PRODUCTION SYSTEMS AND CANOPY ARECHITECTURE

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In South India, cocoa is mainly grown under arecanut, coconut and to some extent in oil palm gardens. Cocoa is a perennial tree with typical plant habit, highly responsive to climate changes and growing environments like other beverage crops tea and coffee with their quality produce. It is thus necessary to have long term and dynamic improvement programs as well as different canopy management strategies in the cropping systems comprised of cocoa.

1).Cultivation systems

Cocoa is a crop of humid tropics grown under shade. The basic temperatures preferred are between 21- 23^0 C, with a rainfall of 1,000 to 2,500 mm per year without drought. Altitudes of cocoa growing regions are in the range of 650 m to 1000 m, having high humidity, 100% during night falling to 70-80% by day. During rainless periods supplementary irrigation is required since cocoa is sensitive to water stress. Most of the cocoa plantations of India are in laterite soils, whereas, black and alluvial soils are also suitable for cocoa. The ideal soil for cocoa should have 1.5 m depth, 3.5% organic matter, >9 C/N ratio, >12 me/100 g soil base exchange capacity and >35% base saturation. Cocoa is a deep rooted crop and vertical penetration of cocoa roots is up to 3.5 m, tend to be highly competitive to main crop. Thus, it is essential to meet the water and nutrient demand of both component crops adequately as well as minimizing the canopy of cocoa.

Shade requirement of cocoa

Traditionally cocoa is a forest crop grown under tall trees and partially cleared forests. Commercially also cocoa is under shade because it needs crop cover for its better development and yield. Intensity of shade requirement varies from place to place and growth stages. If shade is not sufficient for seedlings, there will be high weed growth, insect infestation, high percentage of small and inferior beans and shorter life cycle (Nair *et al.* 1996). If shade is too much for the grown up trees, it will affect the yield and more light will induce short internodes and more branching, resulted in bushy trees. Thus shade and sunshine management in cocoa garden is very crucial.

Agro forestry systems

Cocoa based agro forestry systems are the predominant cropping model practised in traditional and commercial zones of Latin America and Africa, which deposits high organic matter in the soil and have positive effects on the environment. When the forest trees are thinned and under planted with cocoa, it is called as cocoa forest or 'Cabruca', which is the conventional way of growing cocoa in Bahia, Brazil and these acts as Biodiversity hotspots. Cocoa grows both under temporary and permanent shade trees. In case of temporary shades, once the cocoa canopy develops, they are removed to increase the light transmission. Plantain, Tapioca, *Gliricidia, Xanthosoma* spp., *Colocasia* spp., Tree cassava or Ceara rubber (*Manihot glazovii*), pigeon pea (*Cajanus cajan*), Papaya (*Carica papaya*) and Castor (*Ricinus communis*) are being used as temporary shades in different countries (Wood and Lass, 1985). Over 100 species of permanent shade trees are used for cocoa. *Erythrina* spp., *Leucaena*

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leucocephala, Cordia alliodora, Tabebuia rosea, Cedrela odorata, Cola nitida, Myristica fragrans, Gliricidia sepium, Albizzia falcataria, A. chinensis and *Parkia javanica* are used as permanent shade trees. *Mangifera indica, Calophyllium antillanum, Dracaena* spp., *Hibiscus spp., Eugenia aromatica, E. malaccensis, Swietenia macrophylla, Tectona grandis, Cinnamomum zeylanicum, Cashuarina* are the mixture of trees grown as wind breaks to protect cocoa. Hills and valleys of Kerala and Karnataka with available permanent shade trees can be utilised for rejuvenation of traditional belts.

Cocoa under rubber

In Sri Lanka, cocoa is used as a 'catch crop' in rubber plantations. After planting cocoa, old rubber is cut and replanted with new rubber and so several crops of cocoa could be harvested before rubber over shades cocoa (Blencowe, 1968). In Brazil two closed rows of rubber and two rows of cocoa are alternatively planted. In Kerala, in Wayanad region few plantations are established in old rubber gardens after back tapping.

Cocoa under palms

In Asia- Pacific region cocoa became a compatible intercrop with palms and palm based cropping systems with arecanut, coconut and oil palm. Because of the high proportion of light that penetrates through the canopy of coconut palms, they are considered as the most suitable shade trees for cocoa in India, Indonesia, Malaysia, Philippines, Vietnam and Papua New Guinea. In Malaysia, cocoa under-planted with oil palm showed increased productivity.

2) Plant habit and growth of cocoa

Cocoa has a typical and interesting plant habit. Vertical or orthotropic growth continues and at a particular height the terminal bud of the main stem ceases, forms five lateral plagiotropic branches or 'fans' and this process is called 'jorquetting'. Further vertical growth (chupon) continues on the main stem by the activation of the orthotropic buds in the leaf axils below the whorl of lateral branches or the jorquetting point. This pattern of branching in tiers continues until the tree reaches an average of 20 m height in wild. Cocoa trees shown horizontal, erect, intermediate and pendulous growth patterns, which differed with genotypes. In the intercropping scenario trees with intermediate growth habit is preferred for easy management.

Self- shading

In the canopy of cocoa tree, upper leaves and branches cast shade on lower leaves and the neighbouring cocoa trees also cast shade on each other and this is called 'self shading'. Young plants have small crowns with low self shading and so overhead shade is needed, if self shading is high in grown up plants, less over head shade is needed. Grafted cocoa trees tend to be shorter and more open crowned than trees from seed and less self shading is expected in well managed clonal cocoa.

3) Palm based cropping systems

Cocoa under arecanut

In Karnataka state of India cocoa is widely grown under arecanut and at CPCRI, Regional Station, Vittal majority of germplasm is maintained under arecanut (Fig.1). Currently, cocoa is being planted at 2.7m x 5.4m spacing in arecanut garden spaced at 2.7m x 2.7m. To increase the income per unit area several crop combinations were tried and Arecanut + Cocoa + Banana + Pepper model is considered as a profitable system and other location specific models are also developed. A system of same time planting of arecanut and cocoa at 3m x 3m also offered optimal shade, good growth and yield in both the crops. Fertilizer dose of 100:40:140 g N: P_2O_5:K_2O/tree/year and 20 liters of water/day/tree as drip and fertigation with 106 g Urea, 145 g Diammonium Phosphate and 180 g Muriate of Potash is recommended to get maximum yield from cocoa.

Fig.1. Cocoa under arecanut

Cocoa under coconut

Coconut+Cocoa is the well established system in the Asia Pacific countries (Fig.2). Coconut intercepts only 44% of the incident solar radiation and the remaining is available for intercrops. Interplanting coconuts should be adopted where soil conditions are also compatible for cocoa because in many countries coconut is growing in sandy soils which may affect the growth of cocoa. Coconut provides aerial, land and root space for cocoa. In coconut plantation of 7.5 m x 7.5 m spacing, cocoa is planted at 2.7 and 3 m distance in the centre of two rows of coconut as single hedge. When the spacing of coconut is more, two rows of cocoa can be accommodated between two rows of coconut as a double hedge system and the spacing of cocoa may be 2.5 to 2.7 m. However, it is advised to leave 3 m from the base of coconut palm. System of planting single hedge of cocoa in the middle of palms and one plant in the coconut row, planting cocoa in triangular system between two rows of coconut are also followed in few regions. Coconut based multi species cropping system involved Coconut + Cocoa + Banana + Pepper, Coconut + Cocoa + Nutmeg/ Clove + Pine Apple and few other location specific models. In double hedge systems damage due to fallen coconut fronds is more and so single hedge is recommended for commercial planting. A common, comfortable spacing of 3 m x 3 m for cocoa under coconut is recommended to be followed in Asia- Pacific countries for uniform evaluation, management and plant protection strategies.

Fig.2. Cocoa under coconut

Cocoa under oil palm

In oil palm gardens of 9.9 or 10.5 m triangular plantings, cocoa is grown at 2.4 m spacing. Cocoa should be 2 m away from the base of palm. Shade in oil palm plantations is very high and so age of the palms, square plantings of oil palm and wider spacings are to be considered.

4) Canopy architecture

In most of the cocoa producing countries perfect horticultural practices include systematic pruning and training except in West Africa. It is an important operation especially, when cocoa is grown as an intercrop. The main objective of pruning is to maintain the shape to make it more productive and efficient through induction of flowering and distribution of nutrients towards developing pods. Pruning system varies with young plants, mature trees, seedlings as well as clones. Pruning will decide the height of first jorquette, fan branches per jorquette and number of jorquettes per tree (Wood and Lass 1955; Willson 1999). It is also one of the most labour demanding management practices in cocoa cultivation.

a) Pruning and training in young plants

Formation Pruning

Formation pruning is being practised in young plants during the initial period of development,

which helps in training the crop to determine the shape of the tree. If the cocoa tree is allowed to grow naturally, the first jorquette will be formed at a height between 1 and 2 m. A low jorquette or low lying branches will make it difficult to move into the garden, to carry out harvesting, spraying and any other farm operations, so that a jorquette at 1.5 m is optimised. If the jorquette forms too low, it may either be left as such so that the second jorquette will be formed at a more convenient height or alternatively the jorquette may be removed at an early stage to encourage further upward growth. The young plants are to be inspected monthly to remove jorquettes forming below 1.5 m. Below the point of pruning one or more chupons grow from which the strongest is allowed to develop. At the jorquette five fan branches are normally formed and four fans in all four directions will be advantageous in holding the tree in position and three fans are preferred in older trees. Removal of basal chupons at regular intervals, trimming, cutting back or removal of low branches is important. Some cocoa seedlings may produce two stems. In such cases also retain the most vigourous one and remove the other.

b) Pruning and training in mature trees

1. Structural pruning

An umbrella or cone shaped structure is standardised for intercropping system (Fig.5). First jorquette is adjusted at 1.5 m with 4 fan branches and retaining the vertical growth to one level or first tier. Further orthotropic shoots or chupons arising from jorquette is regularly removed including criss- cross branches which enhance light interception and maintain desired size and shape. In Kerala and Karnataka, pruning is practised in the month of August- September after main harvest. Flushing is observed in October and the morphological measurements are taken during December and the canopy area is correlated with the pod bearing in the coming year. Total plant height, first branching or jorquetting height and the canopy spread both east west and north south directions are measured, considering the canopy as cone shaped the canopy area is calculated using the formula ðrl, whereas r= EW+NS/ 4 and l= "r^2 + h^2, h= canopy height. Canopy size of 15-20 cm^2 is found to be optimal in the arecanut garden. Depends on cropping systems, plants with medium vigour with optimal canopy is preferred, whereas clones with small canopy is prefered for high density planting. Few countries follows two to three pruning regimes in a year where the dry period is only three months, whereas in India only one annual pruning is followed since the rainless period spreads over 5-6 months.

2. Sanitary pruning

Diseased, damaged and unwanted branches are removed at regular intervals to maintain the health and vigour of the tree. It includes removal of chupons, dead branches, epiphytes, climbing plants, ant nests, rodent- damaged, rotten and over ripe pods. Frequency of sanitary pruning may be increased according to season and incidence of pests and diseases

3. Pruning of seedlings

The method explained in the structural pruning is followed normally in the seedling progenies (Fig.3). The canopy spread of 3.8 to 4.0 m and height 2.7 m are the ideal canopy architecture for optimum yield in trees of middle age group from 12-15 years old. Pruning is to be followed to the extent of retaining 20-30 leaves/ developing pod. A funnel shaped architecture is also suggested in grown up trees of seedling origin (Janny et al., 2003). It provides good ventilation and exposure to sun, by cutting low hanging branches first, then chupons and branches within 60 cm from the jorquette. Top pruning to a height of 4 m is recommended to facilitate harvesting and removal of mummified pods.

Fig.3. Pruning in trees raised from seedlings

4. Pruning of clones

Cocoa is multiplied clonally using fan branches which tend to give lower and multiple branching habit. In the first or second year of planting, primary pruning should be done to obtain a supporting framework of one or more upward growing main stems. Then drooping or inward growing branches are to be removed. After third year secondary pruning is suggested to develop umbrella shaped canopy (Fig.4). As the tree grows, systematically pruned clonal trees will look like a seedling tree at the age of 15 years. In another method, only one strong shoot is allowed removing all other fans and in this case the disturbance to stem is more which, may affect the initial years of bearing. Chupon grafted plants will give seedling like architecture but fans are used in commercial nurseries since the number of fans available per tree is more. In general, clonal trees are the most engineered plants by breeders and growers to ensure specific architecture and assured yield especially in the Asia-Pacific region, where cocoa trees are maintained like a shrub or small tree.

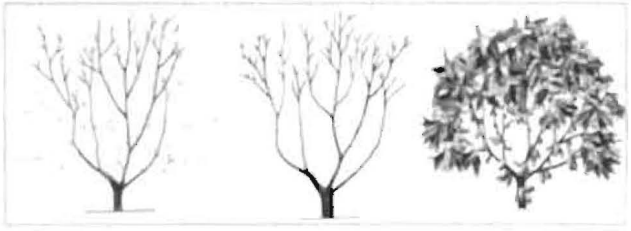

Fig.4. Pruning in trees raised from clones grafts

5. Maintenance pruning

While pruning care should be taken to give minimal disturbance to the bark, plant with flowers, cherelles and young pods. After initial pruning, maintenance pruning to be followed without fail to keep the canopy structure intact. When the climate is cool, with sufficient shade and water, slight trimming should be practiced. In all pruning methodologies all cut ends or exposed wood surface should be swabbed with Bordeaux paste immediately after pruning to avoid fungal infection, which is predominant in the humid environment.

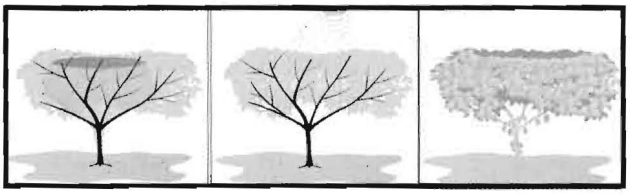

Fig.5.Funnel shaped canopy (CABI)

6. Effects of canopy architecturing

Vigour of cocoa trees is commonly assessed by measuring the trunk circumference which is correlated with yielding efficiency of the crop after systematic pruning. Pruning has a positive effect on flushing, flowering and fruiting rates in cocoa. In Karnataka, the main flushing occurs in the month of October followed by flowering in the month of November-December, fruit development in summer, harvesting correlates with monsoon during May-August. Even pruning helps in managing the pod rot incidence, before infection matured pods are being harvested. In clonal plants, continuous flowering in different rhythms are noticed which favours second season bearing with adjusted pruning regimes. Canopy architecturing helps in maintain an optimal canopy, reducing the intensity of cherelle wilt and give anchorage to hold maximum number of pods in main stem as well as the branches. New flushes after pruning is highly susceptible to tea mosquito bug attack and control measures to be initiated during flushing to safeguard the crop. The canopy density and light interception are related to the leaf area index which may vary between genotypes and with

canopy architecturing. In an experiment with clones, the photosynthetically active radiation (PAR) and light interception varied significantly over the years with two spacings (2.7 m x 2.7 m and 2.7 m x 5.4 m) and three canopy sizes (small, medium and large) and similar results were noticed with transpiration rate and stomatal conductance also (Balasimha, 2006). Photosynthetic efficiency is a primary determinant of cocoa productivity and it can be estimated by the growth analysis or by determining the photosynthetic rates of seedlings or individual leaves and ascertaining the canopy structure. Studies conducted on 22-year-old cocoa trees cultivated under the shade of arecanut palms showed that chlorophyll synthesis increased after completion of leaf expansion (Balasimha *et al.*, 1991).

7. Top working

Top working is followed to rejuvenate old and unproductive fruit trees. Trees selected for top working should have strong and healthy root and shoot system. In one method, decapitation of shoot of old trees at certain height is done, which initiates upward growing or orthotropic shoots or chupons. On these chupon shoots budding or grafting may be practised with bud/ scion from elite clones. In the technique standardised by KAU snapping back of main shoot below the jorquette or first branching after cutting half way is practised, which is highly a skilled operation. The snapped canopy continues to have contact with the trunk. Many chupons will arise below the point of snapping, patch budding is done on three to four vigourous and healthy shoots using scions from high yielding, disease resistant clones. About 50% improved yields in second year and 100% increase in the third year are obtained from top worked trees. Lateral grafting is practiced in Cocoa research centre (CEPEC), Brazil, a chupon from bottom of a senile tree is allowed and grafted with disease free high yielding scion to overcome the debilitating diseases like Witches' broom and *Ceratocystis* wilt.

- Cocoa tree is amenable to modified architecture as a positive management strategy in the intercropping system.
- Considerable genetic variation is observed with morphological and physiological characteristics and the interaction between different environments.
- Multiple clones with modified canopy architecture are to be tested in multi locations covering different agro climatic conditions and varying crop canopies is required.
- Not only more crop per drop but more crop per small canopy is important for sustainable cocoa cultivation.

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