

## A WHOLE-PLANT STRUCTURE: FUNCTION MODEL FOR COCOA\*

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### ABSTRACT

A functional model for growth and yield of cocoa is described. The effects of growth parameters viz., relative growth and net assimilation rates on yield as well as partitioning efficiency of dry matter, carbon and nitrogen are considered. The major environmental variables that influence growth and yield components are light and water stress. The relationships developed here will enable efforts to increase cocoa productivity.

### INTRODUCTION

Growth and yield component analysis describe quantitatively various parameters of plant development. In cocoa physiological research have been done over the past three decades or so, but little attempt was made to integrate various processes determining productivity (Alvim, 1977; Balasimha, 1988). This paper is an attempt to build a physiological model for structure and function relationships of cocoa plant.

### MATERIALS AND METHODS

Cocoa (*Theobroma cacao* Linn.) plants were planted under the shade of 18 year old arecanut palms in 1982 at a spacing of 2.7 x 2.7 m. Each plant was manured annually with 100 g N, 40 g P<sub>2</sub>O<sub>5</sub>, 140 g K<sub>2</sub>O and irrigated once a fortnight during dry periods of the year.

Periodic destructive sampling was done, sample size being 10 plants initially and 5 plants after 40 months. Leaf areas were calculated from 10 representative leaves from each tree using linear measurements (Reynolds, 1971) and computed for

the whole tree. Canopy area was computed from height and radius measurements assuming it to be in the shape of a cone. From this basic data growth analytical parameters were derived (Kvett et al., 1971). Total reduced N was determined by Microkjeldahl method and total carbohydrates by the method of Dubois et al., (1956). The starch residue was digested in perchloric acid (30%) and estimated for sugars.

### RESULTS

The cocoa model is shown schematically in Fig. 1. An understanding of sequential plant growth, their inter relationship, photosynthesis and partitioning is necessary to describe productivity.

#### Structural growth rates

The changes in primary and derived growth variables are given (Figs. 2 and 3). In the classical growth analysis, it is assumed that relative growth rate (R) is the product of leaf area ratio (F) and net assimilation rate (E). Although in the present study

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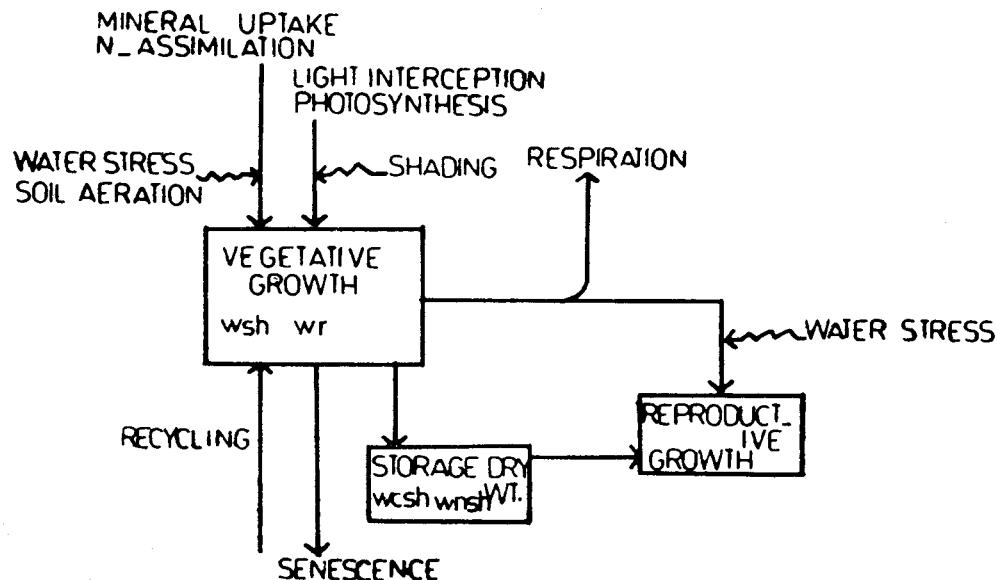


Fig. 1. Schematic diagram showing structural and functional relationship

the values used are from destructive sampling, it is rather difficult to get such data always. To overcome this difficulty, it is desirable to use relative production rate (R<sub>i</sub>) instead of classical R (Brand, Weetman and Rehsler, 1987). This can be derived from any growth variable viz., canopy area, stem girth etc. Any limitations on E and F would obviously affect R upto certain

stage of development. This is well illustrated in cocoa where a steady state level is reached at the beginning of reproductive phases (Figs. 2, 3 and 4). Thus any increases in leaf area beyond this optimum level may not have any additive effects on dry matter accumulation (Fig. 5) or yield (Table 1).

Table I. Correlation coefficients for yield and other yield components

Character	Yield	
	5 years	12 years
Stem girth	0.70*	0.31
Stem height	0.16	-0.05
Stem dry weight	0.73*	0.36*
Total plant dry weight	0.77**	0.36*
Canopy area	0.78**	0.16
Number of fruit bearing branches	—	0.34*
Harvest index	—	0.91**

\* Significant  $P > 0.05$  \*\* Significant  $P > 0.01$

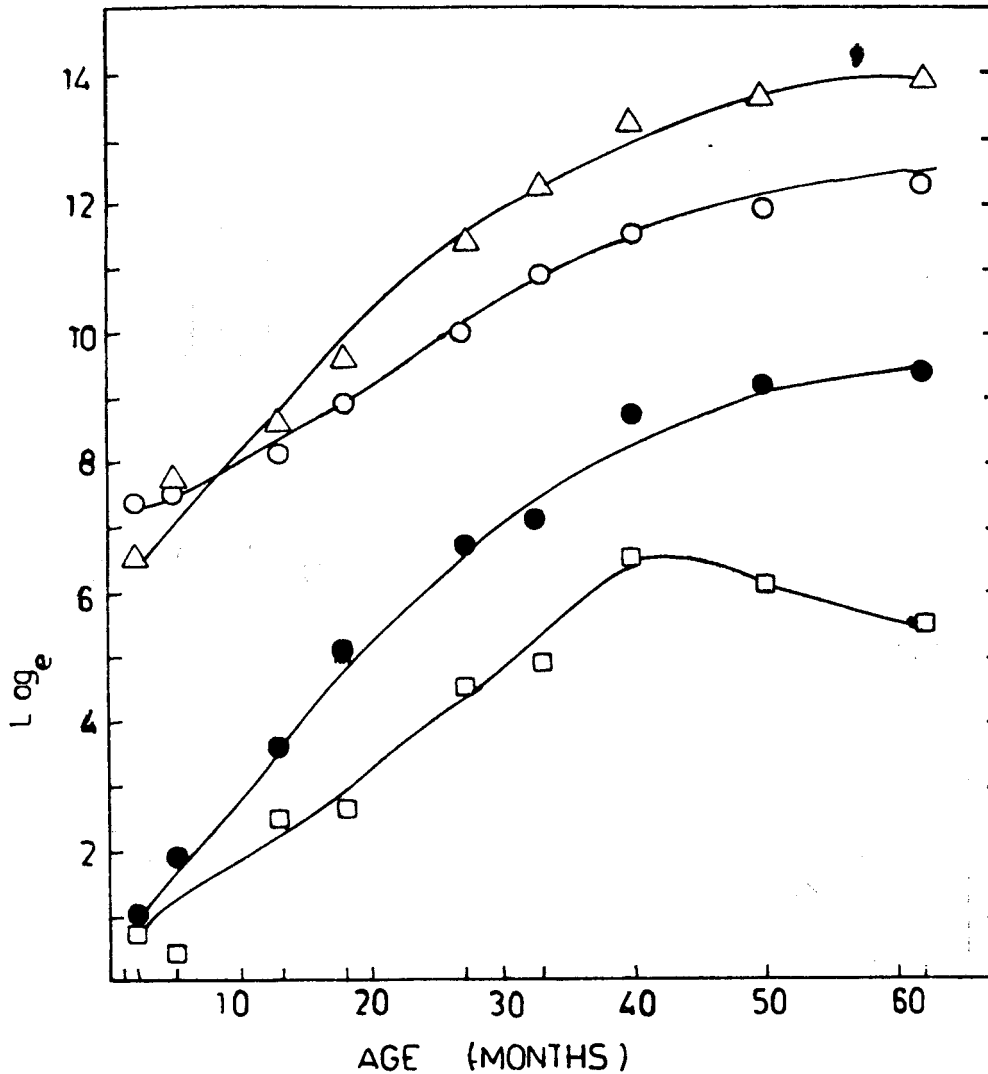


Fig. 2. Mean primary values for canopy area, cm<sup>2</sup> (○), leaf area, cm<sup>2</sup> (△), dry weight g (●) and mean growth rate, g g<sup>-1</sup> month<sup>-1</sup> (□) per plant during growth

#### Leaf area index, light interception and photosynthesis

The growth and productivity of cocoa is modulated by light interception efficiency and leaf area index (L); both of which reach optimum levels when reproductive phase is switched on. The photosynthetic

accumulation of assimilates is very low in cocoa (Alvim, 1977) and this can be modified by increasing light availability to a certain extent (50% of total radiation). There is also high correlation between specific leaf weight and yield capacity (Balasimha, 1988).

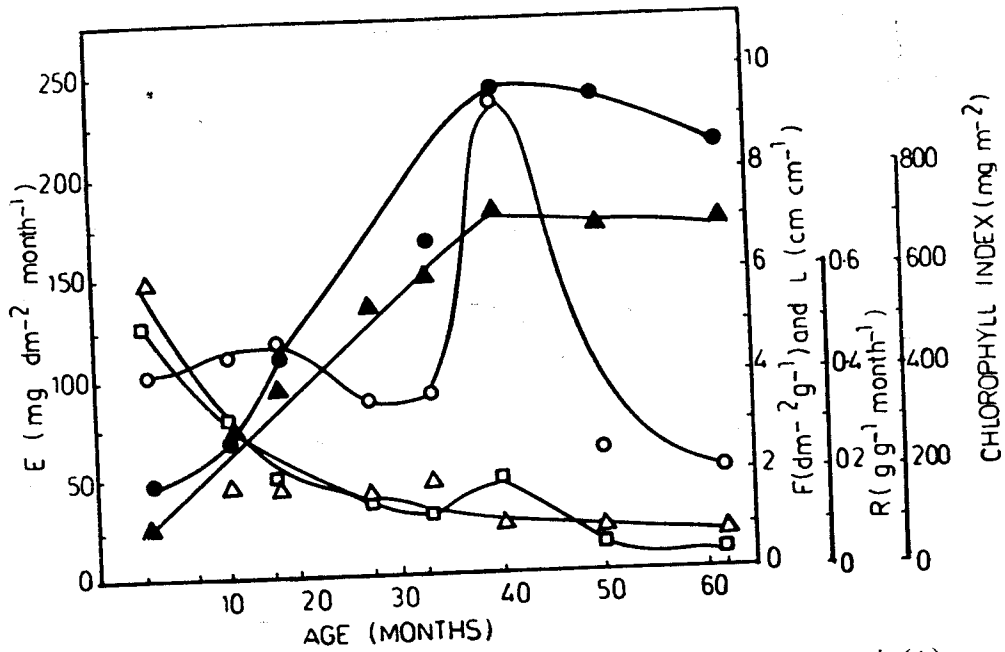


Fig. 3. Derived growth analysis values for net assimilation rate (O), leaf area ratio ( $\Delta$ ), leaf area index ( $\bullet$ ), chlorophyll index ( $\blacktriangle$ ) and relative growth rate ( $\square$ ) during plant growth

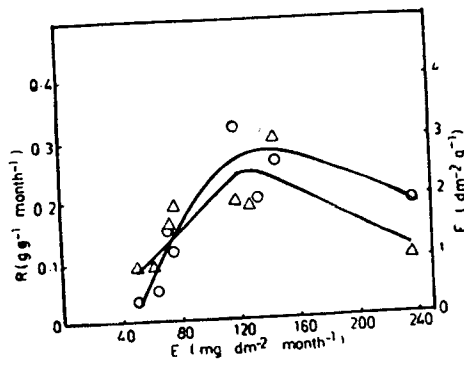


Fig. 4. Relationship of net assimilation rate (E) to relative growth rate (R, O) and leaf area ratio (F,  $\Delta$ )

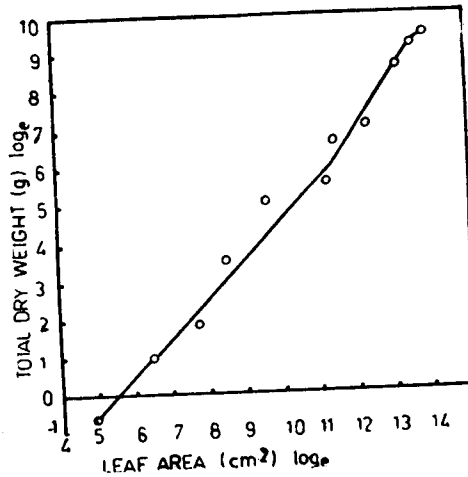


Fig. 5. Relationship between leaf area and total dry matter

### Partitioning

The Reynolds and Thornley (1982) model for total growth rate is denoted as:

$$\frac{dw}{dt} = K CN (W_{sh} + W_r)$$

where K is growth rate coefficient.

The net carbon and nitrogen flow can be represented as  $\delta CW_{sh}$  and  $\delta_N W_r$  (Johnson, 1985). The accumulation of carbohydrates and total N was slow initially and rapid after second year of growth (Fig. 6)

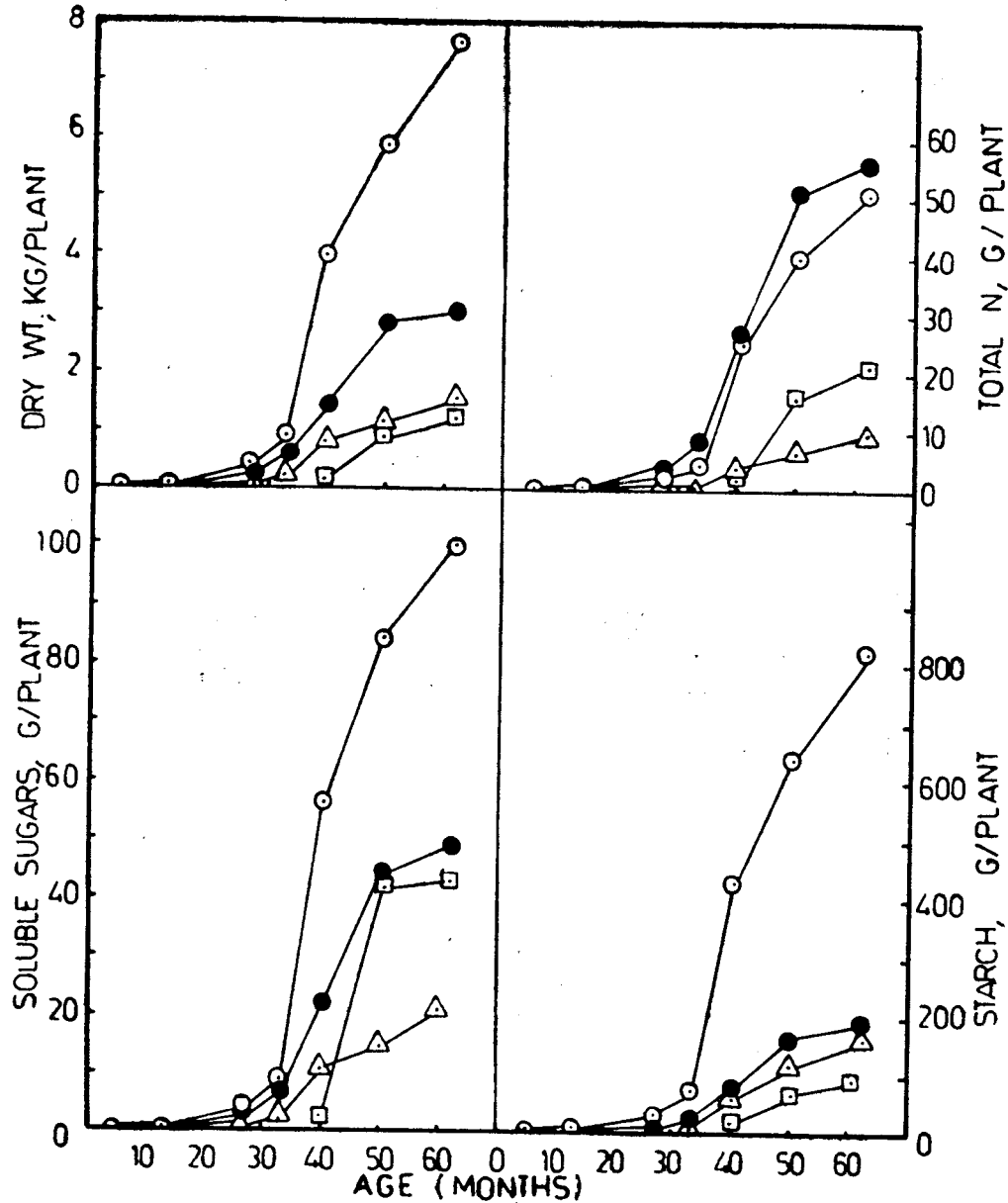


Fig. 6. Changes in dry weight and nutrient composition; stem (○), leaf (●), root (△), pod (□)

The stem was major organ of nutrient storage. The carbon content is influenced by light, LAI and water stress. The ratio of distribution of C and N between vegetative and reproductive parts is dependent

not only on C-assimilation but the reserve capacity. Thus, it is important to know the size of productive organs *e.g.*, roots and leaves and reserve pool to predict yield. The shoot: root ratio is related to the C/N

ratio which in turn will be influenced by  $\delta C$  and  $\delta N$ . There is change in C/N ratio from 8.9 to 11.1 with onset of reproductive phase.

#### Senescence and recycling

The losses of assimilates/nutrients to the system are in the form of senescence (leaf fall), respiration and removal of pods. Only the latter two can be regarded as totally lost since leaf fall is recycled into the system. The efficiency can however be enhanced by recycling the pod husk which is usually removed and may contribute 10% of nutrients and carbon.

#### Effects of water stress

The parameters R and E are sensitive to water stress and are reduced by about 30 to 50% (Balasimha, 1987). This is also accompanied by nearly 50% reductions in nitrogen assimilation and chlorophyll contents (Balasimha, 1988). Thus it can be expected that the  $\delta N$  and  $\delta C$  will be reduced proportionately.

#### Yield components

The increments in growth parameters at pre-bearing age will influence the yields. Once the stem area is fixed, it is difficult to enhance further productivity in cocoa. This is seen in the lack of correlations between stem height, girth or canopy area to yield at a later stage (Table I). The only possibility would be to increase the number of fruit bearing branches which shows significant positive correlation with yield. There were significant correlations of yield with biomass and harvest index (Table I).

#### DISCUSSION

The model for cocoa described here takes into account data available on various processes with least possible theoretical

considerations. The crop yield is considered here as mainly a product of R (= E x F), L and partitioning efficiency of C and N. The record annual yield of 3700 kg per ha (Ahenkorah, Akrofi and Adri 1974) can be considered as potential yield of presently known cocoa cultivars and about 60% of this only could be realised in experimental farms. So, shifting excessive vegetative development to greater partitioning into fruits for enhancing harvest index may have to be considered. Concurrently efficient photo-assimilate partitioning and increases in reserve pools should be made possible. The main environmental constraint in cocoa productivity is water stress and any breeding programmes for yield increases should include drought tolerance traits also. There is sufficient evidence to show that stomatal regulation is important in tolerance to drought (Balasimha, et al. 1988) which can be taken as another component for increasing productivity. The selections for high yield and other favourable characters are done taking into account various component characters combined into a score or index. This model thus, will enable attempts to increase productivity by breeding and/or improved agronomic practices.

#### ACKNOWLEDGEMENTS

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#### REFERENCES

- AHENKORAH, Y., AKROFI, E. S. and ADRI, A. K. 1974. The end of the first cocoa shade and manurial experiment at the Cocoa Research Institute of Ghana. *J. Hort. Sci.* 49 : 43-51.
- ALVIM, P. de T. 1977. Cacao. In *Ecophysiology of Tropical Crops*, (Eds.) Alvim, P. de T. and Kozlowski, T. T. pp. 279-313. Academic Press, London.

- BALASIMHA, D. 1987. Water relations, growth and other indicators of water stress in cocoa under drought. *Proc. 10th Intn. Cocoa Conference*, Santo Domingo Dominican Republic. (In Press).
- BALASIMHA, D. 1988. Cocoa. In *Tree Crops Physiology*. (Eds.) Sethuraj, M. R. and Raghavendra, A. S. pp. 263-285. Elsevier Science Publ. Amsterdam.
- BALASIMHA, D., RAJAGOPAL, V., DANIEL, E. V., NAIR, R. V. and BHAGAVAN, S. 1988. Comparative drought tolerance of cocoa accessions. *Tropical Agric.* 65 : (In Press).
- BRAND, D. G., WEETMAN, G. F. and REHSLER, P. 1987. Growth analyses of perennial plants: The relative production rate and its yield components. *Ann. Bot.* 59 : 45-53.
- DUBOIS, N., GILLES, K. A., HAMILTON, J. A., REBERS, P. A. and SMITH, F. 1956. Colorimetric method of determination of sugars and related substances. *Anal. Chem.* 28 : 350-356.
- JOHNSON, I. R. 1985. A model of the partitioning of growth between shoots and roots of vegetative plants. *Ann. Bot.* 55 : 421-431.
- KVETT, J., ONDOCK, J. P., NECAS, J. and JARVIS, P. G. 1971. Methods of growth analysis. In *Plant Photosynthetic Production*, (Eds.) Zestak, Z., Catsky, J. and Jarvis, P. G. pp. 343-391. Dr. W. Junk N. V. Publ. The Hague.
- REYNOLDS, S. G. 1971. A note on the estimation of leaf areas of cocoa (*Theobroma cacao* L.) from three leaf parameters. *Tropical Agric.* 48 : 177-179.
- REYNOLDS, J. F. and THORNLEY, J. H. M. 1982. A shoot: root partitioning model. *Ann. Bot.* 49 : 585-597.