



## Improvement of productivity in coconut- Physiological approaches

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Coconut production depends on various physiological and biochemical processes at different developmental stages starting from nut germination through early seedling growth, flowering and fruit development and these processes are influenced by both abiotic and biotic factors. The optimum weather conditions for good growth and nut yield in coconut are well distributed annual rainfall between 130 and 230 cm, mean annual temperature of 27 °C, abundant sunlight ranging from 250 to 350 Wm<sup>-2</sup> with at least 120 hours per month of sun shine period (Child, 1974; Murray, 1977).

### Seed germination and seedling growth

The coconut palm is a monocotyledonous tropical, seed propagated tree crop with the fruit (drupe) having a thick epicarp, fibrous mesocarp and a hard endocarp (shell) lined by the solid endosperm. The nut is self sufficient for the embryo germination and growth as it contains all nutrients, hormones and carbon sources required for the process. The germination process starts as soon as mature nut comes into contact with moisture for sufficient duration. For germination, the dwarfs require 10 days, hybrids 15 days, while the tall require an average of 20 days (Wuidart, 1981, Manjula, *et al.*, 1995). The haustorium absorbs food materials from the nut water and kernel and supplies to the growing plant. Physiological and biochemical changes occurring during early phase of germination viz., solubilization of stored food material and its utilization, are influenced by absorption of water by the nut and activity of enzymes and hormones present in the endosperm. Coconut endosperm comprises mainly lipids (68-70%), sugars (6-7%) and protein (6-9%) (Nathanael, 1967). Lipids get solubilized faster during the early stage of germination with a concomitant increase in the activity of lipase (Manjula *et al.*, 1995).

The growth of coconut seedling is dependent on nut reserves for almost one year. By fourth month after sowing, plant is entirely dependent upon the endosperm for its growth and by 15<sup>th</sup> month, it becomes fully autotrophic (Foale, 1968). Seedling selection for high vigour is of paramount importance in establishing a stand of superior yielders. Conventionally, selection of vigorous seedlings is done based on girth at collar, total number of leaves, plant height, length and breadth of leaves or leaflets, and early splitting of leaves. Since growth is a function of leaf area development and dry matter (DM) production, important contributing factors for the vigour of the seedling are LA, girth at collar and SDM (Ramadasan *et al.*, 1980). In seedlings, leaf area at six months age was correlated with SDM at one year age (Kasturi Bai and Ramadasan, 1990) thus implying that vigour of the seedlings can be determined before the attainment of complete autotrophy.

Number of leaves produced during the first 40 months is highly correlated to yield of copra at the age of 13-14 years (Liyanage and Abeywardena. 1957). Significant differences among the hybrids in growth attributes viz; CGR and RGR and rates of nitrate reductase activity, nitrogen assimilation and nitrogen uptake efficiency were noted (Shivashankar and Kasturi Bai, 1988). Superiority expressed in some of the hybrids at seedling stage in terms of morphological, physiological and biochemical characteristics was maintained throughout vegetative phase (Voleti *et al.*, 1988). These seedlings also expressed precocity in flowering and superiority in yield components like frequency of spathe production, number of pistillate flowers per bunch and number of bunches per year (Table 1). These studies have conclusively established the close correlation between seedling vigour and nut yield. Composition of potting medium also was found to influence the seedling growth and vigour as well as photosystem II efficiency and net photosynthetic rates (Srinivasa Reddy *et al.*, 2001).

Table 1 : Relationship between seedling vigour and nut yield



Hybrid	Age at 1 <sup>st</sup> flowering (months from planting)	Frequency of spathe production/year	No. of pistillate flowers/bunch	No. of bunches produced	No. of nuts/bunch	Cumulative yield of nuts (first two years of bearing)
COD x WCT	54.3	42	12	8.7	7.1	113.3
MOD x WCT	53.9	38	14	9.6	8.8	136.2
MYD x WCT	44.7	31	20.6	11.8	10.6	291.8

In embryo culture also, plantlets undergo chlorophyll and leaf morphological acclimatization (Ranasinghe *et al.*, 1999). The ratio of PEPCo to RUBISCO decreased during the *in vitro* development and is an indicator of transition from heterotrophic to autotrophic phase in coconut (Triques *et al.*, 1997 a and b). Plantlets also undergo photosynthetic acclimatization with increased PSII efficiency and water use efficiency (Naresh Kumar *et al.*, 2001). Composition of culture medium also influenced the growth and development of embryo and plantlets (Magat and Margate, 1990; Santamaria *et al.*, 1999; Naresh Kumar *et al.*, 2002).

### Flowering and fruit development

In coconut, commencement of flowering is the appearance of first inflorescence (spadix) in the leaf axil, which takes place around the age of five years or at the 45<sup>th</sup> leaf stage of growth or beyond, although initiation of inflorescence primordium occurs in the 10<sup>th</sup> to 14<sup>th</sup> leaf axil. Cultivar differences also occur in the flowering duration in palms. In fruit trees, a high carbohydrate reserve in the stem is an essential pre-requisite for early initiation of flowering. In eight year old WCT palms a higher C/N as well as higher leaf number are observed in palms that have commenced flowering over those that have not flowered. This indicates that only a rapid rate of leaf production coupled with a large number of leaves on the crown ensure adequate carbohydrate reserve in the trunk, required for the early commencement of flowering (Ramadasan and Mathew, 1977). The hybrids are superior to WCT in their efficiency in the mobilisation of carbohydrate fractions to inflorescence primordium (Kasturi Bai and Ramadasan, 1983). Increased availability of soluble carbohydrate fraction is a prerequisite for the development and continued growth of the inflorescence. This situation is attained only beyond June because adequate rainfall occurs only during this period. (Kasturi Bai and Ramadasan, 1978). Under un-irrigated condition, availability of adequate soluble carbohydrate fraction is restricted to monsoon season. Increased productivity in irrigated condition can be due to the assured availability of soluble carbohydrate fractions throughout the year for the initiation and the development of inflorescence. This implies that there is an operation of a pool of carbohydrate from the source (stem) to the sink (inflorescence) for attaining higher productivity levels, which in turn is controlled by environmental variables (Kasturi Bai and Ramadasan, 1982).

Growth of the fruit begins immediately following fertilization, with a rapid development of the pericarp at basal region which remains soft and white until fruit is nearly mature. Endocarp is already differentiated as a soft, creamy white structure long before the time of fertilization. During the development of fruit to maturity, embryo sac increases in size leaving a large cavity in the centre. Coconut water (liquid endosperm) starts



forming in small quantities from the third month of nut development and reaches maximum by eighth month and declines thereafter with nut maturity. The liquid endosperm being a site of active metabolism plays a vital role in fruit development.

Fat synthesis starts at seventh month when the kernel begins to form and increases up to the 12<sup>th</sup> month. The typical fatty acid composition of coconut oil includes C6:0, C8:0 and C10:0 C12:0 C14:0, C16:0; C18:0; C18:1; C18:2 C18:3 and C20:0 acids (Oo and Stumpf, 1979; Naresh Kumar *et al.*, 2000). Neutral lipids formed major fraction (about 94%) in coconut oil followed by the glycolipids (3.5%) and phospho lipids (2.5%), and lipid fraction content varied with cultivar (Naresh Kumar and Chempakam, 2000). The oil content in coconut copra and yield per hectare varies among the cultivars with WCT having ~68% oil and the oil yield/ ha ranged from 4 t/ha in WCT to ~3 t/ha in COD x WCT (Naresh Kumar and Chempakam, 2000). Even though variability among the coconut cultivars for fatty acid composition is not very high, in general, the hybrids have low saturated/unsaturated fatty acid ratios indicating better value over the oil from tall for edible purpose (Naresh Kumar *et al.*, 2000 a).

### Growth and Dry Matter Production

The palm is in general an unbranched stem of uniform thickness in adult stage. Annually 12 to 14 leaves are produced. In adult palms, along with the production of leaves, spadices are also produced in each leaf axil. Variation exists in the morphology of leaves, leaf area and dry weights between the cultivars and hybrids (Table 2. Kaşuri Bai *et al.* 1996). The dry weight of individual leaf ranges from 0.97 to 1.36 Kg. Besides leaf area and dry weight, leaf anatomy has also been recognized as an important component of productivity. Cultivars differences were observed in leaf thickness and tissue density (Ramadasan and Satheesan, 1980) with hybrids having higher tissue density. However, the coconut leaf tissue in general has less tissue density with more inter cellular volume, which is characteristic of all C3 species, and the leaflets are hypostomatus (Naresh Kumar *et al.*, 2000c). Variations were observed in stomatal frequency and stomatal index among the tall, dwarfs and hybrids (Rajagopal *et al.*, 1990).

Table2 : Growth characteristics of coconut

Parameter / cultivar	Tall	Dwarf	Hybrid
Total leaves (No.)	35	31	32
Leaf production / year	12	10	10
Leaf length (m)	4.02	3.39	3.83
Rachis length (m)	1.39	1.09	1.28
Leaf width (m)	2.21	1.85	1.87
No of leaflets/leaf	226	201	234
Leaf area (m <sup>2</sup> )	5.83	4.53	5.66
Leaf dry weight (Kg/year)	30.42	16.44	25.62
Leaf scar (No.)	12	12	12
Stem growth/year (cm)	36	25	23
Stem dry weight (Kg/year)	2.87	1.87	2.25



The trunk of coconut grows erect to a height of 10 to 24 meters. Annual growth of stem is by addition of "scars" with mark of leaf base as a result of the annual production of 12 to 14 leaves on the crown. The capacity for DM production significantly differ between tall, dwarfs and hybrids (Table 3. Kasturi Bai *et al.*, 1996). The dry weight of stem and leaf together constitute the Vegetative dry matter production (VDM) of palm and is a useful criteria for selection. Low VDM is associated with high HI. Significant variation exist in the VDM between the tall, dwarf and hybrid (Kasturi Bai *et al.*, 1996 a). Dwarfs exhibited lower production of VDM (18.3 kg) than in tall (30.6 Kg).

Total nut production per palm per year shows great variation among the cultivars / hybrids, but bunch production do not vary significantly among them. However, pistillate flower production varies significantly among the cultivars/hybrids (range 100 to 400). Higher pistillate flower production is observed in hybrids than cultivars (Kasturi Bai *et al.*, 1996). Dry weights of spathe, bunches and nuts constitute the reproductive dry matter (RDM) thus its' production depends mainly on the nut production and partitioning of nut dry matter towards its components, viz.; husk, shell and copra. Nut composition shows significant variation between the cultivars and hybrids that reflect in the partitioning of nut dry matter towards its components viz.; husk (43-58%), shell (20- 27%) and copra (27-34%) (Kasturi Bai *et al.*, 1996). The importance of increased partitioning of the total dry matter towards the copra at the expense of other nut components for yield improvement was emphasized (Green and Foale, 1961; Corley, 1983) and selection of parents should be based on nut composition rather than on the total dry weight of the nut.

Based on the dry matter accumulation in the vegetative and reproductive parts, TDM production also greatly varies between the cultivars and hybrids. Kasturi Bai *et al.* (1996) reported a TDM production of 17 t ha<sup>-1</sup> year<sup>-1</sup> in WCT x COD hybrids. However, 30 t ha<sup>-1</sup> year<sup>-1</sup> has been reported in Dwarf x West African Tall hybrid (Corley, 1983). This indicates that there is a huge gap in the realization of yield and the production potential of the palms.

**Table 3: Dry matter production (Kg palm<sup>-1</sup> year<sup>-1</sup>) in rainfed coconut palms of stabilized yield.**

Genotypes	VDM		RDM	Economic yield		HI	
	Stem DM	Leaf DM		Copra	Nut DM	Copra*	Nuts*
<b>Talls</b>							
WCT	3.0	32.2	52.6	16.6	48.1	0.19	0.54
PHOT	2.8	33.0	29.3	8.4	25.4	0.13	0.39
ADOT	2.8	27.8	36.4	10.9	31.2	0.16	0.44
<b>Dwarfs</b>							
MYD	1.8	17.9	24.5	7.6	21.4	0.16	0.46
<b>Hybrids</b>							
WCT x WCT	2.2	32.1	48.3	13.3	43.9	0.16	0.53
WCT x COD	2.4	24.8	73.3	23.0	67.7	0.23	0.67
COD x WCT	2.1	19.8	33.7	11.0	29.8	0.21	0.55
LCT x GBGD	2.5	25.8	65.5	19.9	62.2	0.21	0.66
LCT x COD	2.1	25.3	60.9	20.0	56.7	0.23	0.64

(\*HI on the basis of copra out turn and total dry weight of nut)



In coconut HI is worked out by taking into account annual increment in DM production and expressed as the ratio of the dry weight of the economic product to total dry matter production in a year (Ramadasan and Jacob Mathew, 1987). Being a crop of continuous productivity annual productivity index (API) is an appropriate criterion comparable to the harvest index of annual crops. In coconut, since all the parts are economically important several values of API could be calculated. The values of API estimated ranged from 0.4 - 0.5 in a group of palms in which the annual yield of nuts ranged from 45 to 91 nuts. HI is observed to be higher in hybrids indicating better nut composition than tall and dwarfs (Kasturi Bai *et al.*, 1996).

### Constraints in coconut production

Like any other crop, productivity of coconut palm is constrained by the abiotic (rainfall, temperature, sun shine duration and relative humidity, soil moisture) and biotic stresses (insect, pests and diseases). Research efforts led to understand response of palms to these stresses, which helped in identification of tolerant cultivars. Coconut palm's growth and production gets hampered when exposed to irradiation above  $265 \text{ Wm}^{-2}$ , temperature of  $>33^\circ \text{C}$  and vapour pressure deficit of 26 m bar (Kasturi Bai *et al.*, 1988), aggravated by soil water deficit during the period (Rajagopal *et al.*, 1989). Annual rainfall and its distribution have greater influence on the nut production in coconut. An aridity index of 100% for a prolonged period of 5 to 10 weeks drastically affects productivity of coconut palm. Duration of dry spell during initiation of inflorescence primordium, ovary development and button size nut stages, in that order have greater influence on nut yield than other stages (Rajagopal *et al.*, 1996).

The photosynthetic rate, dry matter production and its partitioning are influenced by the soil water status (Kasturi Bai *et al.*, 1998). In general, palms suffer more in red sandy loam than in laterite soil as indicated by the stomatal resistance and leaf water potential components (Voleti *et al.*, 1993a). The typical symptoms of coconut palm under drought stress are bending and breaking of dry leaves, poor spathe development and bunches with only one or two nuts. Drought Index, calculated based on the morphological symptoms, is related to nut yield and varied among the cultivars and hybrids (Ramadasan *et al.*, 1991; Pomier and de Taffin, 1982)

### Physiological responses to drought stress

Coconut palm adapts to drought stress by maintaining leaf water potential through effective regulation of stomata, deposition of wax on the leaf surface (Rajagopal *et al.*, 1990) and osmotic adjustment by accumulating organic solutes (Kasturi Bai and Rajagopal, 2000). The leaf to air vapour pressure deficit (LAVPD) and leaf to air temperature difference (DT) influenced the photosynthetic efficiency of coconut in irrigated and rainfed conditions (Rajagopal *et al.*, 2000 a). Cell size and number, sub-stomatal cavity size, stomatal frequency, epicuticular wax content and thickness, leaf thickness, stomatal resistance, water potential components and cell membrane stability coupled with higher activities of protective enzymes are the essential anatomical and physiological and biochemical traits for assessing moisture stress in palms (Rajagopal *et al.*, 1991; Chempakam *et al.*, 1993; Kasturi Bai *et al.*, 1996 b; Naresh Kumar *et al.*, 2001 c).

Anatomical basis of physiological efficiency for drought tolerance in coconut is delineated (Naresh Kumar *et al.*, 2000c). The structure favorable to high photosynthetic rates (large palisade parenchyma tissue surface, i.e., small parenchyma cells) induces at the same time high E due to higher intercellular space. The cultivars tolerant to water stress, had thick leaflets, thick cuticle on both sides, larger parenchyma, hypodermal and water cells compared to less tolerant. Drought tolerant types also had more scalariform thickening on xylem tracheids in vascular bundles and large sub-stomatal cavities. It is possible that cumulative effect of all these traits contribute to the adaptation to drought stress (Naresh Kumar *et al.*, 2000c).



Due to water stress, more reduction in  $P_n$  was noticed in susceptible types than in tolerant types. The ratio of  $P_n$  to  $g_s$  increased during stress period and drought tolerant hybrids exhibited higher increase in  $P_n/g_s$  ratio and water use efficiency (WUE) than the susceptible types. (Kasturi Bai *et al.*, 1998).

The potential of palms for higher DM production is reflected on WUE. WUE based on dry matter accumulation ranged between 28.8 to 69.3 g DM. mm<sup>-1</sup> used among the cultivars/hybrids. WUE was high in un-irrigated palms than in irrigated palms (Rajagopal *et al.*, 1989). WUE correlated with the total dry matter production and HI (Kasturi Bai *et al.*, 1996). Under mild stress conditions, WUE increases, whereas overall carbon assimilation efficiency is low in rainfed palms (Rajagopal *et al.*, 2000a).

Based on the aforesaid parameters cultivars like WC LCT and hybrids WCT x COD, LCT x GBGD, LCT x COD were identified as drought tolerant types (Rajagopal *et al.*, 1990). This helped in deciphering the mechanism of drought tolerance and stability in yield of coconut under water stress conditions. To sum up, drought tolerance in coconut is the cumulative effect of several productive morphological, anatomical, physiological and biochemical mechanism (Rajagopal and Kasturi Bai, 2002; Naresh Kumar *et al.*, 2000c). The genotypes with the above traits for tolerance to drought can be used in the selection for breeding strategies. Further the genetics of these important traits are being looked into for developing future crop improvement strategies.

### Button shedding in coconut

Shedding of buttons is another major constraints in coconut production. The production of large number of pistillate flowers, good fruit set and retention of nuts have an important role in improving the production potential of the palms. This can be achieved by checking the button drop. Spraying of freshly opened inflorescence by 2mM salicylic acid gave encouraging results in checking button drop. During summer months under un-irrigated condition, soil water deficit is the major cause for the shedding of buttons, which gets aggravated with the changes in the micrometeorological variables. Although high rainfall is not harmful to the palms growth and productivity, shedding can be observed due to the impairment of pollination and fertilization.

Significant differences have been observed in pistillate flower production, shedding of buttons and nut production between the cultivars and the increase or decrease in the button shedding depends on the number of pistillate flowers in the spadix. Seasonal variation in pistillate flower production and button shedding under irrigated and un-irrigated conditions have been observed. C/N in the leaf showed negative correlation with the shedding of buttons (Kasturi Bai and Khan, 2002) while leaf area correlated with pistillate flower production and nut production. (Kasturi Bai *et al.*, 2003). This implies that coconut palm regulates the pistillate flower production and shedding of buttons through the operation of a steady carbon-nitrogen metabolism and in turn is regulated by the environmental variables.

### Soil moisture conservation and irrigation management for improving productivity

Ideally coconut palms should receive water every week for good yields. The frequency and amount of irrigation influences the water relations and DM production of coconut palm (Rajagopal *et al.*, 1989). Soil moisture conservation practices like husk burial in basins, leaf mulching, application of compost and farm waste, in basins increase nut yield (Rajagopal and Naresh Kumar, 2001; Rajagopal *et al.*, 2002; Naresh Kumar *et al.*, 2003). Potassium nutrition also plays important role in improvement of yield under drought (Ollagnier *et al.*, 1983; Rajagopal and Naresh Kumar, 2001; Rajagopal *et al.*, 2002). Inadequate supply of K<sup>+</sup> and Cl<sup>-</sup> results in symptoms like yellowing and drying of leaves and yield reduction caused by an imbalance in the water relations of palms.



**Table 4: Summary of physiological condition of source and sink as influence by the type of irrigation.**

Source	Sink	Condition	Yield /WUE (instantaneous)	Remarks
Low $\Psi_{leaf}$ , $E$ , $g_s$ and $P_n$	Less pistillate flower production, nut retention	Rainfed	Low/Low	less available water in root zone
Low $\Psi_{leaf}$ , high $E$ , $g_s$ and $P_n$	More pistillate flower production, nut retention	Basin irrigation	High/Low	Adequate availability of water; no dry pockets in root zone
High $\Psi_{leaf}$ , medium $E$ and $g_s$ and high $P_n$	More pistillate flower production, nut retention	Drip irrigation	High/High	Availability of water in optimum; dry pockets in root zone

The increase in yield due to irrigation predominantly is a result of increases in source (the  $P_n$  rates) and sink (pistillate flower production) efficiency. In such a situation the final nut yield is directly proportional to the number of pistillate flowers produced. Under rainfed conditions, the palms grown on sandy soil produced less number of pistillate flowers compared to those grown on laterite soils. The three physiological conditions of source and sink in palms grown under different systems of irrigation are defined (Table 4). The drip irrigation provided conditions for better physiological efficiency of source and sink for high WUE and yield. Drip irrigation increases the WUE at not only field level but at plant and leaf level also. From the study it is indicated that even in basin irrigation, by applying water in such a way that the dry pockets are created in root system, it may be possible to increase WUE with high yields (Naresh Kumar *et al.*, 2000b).

#### **Nut yield in relation to intensity and length of drought stress**

Being perennial in nature, coconut palm had a long duration between inflorescence primordial initiation to nut maturity (~ 44 months) with longer pre-fertilization period (~32 months) than post-fertilization (12 months) period. The intricate relationship between dry spell and stages of nut development right from inflorescence initiation to the nut maturity indicated that coconut production under rainfed condition is influenced by the length of dry spells at critical stages such as primordial initiation, ovary development and button size nut (Rajagopal *et al.*, 1996) and annual nut yield in different agroclimatic zones (Rajagopal *et al.*, 2000c). This implies that by giving life saving irrigation during summer months the adverse effects of dry spells, especially on the development of the inflorescence primordium can be reduced. The summer rains received during March to May influenced favorably the nut yield of the subsequent year by lowering the atmospheric and soil temperature as well as by building adequate soil moisture content. The influence of drought on nut yield was seen in the subsequent year (Jacob Mathew *et al.*, 1988; Bhaskara Rao *et al.*, 1991). Some of the cultivars identified as drought tolerant based on physiological traits are also proved to be good yielders under drought condition (Rajagopal *et al.*, 1992).



The length and intensity of dry spell and influence of rainfall and dry spell on the nut yield in major coconut growing areas in different agroclimatic zones, indicated that the impact of such variations in dry spell on nut yield was discernible (Rajagopal et al., 2000a&b). The longer dry spell affects the nut yield in the fourth year to follow. Fluctuations in coconut yield during different years could thus be explained on the basis of rainfall distribution. However the length and number of dry spells coinciding with the critical stages are more important than the total rainfall per se which influence the nut yield (Rajagopal et al., 2000b). This perhaps paves the way for developing a computer model for prediction of coconut yield based on an integrated approach on weather variables particularly length of dry spell and critical stages

### Future thrust

- \* Improvement of coconut cultivars for stable growth and yield performance vis a vis abiotic and biotic constraints
- \* Improvement of WUE and HI for enhanced productivity
- \* Breeding for biotic and abiotic stress tolerance
- \* Studies on heritability of productivity parameters
- \* Development of molecular markers for productivity and stress tolerance traits for marker assisted selection (MAS)
- \* Development of simulation model for coconut growth and yield

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