_3	Mean
T_1	3.10	2.68	2.25	2.68
T_2	3.12	3.01	2.16	2.76
T_3	3.05	2.55	2.30	2.63
T_4	3.10	2.59	2.42	2.70
T_5	0.96	2.86	2.30	2.04
Mean	2.67	2.74	2.29	

S.E/plot - 0.43

C.V (%) - 16.59

C.D. for Treatments - 0.351 **

C.D. for Seasons - 0.272 **

C.D. for TxS - 0.607 **

Table 18 Character - Carotenoids (mg g^{-1} Fresh weight)

	Seasons			
Treatments	S_1	S_2	S_3	Mean
T_1	0.40	0.37	0.29	0.35
T_2	0.49	0.38	0.31	0.39
T_3	0.32	0.36	0.34	0.34
T_4	0.49	0.35	0.31	0.38
T_5	0.43	0.37	0.28	0.36
Mean	0.43	0.37	0.31	

S.E/plot - 0.06

C.V (%) - 15.04

C.D. for Treatments - 0.045

C.D. for Seasons - 0.035 **

C.D. for TxS - 0.079 *

Photosynthesis of cocoa leaves saturate at 350 to 400 micro mol m^{-2} s^{-1}(Balasimha et al. 1989a). Unpruned Cocoa had this optimum PAR (Table 3) (536 micro mol $m^{-2}s^{-1}$). PAR then increased with the extent of pruning and culminated in T_4 (1007.22 micro mol $m^{-2}s^{-1}$), a 2.5 fold increase from the saturating intensity. RajaHarun and Hardwick (1988b) reported a sudden decline of PN when cocoa leaves were exposed to light intensities exceeding saturating intensities. Such a reduction of PN has not been observed during the present study despite high PAR, perhaps due to the positive effect of high SLW (Barden 1977) and high nitrogen content (Givnish 1988; Boardman 1977) of leaves. Inability of the pigment machinery to acclimatize to the new light intensities and the absence of high PN despite high PAR, SLW, leaf nitrogen content and stomatal conductance observed during the present study implicate the limited ability of cocoa leaves to utilize high light intensities. RajaHarun and Hardwick (1988a) reported a linear increase of leaf resistance with saturating light intensity values exceeding 50%. They concluded that this increase of leaf resistance is an indication of biochemical malfunction of photosynthetic mechanisms and hence photooxidation of photosynthetic pigments and photoinhibition of photosynthesis can take place in high quantum fluxes. Photobleacing has not been observed during the present study. However , Balasimha (1982) noted photobleaching in the leaves of the outer canopy of cocoa during the period of high solar radiation.

During the sun exposure of T_4 and T_5 treated trees more photoassimilate had to partition towards the vegetative parts for the thickening of the leaves and to increase the nitrogen content of the leaves. However high photosynthetic activity associated with the leaves having high SLW (Barden 1977) and nitrogen content (Boardman 1977; Givnish 1988) has not been observed during the present study. When considering the high cost investment involved in the allocation of more starch and nitrogen for the thickening and high nitrogen content of the leaves respectively, the marginal increase of PN observed during the present study is insignificant. The high transpiration rate was mainly due to PAR induced stomatal opening (Burrows and Milthorpe 1976). From the cocoa accessions introduced from Nigeria and Malaysia and planted at CPCRI regional station Vittal, six acessions were reported to be drought tolerant due to their effective stomatal regulation resulting in decreased transpiration rate. They had high leaf water potential and epicuticular wax also (Balasimha et al. 1988).Later on, a significantly high yield and WUE was noted in these accessions comparing to drought susceptible accessions (Balasimha et al. 1989b). Drought tolerant and susceptible accessions did not show significant difference in PN. Therefore the increased yield of the drought tolerant accessions can be partly attributed to their effective water conservation. Stomata of the cocoa is highly sensitive to RH and WVPD (Balasimha and Rajagopal 1988; RajaHarun and Hardwick, 1988b). It is obvious that low transpiration rate and hence high water status of the plant is one of the key factors regulating the improved yield of cocoa. So, the high transpiration rate observed in T_4 and T_5 could affect the yield potential of the plants. Less Tr observed in T_3 indicates less exposure of its leaves to sun and hence effective water conservation. In short increased PAR associated with pruning could not fetch positive effects in the form of enhanced photoassimilation due to the inability of cocoa leaves to utilize high light intensities.

4.3. Vegetative and reproductive growth in relation to carbohydrate content

Immediately after pruning, there was a continuous leaf flushing which declined later in the season. A gradation of flushing was observed in the pruned treatments with minimum in T_3 and maximum in T_4. To avoid the hindrance of flowering due to the over crowding of newly formed flushes, the flushes around main stem and main bearing branches were removed once in 15 days. The changes in sugar, starch, and starch/sugar ratio of stem and leaf and of the sugar from phloem leaching during three seasons are shown in Tables 19 to 25.

Leaf sugar content of all the pruned treatments was significantly high during S_1 followed by a significant reduction during S_2 in T_4 and T_5. A 15% reduction of leaf sugar content observed in T_3 during S_2 was not significant. A reverse trend was observed in T_1 and T_2 during S_1 and S_2. Due to the heavy translocation of current photoassimilate from the leaves of all pruned treatments, the starch/sugar ratio of leaf was significantly reduced during S_1. In all the treatments leaf sugar content increased significantly in S_3 when compared with S_2. High leaf sugar content of all the pruned treatments during S_1 and of all the treatments in S_3 was probably due to the translocation of current photoassimilate for flushing . A significant increase of leaf sugar content in T_1 and T_2 in S_2 when compared with S_1 indicates the sink demand excerted by the pod. But the reduction of leaf sugar concentration in pruned treatments during S_2 on comparison with S_1 may be due to the reduction of sink demand excerted by flushing.

Leaf starch content did not show significant difference between the treatments in any of the seasons. Leaf starch was higher in all the pruned treatments in S_1. When soybean plants grown under moderate irradiance were abruptly transfered to high irradiance, the CO_2 exchange rate of leaves increased and the additional photoassimilate was partitioned into starch (Silvius et al. 1979). A marginal increase of PN was observed in all the pruned treatments with highest value in T_4 during the present study also. Enhanced partition of photoassimilate to starch is associated with the light induced increase of SLW. Due to the strong sink demand exerted by flusing/pod load, a major portion of the current photoassimilate was translocated. A negligible portion invested for the thickening of the leaves in the form of starch led to the marginal increase of leaf starch .

The carbohydrate requirement for developing flushes may exceed that available from current photosynthesis (Machado and Hardwick 1988). A similar deficit can be expected at the time of pod filling

Table 19 Character - Sugar from Leaf (mg g^{-1} Dry weight)

	Seasons			
Treatments	S_1	S_2	S_3	Mean
T_1	17.25	30.03	38.91	28.73
T_2	18.84	27.06	38.47	28.13
T_3	30.53	25.84	39.53	31.97
T_4	40.56	27.06	42.09	36.57
T_5	43.34	26.59	41.09	37.01
Mean	30.11	27.32	40.02	

S.E/plot - 5.55
C.V (%) - 17.10

C.D. for Treatments - 4.578 **
C.D. for Seasons - 3.546 **
C.D. for TxS - 7.929 **

Table 20 Character - Starch from Leaf (mg g^{-1} Dry weight)

	Seasons			
Treatments	S_1	S_2	S_3	Mean
T_1	63.00	68.88	130.00	87.29
T_2	65.63	63.25	127.00	85.29
T_3	74.13	58.38	133.88	88.79
T_4	72.75	69.00	130.37	90.71
T_5	72.37	67.25	131.63	90.42
Mean	69.57	65.35	130.57	

S.E/plot - 7.47
C.V (%) - 8.44

C.D. for Treatments - 6.155
C.D. for Seasons - 4.768 **
C.D. for TxS - 10.661

also. Any photosynthetic carbohydrate deficit is therefore balanced by the import of stored carbohydrate from the stem and root (Bird and Hardwick 1982) Stem is the major repository of starch reserve (Balasimha 1988) for flushing in cocoa with tap root and mature leaves providing further but smaller quantities (Taylor and Hadley 1988). Mobilization of stored stem-starch for flushing and pod load was observed during the present study also. Due to the excessive flushing stem - starch was significantly reduced in T_4 with a remarkable though insignificant reduction in T_5 during S_1. Correspondingly stem-sugar content was increased. Thus excessive mobilization of stem-starch during S_1 could reduce starch/sugar ratio of T_4 and T_5. Due to the pod load at the time of S_2, the stem - sugar content of all the treatments was significantly increased with corresponding reduction in starch content on comparison with S_1. A three fold increase in stem -sugar content was observed in T_1 and T_2 whereas T_4 and T_5 showed only a two fold increase. The least reduction of stem - starch was noted in T_1 during S_2 and its starch content was significantly towards the higher side from all the treatments. During S_3, the stem showed low sugar level and highest starch content when compared to earlier season. During this period there was neither pod load on the plants nor strong sink demand due to leaf flushing. However the regular flushing occuring in the month of September (Balasimha 1987) had begun during this period. Sleigh et al.(1984) have implicated carbohydrate availability as an important factor determining the growth behaviour. When a threshhold level of carbohydrate is reached in the storage pool, growth periodicity will be initiated (Taylor and Hadley 1988). A significantly higher sugar content of phloem leaching in S_3 (Table 25) when compared with the preceding seasons may therefore be pointing to the translocation of sugar to the storage pool or to the developing flushes or to both.

An increase in the photosynthetic activity of soybean leaves was observed when the assimilate demand on a single leaf was increased by shading the rest of the plant (Thorne and Koller 1974). Several work-

Table 21 Character - Sugar from Stem (mg g^{-1}Dry weight)

	Seasons			
Treatments	S_1	S_2	S_3	Mean
T_1	12.19	37.06	26.19	25.15
T_2	11.34	38.59	21.38	23.77
T_3	12.00	28.97	19.22	20.06
T_4	18.34	33.47	19.63	23.81
T_5	19.75	39.75	24.62	28.04
Mean	14.73	35.57	22.21	

S.E/plot - 5.88

C.V (%) - 24.33

C.D. for Treatments - 4.846 *

C.D. for Seasons - 3.753 **

C.D. for TxS - 8.393

Table 22 Character - Starch from Stem (mg g^{-1} Dry weight)

	Seasons			
Treatments	S_1	S_2	S_3	Mean
T_1	82.75	78.42	235.29	132.15
T_2	63.50	59.17	231.00	117.89
T_3	73.13	56.67	189.25	106.35
T_4	62.50	54.83	195.75	104.36
T_5	67.63	55.17	177.75	100.18
Mean	69.90	60.85	205.81	

S.E/plot - 11.93

C.V (%) - 10.64

C.D. for Treatments - 9.836 **

C.D. for Seasons - 7.619 **

C.D. for TxS - 17.036 **

Table 23 Character - Starch/Sugar Ratio of Leaf

Treatments	Seasons			
	S_1	S_2	S_3	Mean
T_1	4.21	2.34	3.36	3.30
T_2	3.60	2.37	3.34	3.10
T_3	2.81	2.32	3.39	2.84
T_4	1.82	2.65	3.10	2.52
T_5	1.68	2.54	3.21	2.47
Mean	2.82	2.44	3.28	

S.E/plot - 0.75

C.V (%) - 26.28

C.D. for Treatments - 0.617 *

C.D. for Seasons - 0.478 **

C.D. for TxS - 1.069

Table 24 Character - Starch / Sugar Ratio of Stem

Treatments	Seasons			
	S_1	S_2	S_3	Mean
T_1	7.03	2.30	8.98	6.10
T_2	5.89	1.55	10.81	6.08
T_3	6.29	2.12	10.00	6.14
T_4	3.66	1.87	9.98	5.17
T_5	3.35	1.41	7.28	4.01
Mean	5.25	1.85	9.41	

S.E/plot - 1.11

C.V (%) - 20.13

C.D. for Treatments - 0.913 **

C.D. for Seasons - 0.707 **

C.D. for TxS - 1.581 **

ers have demonstrated the increase of PN with enhanced sink demand (Ho 1979; Harold 1980). Such change in photosynthetic rates are likely to be valuable at the time of increased assimilate demand. On the contrary, in cocoa leaf, photosynthesis was not shown to increase with increased sink demand (Bird and Hardwick 1982) but rather decreased due to the mobilization of nitrogenous compounds especially dark reaction enzymes (Machado and Hardwicks 1988). The growth of cocoa is characterized by flush cycles followed by a normal non flushing period (Balasimha 1987). As put forwarded by Bird and Hardwick (1982) and confirmed by Machado and Hardwick (1988), cessation of leaf production during one flush cycle is a consequence of carbohydrate stress, particularly as the mature leaves cannot compensate for the increased sink demand. Thus all the pruned treatments had consistently experienced a carbohydrate stress during the critical time of flowering and pod load due to the flushing induced cabohydrate exhaustion. In India, flowering of cocoa starts during the month of October (Balasimha 1987). The significantly low stem - starch content observed in pruned treatments during the third season is indicating their inability to overcome the excessive starch drainage experienced during the preceding seasons for flushing. Carbohydrate status of the cocoa plant acts as a triggering factor in flowering and pod setting (Alvim 1965; Hutcheon 1973; Martinson et al. 1987). Alvim (1954) postulated that the main cause of cherelle wilt appears to be a carbohydrate strain on the plant brought about either by the competition of the growing leaf flushes or by young fruits. The result of the present study showed that the current photoassimilate of leaves as well as the stored starch of the stem that could have been utilised for the initiation of flowering and pod setting, were utilized for the pruning induced flushing. Continuous degradation of stem - starch for flushing before pod load and the cumulative effect of sink demand excerted by pod load as well as flushing at the time of peak pod load during S_2 have reduced stem-starch drastically in T_4 and T_5. Thus unneccessary wastage of stored carbohydrate for an unproductive process i.e. flushing, has reduced the pod setting of all the pruned treatments. A negligible reduction in the stem - starch content and no change in stem sugar content observed in T_3 during S_1 is indicating a low sink demand due to the less flushing. This is also showing that the translocation of current photoassimilate could satisfy the sink demand of flushing. In all the pruned treatments sugar content of both stem and leaf during S_2 did not show significant difference on comparison with T_1 and T_2, despite their low pod load. There are conditions where flushes could act as better sink than fruits (Monselise and Goldschmidt 1982). Since the flushing was observed during S_2, it can be inferred that a part of the translocate had been used for flushing instead of being partitioned to pods. However, the stem - sugar content of T_3 showed significantly low value on comparison with T_2. Leaf nitrogen content was reduced significantly with maximum reduction in T_1 during the second season (Table 26). The minimum leaf nitrogen level in T_1 during S_2 can be attributed to the maximum shifting of nitrogen due to the highest pod load. However stem - nitrogen content did not show any effect due to treatment (Table 27).

4.4. Yield

From the foregoing discussion it is clear that the three consequences of pruning, viz increased transmittance of light through cocoa canopy, flushing and reduction of canopy area had adverse effect on the productivity of cocoa. The yield of pods, among treatments are presented in Table 29. In pruned trees, yield was lower as compared to unpruned control (T_1). The two unpruned treatments did not differ significantly. Number of pods per tree reduced correspondingly with the increase of pruning. The minimum number of pods were recorded in T_4.

Reduced number of pods though not significant from T_1, observed in T_2 despite its significantly higher number of branches and canopy area may be due to two reasons: (1) Glendinning (1966) observed a

Table 25 Character - Sugar from Phloem leaching (micro g /cm^2)

	Seasons			
Treatments	S_1	S_2	S_3	Mean
T_1	0.11	0.15	0.45	0.24
T_2	0.11	0.19	0.56	0.28
T_3	0.18	0.12	0.55	0.28
T_4	0.17	0.14	0.50	0.27
T_5	0.11	0.14	0.48	0.24
Mean	0.14	0.15	0.51	

S.E/plot - 0.10
C.V (%) - 36.19

C.D. for Treatments - 0.079
C.D. for Seasons - 0.061 **
C.D. for TxS - 0.136

Table 26 Character - Total Nitrogen from Leaf
(mg g^{-1} Dry weight)

	Seasons			
Treatments	S_1	S_2	S_3	Mean
T_1	23.38	17.10	20.68	20.39
T_2	22.61	20.18	19.84	20.88
T_3	24.31	20.19	18.41	20.97
T_4	24.85	21.17	21.17	22.40
T_5	25.16	19.25	20.79	21.73
Mean	24.06	19.58	20.18	

S.E/plot - 1.54
C.V (%) - 7.24

C.D. for Treatments - 1.270 *
C.D. for Seasons - 0.984 **
C.D. for TxS - 2.200 *

Table 27 Character - Total Nitrogen from Stem
(mg g^{-1} Dry weight)

Treatments	Seasons			
	S_1	S_2	S_3	Mean
T_1	8.82	7.77	7.59	8.06
T_2	8.61	7.59	6.93	7.71
T_3	9.59	7.56	7.54	8.23
T_4	8.15	8.63	8.59	8.46
T_5	9.06	8.50	7.80	8.46
Mean	8.85	8.01	7.69	

S.E/plot - 1.03
C.V (%) - 12.54

C.D. for Treatments - 0.846
C.D. for Seasons - 0.655 **
C.D. for TxS - 1.466

Table 28 Correlation Matrix of S_3 Characters

1. Canopy area, 2. Number of branches, 3. Yield, 4. SLW, 5. PN, 6. Sugar from stem, 7. Sugar from leaf, 8. Starch from stem, 9. Starch from leaf, 10. Nitrogen from stem, 11. Nitrogen from leaf

	2	3	4	5	6	7	8	9	10	11
1	0.7919**	0.6954**	-0.5891**	-0.1270	0.2540	-0.2676	0.4276	0.0122	-0.5902**	-0.4339
2		0.6491**	-0.6972**	-0.3164	0.2397	-0.3695	0.6881**	-0.1606	-0.5330*	-0.2416
3			-0.3584	-0.4357	0.5368*	-0.0451	0.4117	0.0501	-0.3444	-0.2149
4				0.3947	0.1707	0.4706*	-0.5022*	0.2332	0.2569	0.2405
5					-0.1327	0.2385	-0.1345	0.1519	0.1589	0.2767
6						0.0824	0.2684	0.0270	-0.0871	0.2919
7							-0.2791	0.2162	0.4767*	0.1223
8								-0.2638	-0.0669	-0.1851
9									-0.2637	-0.3453
10										0.5021*

Table 29 Character - Yield (Number of Pods/Tree)

Treatments	S_3
T_1	40.28
T_2	30.51
T_3	22.39
T_4	15.43
T_5	19.97

S.E/plot - 10.11

C.D. for Treatments - 15.57*

C.V (%) - 39.29

negative relationship between yield and current rate of trunk diameter increase after the full bearing stage of cocoa. Once varieties are well into bearing, current rates of trunk diameter have little influence on yield. While considering this observation it can be said that a negative correlation can be expected of canopy area and number of branches with yield. (2) T_2 had experienced excessive shade as evident from their high chl a/chl b ratio (Table 17) and low SLW (Table 5). A high canopy height (3.2m) and low canopy diameter/canopy height ratio (1.42) in T_2 as compared to T_1 (2.6m and 1.54) implicate more self shading of leaves. This excessive shading could significantly reduce starch content of stem in T_2 (Table 22) when compared to T_1 (Taylor and Hadley 1988). Since stem-carbohydrate is an important factor regulating productivty of cocoa, this reduction of stem carbohydrate might have manifested on yield. From this it appears that an optimum canopy area and number of branches need to be maintained for maximum productivity.

5. Conclusion

From the extensive literature published on cocoa physiology it is indicated that high water conservation, superior carbohydrate status of the plant and high canopy area are the three key factors determining the high productivity of cocoa . As a consequence of pruning; transpiration rate increased due to the increased transmittance of PAR, carbohydrate budget of the plant has been totally disturbed by pruning induced flushing and finally the canopy area, and hence leaf area were reduced significantly by the removal of branches during the pruning. Even in T_3, the pruning which is considered to be as the farmers' pruning, a 45% reduction of pods was observed when compared to the unpruned.

This study has shown that cocoa does not require much of pruning. By opening up the canopy there was no significant increase in PN. As the total canopy PN (PNxLA) is more important to maintain high photo-assimilation, pruning may have to be restricted for maintaining the shape and height of the plant. However, whenever it is found that there is excessive shading, pruning should be done by removing the bottom and interior branches in such a way that flushing must be as minimum as possible. This is very essential as highly shaded leaves do not show net photosynthesis but are maintained at the cost of other exposed leaves. Major bearing branches i.e fan branches should not be removed and finally pruning should not open canopy to excessive sunlight. On the basis of the present study it can be suggested that a second jorquette branching and therefore double storied nature may be prevented at the initial stages of jorquette branching. In short a spreading unpruned canopy without shaded interior branches is ideal for cocoa productivity. The building up of this canopy area should be started from the early years of growth and under any circumstances removal of canopy area should not allow the increased light transmittance.

Since the data collected is from only one year, it has its own limitations. Neverthless, this experiment has given clear indications on canopy architecture in relation to yield. The experiment should give useful and clear trends in yields due to pruning treatments when the yield data are compiled for another 2 to 3 years, while maintaining the canopy shape.

6. Summary

An optimum canopy architecture, density and shape of cocoa should be maintained to be accommodated in the available light and air space of arecanut or coconut based high density multispecies cropping system. In a tree like cocoa with large horizontally inclined leaves, many leaves receive light far below the light compensation point. The removal of these 'parasitic leaves' which require import of photoassimilates from other leaves to meet their growth and maintenance may increase the partition of photoassimilate to the economic product. The removal of bottom shaded branches can facilitate agronomic practices like weeding, spraying and also harvesting. Besides, though farmers do give pruning to cocoa once in an year; systematic study on pruning effects on physiological and biochemical characters and yield have not been done. With this in view, a study was carried out to evolve an optimum canopy architecture and density of cocoa by giving different levels of pruning.

Five different types of pruning (unpruned control T_1, unpruned double storied T_2, pruned cone shaped T_3, severely pruned T_4, and pruned flat spreading canopy T_5) were given during September 1988 and the physiological and biochemical characters, photosynthetic behaviour, light interception efficiency, growth characters and yield were studied. Observations were made thrice in an year viz at the onset of flowering (October/November 1988 - S_1) at the time of peak pod load (March/April 1989 S_2) and just after the completion of harvesting (September 1989 - S_3) for all characters excepting growth characters and yield. Growth measurements were taken twice; once at the beginning of the experiment just after pruning and the other at the end of the experimental period. Annual yield of pods was recorded.

Due to pruning (T_3, T_4, and T_5) the canopy area and number of bearing branches were significantly reduced. A significantly low light interception efficiency with a correspondingly high PAR

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