CHAPTER 9

COCONUT

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INTRODUCTION

The coconut palm (Cocos nucifera L.) is a major oil-producing tropical crop, distributed over America, Africa, Asia and several pacific Islands. In India, coconut is cultivated in about 115400 ha of land yielding nearly six billion nuts annually.

Coconut tree grows well in warm humid weather with about 120 monthly sunshine hours (Murray, 1977), a mean annual temperature around 27° C with a diurnal variation of 5 to 10° C, and rainfall of 1300 to 2500 mm y^{-1}. The rainfall should be well distributed, with not less than 150 mm per month. Prolonged drought of 4 to 5 months affects the growth as well as the yield of palm. Though the palm prefers high humidity areas, it can tolerate low humidity if ground water supply is abundant. The coconut-grown soils vary from littoral to laterite and reclaimed clay, and their pH varying 3 to 7.

The coconut palm has a tall unbranched stem of uniform thickness topped by a massive crown of large leaves numbering from 20 to 40. The inflorescences (bunches) are borne in the leaf axils. A detailed description of morphology of the coconut palm is given in the monograph by Menon and Pandalai (1958).

Cocos nucifera has two broad varieties characterized by the stature - the tall and the dwarf. Hybrids, produced by crossing these two varieties are categorised into two cultivars: tall x dwarf and dwarf x tall (Table 1). Based upon the geographical distribution of the tall palm and the different forms of dwarfs, characterized by the colour of the nuts (orange, yellow, green), different hybrid combinations have been produced.

The present review deals with the following aspects of coconut physiology: growth, development, yield and changes during root (wilt) disease.

TABLE 1

The popular hybrids and their yields of copra.

Cultivar/ hybrid	Copra yield kg $tree^{-1}$ y^{-1}
WCT	13.9
CDO	10.6
T x D	21.3
D x T	27.9

WCT: West Coast Tall; CDO: Chowghat Dwarf Orange; T x D: Tall x Dwarf; D x T: Dwarf x Tall (Mawa hybrid).

Readers interested in general aspects of coconut are referred to the works of Menon and Pandalai (1958), Child (1974) and Thampan (1981).

GROWTH AND DEVELOPMENT

Germination and seedling growth

The seed coconuts of Tall palms require an incubation period of about one month and take about 11 to 12 weeks for germination (Menon and Pandalai, 1958). The period of germination of Tall palms could be reduced by 2 to 3 weeks through injection of the micronutrients like B, Cu, Mn, Fe, Mo and Zn (Sumathykuttyamma, 1964), in 0.01 and 0.02 M KNO_3 and Na_2CO_3 respectively (Thomas, 1974). However chlorine deficiency did not affect germination, possibly due to sufficient chlorine reserves in the nut (Eschbach et al., 1982). Seednuts of Dwarf palms do not prefer incubation (Namboothiri et al., 1973), and germinate quicker than those of Tall palms. The optimum temperature for coconut seed germination is reported to be 32 to 35° C (Sento, 1975).

In young coconut seedlings, the high initial growth rate, upto 4 months, is supported by the endosperm (Foale, 1968). During such early growth, the soluble carbohydrate in the kernel is mobilised into the haustorium, leading to a rapid increase in dry weight of seedlings. A full dependence of the seedlings on their own photosynthesis is achieved only at 17 months after germination.

In coconut, the selection of the seedlings from one year old nursery for planting is done on the basis of girth at collar, height of the seedling and number of leaves, including early splitting of leaves (Liyanage, 1953). In one year old seedlings, the leaf area (y) can be determined by the following equation, developed by Satheesan et al. (1983).

$$\text{Log } y = -0.434 + 1.042 \text{ (N)} + 1.060 \log (x)$$

where N = number of leaves and (x) = average product of length and width of all leaves. The R^2 value for the equation was 49.341. Similarly, the shoot dry weight also can be determined non-destructively, using the equation:

$$y = -112.4464 + 12.5885\ x_1 + 0.2295\ x_2 + -5.6338\ x_3 + 0.0143\ x_4$$

where x_1 = girth at collar region; x_2 = height of seedling; x_3 = number of leaves, and x_4 = the total leaf area.

Employing the above equations, Ramadasan et al. (1980) found that even though the number of leaves and height had a high correlation with shoot dry weight, only the leaf area and girth at collar had a direct effect on shoot dry weight which reflects the seedling vigour (Table 2). In a recent

TABLE 2

The relationship of seedling characters to shoot dry weight in one year old coconut seedlings.

	Girth at collar	Height	No. of leaves	Leaf area
Correlation coefficient (r)	0.9490	0.8822	0.7439	0.9695
Direct effect	0.4171	0.0953	-0.0862	0.5711
Indirect effect (via) height	0.0780	-	0.0607	0.0836
Girth at collar	-	0.3411	0.3293	0.3812
No. of leaves	-0.0681	-0.0549	-	-0.0664
Leaf area	0.5220	0.5007	0.4400	-

Residual effects = 0.0306

study by Kasturibai (personal communication), a high correlation (r = 0.5455) between the leaf area of the 6-month old seedlings and shoot dry weight of 12-month old seedlings was observed. This indicates that the vigour of the seedling, on the basis of which the selection in the nursery is made, is expressed at the 6th month itself.

Adult palms

In an adult WCT (tall) coconut palm; the annual production varies from 30 to 150 nuts per palm and in exceptional 'elite' palms may go upto 400 nuts. The possible reasons for such variability in the nut production, the copra and oil yields are being studied. For example, the total leaf area as indicated by the number of leaves on the crown had a positive correlation (r = 0.7028) with the annual yield of nuts (Table 3). Being a tree crop non-destructive methods have to be employed to determine the parameters like

TABLE 3

Photosynthesis and leaf area in relation to annual yield of nuts in adult WCT palms.

Characters	Correlation coefficient (r)
Rate of photosynthesis with annual yield of nuts	+0.6137
No. of leaves on the crown and annual yield of nuts	+0.7028
Chlorophyll content with annual yield of nuts	+0.2735

Adapted from Mathew and Ramadasan (1975).

stem growth, leaf area or net assimilation rate in adult coconut palms. The annual dry matter increase (y) at the distal end of stem can be determined using the equation (Ramadasan and Mathew, 1986): $y = -113.44 + 93.67x$ where x is the increase in height of segment with 3 leaf scars.

Root growth

An adult coconut palm has about 1200 to 7000 roots and in rare cases even upto 12,000 roots. Based on colour of the roots, the age of the root has been calculated upto 55 years. The rate of growth of young root is reported to be about 1 cm per day. A few roots grow vertically down upto a depth of 4 to 6 m. Rest of rootlets spread horizontally upto about 2 m from the bole, thereby increasing the efficiency of absorption in this region. The lateral rootlets are concentrated more in the first 30 cm depth than in deeper layers, constituting the region of maximum mineral absorption Nethesinghe (1964). The main roots can absorb upto about 250 to 500 ml of water per day during summer months (Ray et al., 1978).

Davis (1961) reported a positive pressure of 1240 cm of water in detached coconut roots while in attached roots the maximum negative pressure was 20.1 cm water only. Milburn and Davis (1973) detected cavitation in water-stressed coconut leaves and felt that root pressure might serve to refill cavitated xylem elements when water is abundant; but no positive pressure was detected in intact roots. These findings suggested that in coconut, as in oil palm, root pressure might not play significant role in water transport.

Leaf characteristics

The leaves are produced in spiral succession generally at the rate of one leaf per month in adult palms, although the rate may vary according to age and variety/hybrid. In young palms the rate of leaf production is slower than that in adult palm and is found related to commencement of flowering. The length of leaf ranges from 4 to 6 m and the number of leaflets 200 to 250 per leaf. The leaf area (LA) and dry weight (DW) of single leaves can be estimated as follows (Ramadasan and Mathew, 1986).

$$LA = -1.3274 + 0.0494\ x_1 + 0.0192\ x_2$$

$$DW = -3.4380 + 0.0197\ x_1 + 0.0202\ x_2$$

where x_1 is dry weight of six leaflets from middle portion of mature leaf and x_2 is number of leaflets in the leaf. The LA of individual leaf of WCT palm ranges from 4.5 to 5.5 m^2 while in T x D and D x T hybrids it is from 5.0 to 6.8 m^2. The DW of leaves of WCT palms ranges from 1.2 to 2.0 kg. In coconut palm, once the leaf is mature, there is little increase in LA or DW.

The leaflet has a thick cuticle on the upper surface, with about 200 stomata mm^{-2} on the lower surface only. The vascular bundles are protected by a bundle sheath, typical of a monocot, but do not possess any chloroplasts (Ramadasan and Satheesan, 1980). The WCT palm leaf has more air space volume and thickness (indicating less tissue density) than that in dwarf or hybrid leaves.

CARBON AND NITROGEN METABOLISM

In a study of photosynthesis in 100 adult WCT palms by manometry (Mathew and Ramadasan, 1974), the youngest fully unfolded leaf had the highest rate of oxygen evolution than other leaves in the crown. Apparent photosynthesis showed a significant positive correlation with the annual yield of nuts (Table 3). High variability was noticed in the rate of net photosynthesis. The study, using an IR gas analyser, conducted 12 palms revealed a range of 6 to 15 mg CO_2 cm^{-2} h^{-1}. The leaves of coconut showed the characteristics of a C_3 plant, namely low net photosynthesis, high CO_2 compensation point and high photorespiration (Eschbach et al., 1982).

A three year study on seasonal changes in leaf carbohydrates in young palms of WCT, WCT x Dwarf green, Dwarf orange x WCT and WCT x Ganga-bondam hybrids revealed that the trend of changes was similar in all cultivars studied (Kasturibai and Ramadasan, 1983). The total carbohydrate content increased significantly during March-April and decreased during July-September. The soluble sugar content, from 1.5 - 2.5% in January to May, increased to 4 - 5% in July. More than 80% of the increased sugars was in the non-reducing fraction. The high carbohydrate content coincided with long periods of sunshine averaging 8 hours per day during December to May. High levels of soluble carbohydrates coincided with short days having 2 to 3 hours per day in June and September (Fig. 1). The modulation by environment of the accumulation and mobilization of carbohydrates was also related to the commencement of flowering (Kasturibai and Ramadasan, 1983).

In a comparitive study of coconut genotypes (Shivashankar et al., 1982) bound a significant difference between the photosynthetic rate of WCT and WCT x CDO (Table 4). But the dark respiration of CDO was more than that in WCT or WCT x CDO. The hybrid WCT x CDO had significantly higher amount of chlorophyll than WCT and CDO. The stomatal frequency was not related to photosynthesis. The area of individual leaves of WCT x CDO was higher than that of WCT and CDO. The level of starch

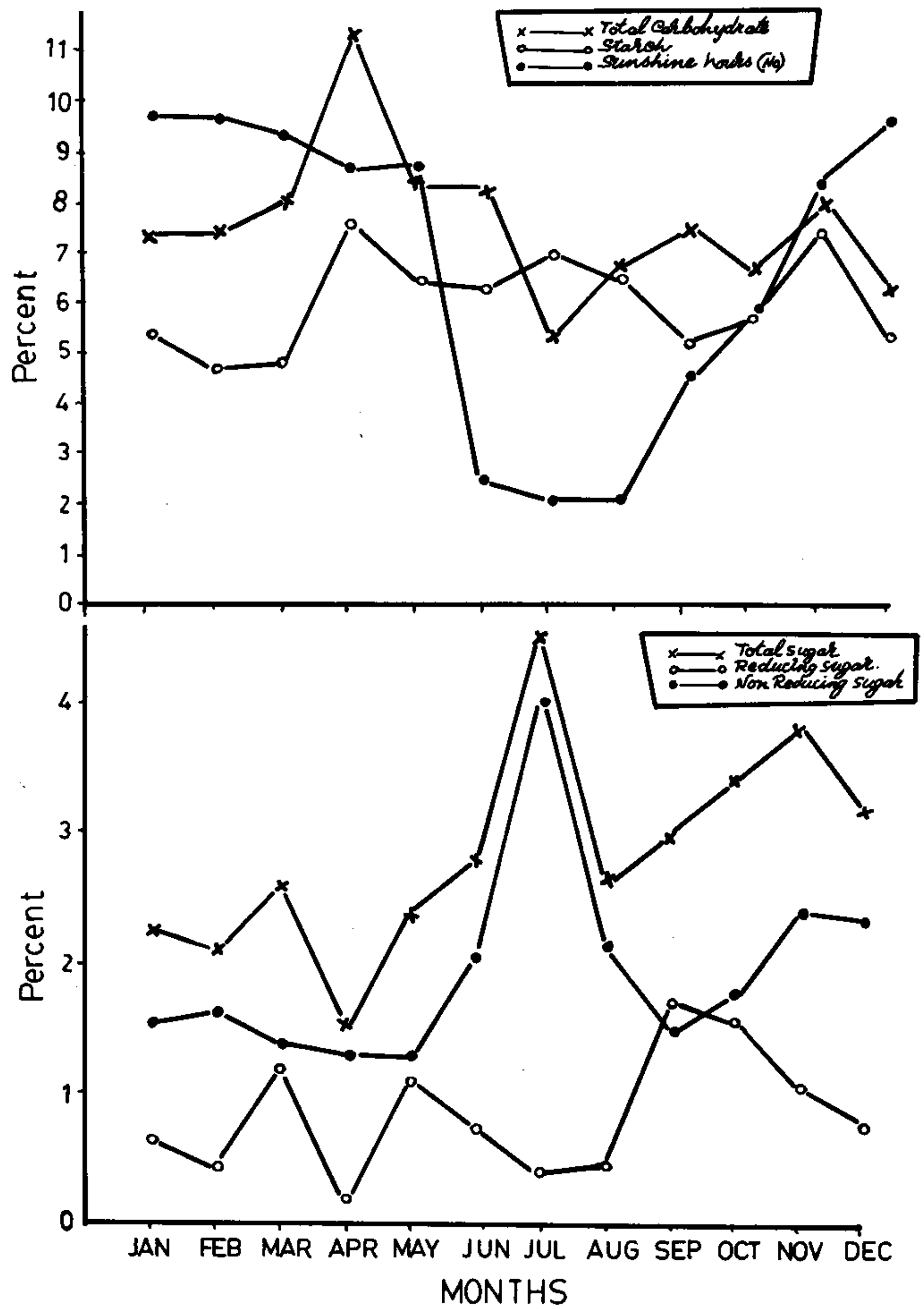

Fig. 1. Seasonal changes in sunshine (h day^{-1}) and the carbohydrate content (%) of the leaves in the hybrid WCT x CDG.

TABLE 4

Rate of apparent photosynthesis, dark respiration, relative assimilation rate and other characters in three coconut genotypes. Abbreviations of genotypes given in Table 1.

Parameter	WCT		CDO		T x D	
	Mean	CV%	Mean	CV%	Mean	CV%
Rate of aparent photosynthesis µl O_2 evolved cm^{-2} h^{-1}	28.11	22.0	32.82	30.2	33.98*	14.0
Dark respiration µl O_2 consumed cm^{-2} h^{-1}	4.23	24.4	6.31	11.8	5.02**	21.5
Relative assimilation rate gm^{-2} $week^{-1}$	2.83	44.1	2.63	38.8	4.70**	23.4
Total chlorophyll mg cm^{-2}	0.05	30.0	0.04	15.0	0.06**	16.0
Total carotenoids mg cm^{-2}	0.02	36.0	0.02	20.0	0.03**	17.0
Stomatal frequency No. mm^{-2}	199.06	10.3	189.50	19.3	203.59	14.0
Leaf area m^2 $leaf^{-1}$	4.50	-	3.60	-	6.80*	-
Mean yield No. of nuts $palm^{-1}$ y^{-1}	58.30	26.4	48.60	33.3	93.10	51.5

** Significant at P = 0.01.

* Significant at P = 0.02.

which increases until 3.4 h after mid-day has been observed to contribute significantly to the specific leaf weight of coconut (Kasturibai et al., 1981).

Recent studies on nitrate reductase (NR) activity in coconut (Shivashankar and Ramadasan, 1983 and Shivashankar and Rajagopal, 1983) revealed a high positive correlation between the inducible NR activity and the annual yield of nuts (r = 0.6855). The activity of NR exhibited a strong diurnal rhythm with a peak at 14.00 h and was independent of tissue nitrate level.

Being a tree crop of large size with simultaneous vegetative and reproductive growth, it is difficult to derive absolute values of NAR. However, since the tree has single growing point at the shoot apex, the rate of leaf production is reckoned as the efficiency of dry matter production the palm (Ramadasan et al., 1984). The values derived are expressed as g m^{-2} $week^{-1}$ and termed as relative assimilation rate (RAR), as this method does not take into consideration the photosynthates transported from the leaf during the intervening period of sampling. The youngest actively growing leaf was the most appropriate leaf for sampling, as other mature leaves did not show any further growth. In adult coconut palms the RAR ranged from 1.9 to 5.9 g^{-2} $week^{-1}$ in WCT and 1.2 to 3.9 g^{-2} $week^{-1}$ in Chowghat Dwarf Green (CDG) palms. The coefficient of correlation with the annual yield of nuts was significant at 1% level, the 'r' values being 0.5813 for WCT and 0.5729 for CDG.

FLOWERING

Coconut palm appears to be a long-day plant. When one year old coconut seedlings were treated with long days, the first inflorescence primordium was noted in the 10th leaf axil, as against the 14th leaf axil in the control (Pillai et al., 1976). This indicates that the inflorescence primordium develops in the leaf axil of 10th to 14th leaf axil, but gets aborted. Studies in Sri Lanka (Wikremasurya, 1968) also confirmed that the spadix initiation and production were greater during March-September when average day lengths are maximum.

Gibberellic acid (GA_3) upto a level of 1000 ppm, did not enhance the rate of growth of leaves, but caused elongation of petiole in the leaf that emerged after the treatment, in one year old seedlings. In a batch of 3 year old young palms, feeding of 500 ml of 1000 ppm GA_3 through the trunk produced the first inflorescence in the 36th leaf axil against the 45th leaf axil in WCT palms.

In adult palms, the female flower production is governed by not only the environmental and soil factors, but also the inherent genetic factors.

Marar and Pardalai (1957) reported that in West of India, the female flower production and consequently the production of copra and oil are higher during the months from January to April than in other months of the year. Kasturibai and Ramadasan (1982) have mentioned that the number of sunshine hours during this period ranged from 8 to 10 hours per day.

In adult palms, an intimate relationship exists between carbohydrate level and commencement of flowering. The ground tissue of the trunk is rich in starch and serves as a reservoir of food. The peak female flower production from January to April coincided with low sugar but high starch content in the stem (Kasturibai and Ramadasan, 1982). In a study on two batches of palms (those that had just commenced flowering and those that had not commenced bearing inspite of the emergence of 45 leaves), the carbohydrate level in the stem at the junction of leaves in flowering palms was significantly higher than those that had not flowered (Table 5).

TABLE 5

Relationship of carbohydrate reserves in the trunk with commencement of flowering in young WCT palms (from Ramadasan and Mathew, 1977).

Character	Group I	Group II	Difference
No. of leaves produced so far	72.0 ± 3.2	60.0 ± 2.0	12.0**
No. of leaves present on the crown	21.0 ± 0.9	17.5 ± 0.7	3.5**
Total carbohydrates in the leaf*	6.3 ± 0.6	7.0 ± 0.4	0.7
Total carbohydrates in the trunk*	13.1 ± 0.5	9.6 ± 0.6	3.5**
Total nitrogen content in the trunk*	12.6 ± 0.7	15.1 ± 0.7	2.5**
Carbohydrate/nitrogen ratio in the trunk	1.0 ± 0.1	0.6 ± 0.0	0.4**

*% of dry weight; **Significant at P = 0.01.

Thus, adequate build up of carbohydrate level in the stem appears to be a pre-requisite for commencement of flowering (Ramadasan and Mathew, 1977). Further, the free amino acid content in the leaves of flowering palms was at least 50% greater than that in non-flowering ones (Balasubramanian, 1971).

The fruit set in Tall coconut palms, for e.g. WCT, is only 20% to 30% and that the rest of the flowers are dropped off (button-shedding). As

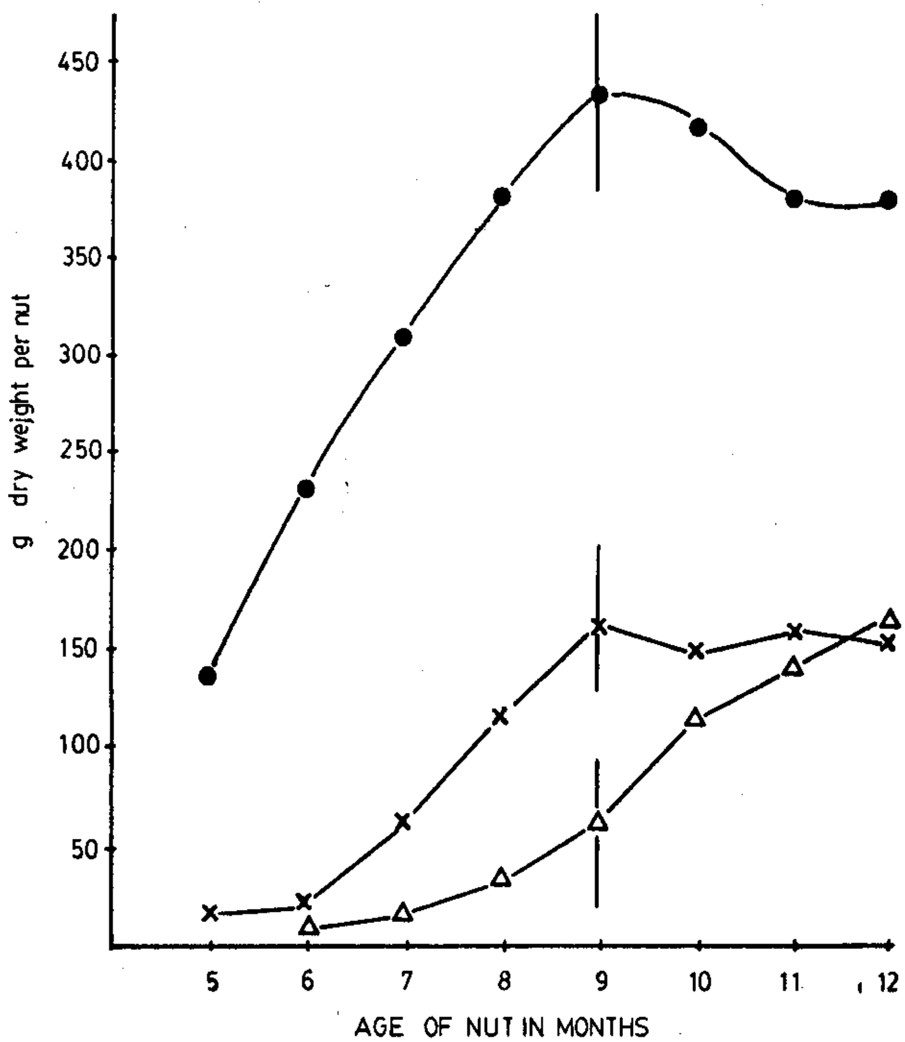

Fig. 2. Dry matter accumulation during the development of nut in WCT palms: -●- husk; -x- shell; -Δ- kernel.

the fruit set is largely governed by genetic factors, it is difficult to enhance the fruit set by normal cultivation practices. It has been found that the extent of flower drop is increased with increase in female flower production. Gangoly and Gopalakrishnan (1957) reported that button shedding could be reduced by spraying the bunches with a mixture of 60 ppm 2, 4-D and an equal quantity of cow's urine or tender coconut water at weekly intervals for a month after fertilisation. The authors pointed out that thinning may be necessary later during the development of nuts. Although the fruit set was almost doubled, the weight of copra per nut decreased, with no difference in oil content; some times, barren nuts were also produced. The fruit drop was significantly more during the second and third week after fertilization. It started earlier in inflorescence with larger number of female flowers.

Poor soil aeration, waterlogging, drought, deficiency of potassium and heavy rainfall - all contribute to enhanced flower drop. Early infestation of inflorescence by Phytophthora sp., mites and mealy bugs also cause heavy flower drop and immature fruit drop.

There is wide variability in the dry weight and its distribution in the fruit (coconut) of different genotypes. The mean dry weight of a nut of 'Tall' palm ranges from 600 to 1000 g. About 40 to 60% of this is in the husk (mesocarp), 15 to 25% in the shell and only 20 to 30% in the copra (kernel). The turnover of oil per fruit is 15 to 20% only. The coconut bunch weighs about 150 to 500 g without nuts. Kasturibai and Ramadasan (unpublished) observed that during fruit development upto 9th month of growth there is a sharp increase in the dry weights of husk and shell and thereafter the partitioning is mostly towards the kernel with very little addition to the shell and husk (Fig. 2).

BIOMASS PRODUCTION AND HARVEST INDEX

Under average management and productivity level, a planting density of 175 palms per hectare, the annual biomass production of WCT coconut palms ranges from 12.1 to 15.0 per hectare. The adult WCT palms producing about 50 nuts annually under normal cultural and agronomic practices including recommended doses of fertilizer application, consume about 11450 k cal of energy per annum, but produce about 24 times as much as energy annually (Baboo and Ramadasan, 1986).

The development of non-destructive method of estimation of leaf area and dry matter production in adult coconut palm has helped in developing a methodology for estimating the harvest index of coconut palm. In annual crops the harvest index (the ratio of dry matter partitioned towards the economic product to the total dry matter produced) is determined with ease, but in coconut it is difficult for obvious reasons. However, based on the least destructive methods of estimation of dry matter production in stem and leaf, and by estimating dry matter produced in nut and bunch samples, a method for estimating the annual productivity index, API, (ratio of dry matter partitioned towards the nuts and bunches, produced in an year to the total annual dry matter produced) has been developed (Ramadasan and Mathew, 1986). The API estimated by this method in ten adult palms (the annual yield of which ranged from 45 to 91 nuts) ranged from 0.4 to 0.5. This ratio has shown good relationship with the annual yield of nuts and appears to be good index in determining the production efficiency of coconut palms. Corley (1983) has reported that in the case of dwarf x tall hybrid palms the annual CGR is 31 t and the harvest index 62%. These figures seem to be on the high side, since in the case of the West Coast Tall palm of India the estimated CGR is only about 15 t ha^{-1} with 175 palms per ha.

PHYSIOLOGY OF ROOT (WILT) DISEASE

The coconut palm is afflicted by a serious malady characterised by predominant wilting of the crown and described as root (wilt) disease. Recent studies on the etiology of the disease have implicated mycoplasma-like organisms (Solomon et al., 1983). The disease is spread over 410,000 ha in eight districts of Kerala state, India, and results in a loss of 900 m nuts every year. The disease occurs in all soil types but with greater incidence in tracts with sandy loam soil subject to high water table and water-logging (Pillai et al., 1973, 1980).

The main characteristic of the disease is the flaccidity of leaves. Other associated symptoms are premature yellowing of older leaves, necrosis of leaves, drying up of spadices and premature shedding of nuts (Radha and Lal, 1972).

Attempts have been made to develop diagnostic tests for an early detection of the disease based on either differential dehydrogenase enzyme activity (Thomas and Shanta, 1963), or extraction of biologically active organic constituents in EDTA (Dwivedi et al., 1977). But these tests are not convincing. However, a sero-diagnostic test (Solomon et al., 1983) and a physiological examination based on stomatal regulation (Rajagopal et al., 1986b) similar to mycoplasma-caused yellow diseases, proved to be more sensitive in detecting the disease well before the expression of visual symptoms.

Root system

As the name of the disease itself implies the damage to roots is the primary symptom. The number of active roots and diameter of the bole were drastically reduced in diseased palms. On the other hand, the percentage of dead roots was higher in diseased palms than that in healthy ones (Menon and Pandalai, 1958; Michael, 1964). Indira and Ramadasan (1968) recorded distintegration of vascular tissues in 60% of the roots from diseased palms, compared to 33% in roots from apparently healthy palms, but the foliar symptoms of the disease appeared only in the former. Majority of diseased roots had tyloses in the vessels and were characterised by deranged permeability. Root sap from diseased palms contained 65 to 72% more dry solids than that from healthy palms.

The uptake of water is affected root (wilt) diseased coconut palms. While single root of healthy palm could absorb 250 to 500 ml water per day, that of a diseased palm could take up only 150 ml of water per day (Davis, 1964). The uptake and upward transport of water through the trunk in diseased palms was also found to be 35% less than that of healthy palms (Ramadasan, 1970). The profiles of soil moisture content in the basins of healthy and diseased palms, at one day interval for five days after irrigation, also indicated that healthy palms caused greater depletion of water than diseased palms, which reflected on the poor uptake of water by the root system of diseased palms (Rajagopal et al., 1986a).

Further evidence on the root damage/derangement was provided by biochemical analysis of roots. Greater depletion of carbohydrates (Mathew, 1977), reduced C/N ratio (Varkey et al., 1969) and increased respiration rate (Michael, 1978) were reported in the roots of diseased palms. Dwivedi et al. (1979) observed lesser uptake of ^{32}P by roots and poor distribution of labeled compounds in diseased palms as compared to that of healthy palms. As indicated in Table 6, roots of diseased palms had higher activities of cellulase (Padmaja and Sumathykuttyamma, 1979), pectinlyase (Sumathykuttyamma and Patil, 1984), polyphenoloxidase and peroxidase (Joseph et al., 1976) than those of healthy ones.

TABLE 6

Activity of cellulase and pectinlyase in the roots of healthy and diseased coconut palms.

Enzyme/sample	Healthy	Diseased
Cellulase	mg glucose liberated h^{-1}	100 mg $protein^{-1}$
Healthy roots	0	0*
Decayed roots	4.5	11.2
Pectinlyase	mg protein liberated min^{-1}	100 mg $protein^{-1}$
Healthy roots	0	0*
Decayed roots	3.4	20.6

*Apparently healthy.

Leaves: water relations and metabolism

The deterioration in structure and function of roots is associated with several abnormalities in leaves, as well. In the diseased leaf, degeneration of chloroplasts, less cuticular deposition and reduced lignin content in the cell was were noticed (Shanta et al., 1959; Shanta et al., 1964; Govindankutty, 1979). The leaves get stunted, with larger number of stomata per unit area. In certain leaflets, the phloem in vascular bundles became necrotic (Govindankutty, 1979). An accelerated transverse division and a restricted longitudinal division of the upper epidermal cells caused the typical bending of leaflets of diseased palms (Govindankutty, 1981).

Mathew (1981) reported that there was no difference in the stomatal index between the healthy and diseased palms, though there was greater stomatal frequency in the latter (Table 7). The stomatal regulation of the diseased palms was impaired leading to excessive water loss at any given time of the day (Figure 3) or season (Rajagopal et al., 1986b). Thus, the water economy of diseased palms was adversely affected. Consequently, leaf water potential of diseased leaves was reduced (Table 8). The marked decrease in leaf turgor potential of diseased palms could be the precise reason for the characteristic flaccidity symptom (Rajagopal et al., 1986b).

Apparently as a consequence of disturbed water economy, various changes in the biochemical constituents occurred in the leaves of diseased

TABLE 7

Cell number, stomatal frequency and stomatal index in the leaves of healthy and root (wilt) diseased coconut palms (Mean of 20 palms).

Parameter/ leaf position	Healthy	Diseased
No. of cells (mm^{-2})		
First leaf	1272	1413**
Middle leaf	1280	1398**
Stomatal frequency (no. mm^{-2})		
First leaf	182	228*
Middle leaf	171	219**
Stomatal index		
First leaf	13.5	15.1***
Middle leaf	13.0	14.8***

t value significant at P = 0.01; * - Not significant.

TABLE 8

Changes in the water status of the leaves in root (wilt) affected coconut palms; values are mean of 8 palms.

Component	Apparently healthy	Diseased
	MPa	
Water potential (Ψ)	-1.34	-1.79
Solute potential (Ψ_π)	-1.68	-1.83
Pressure potential (P)	0.34	0.04

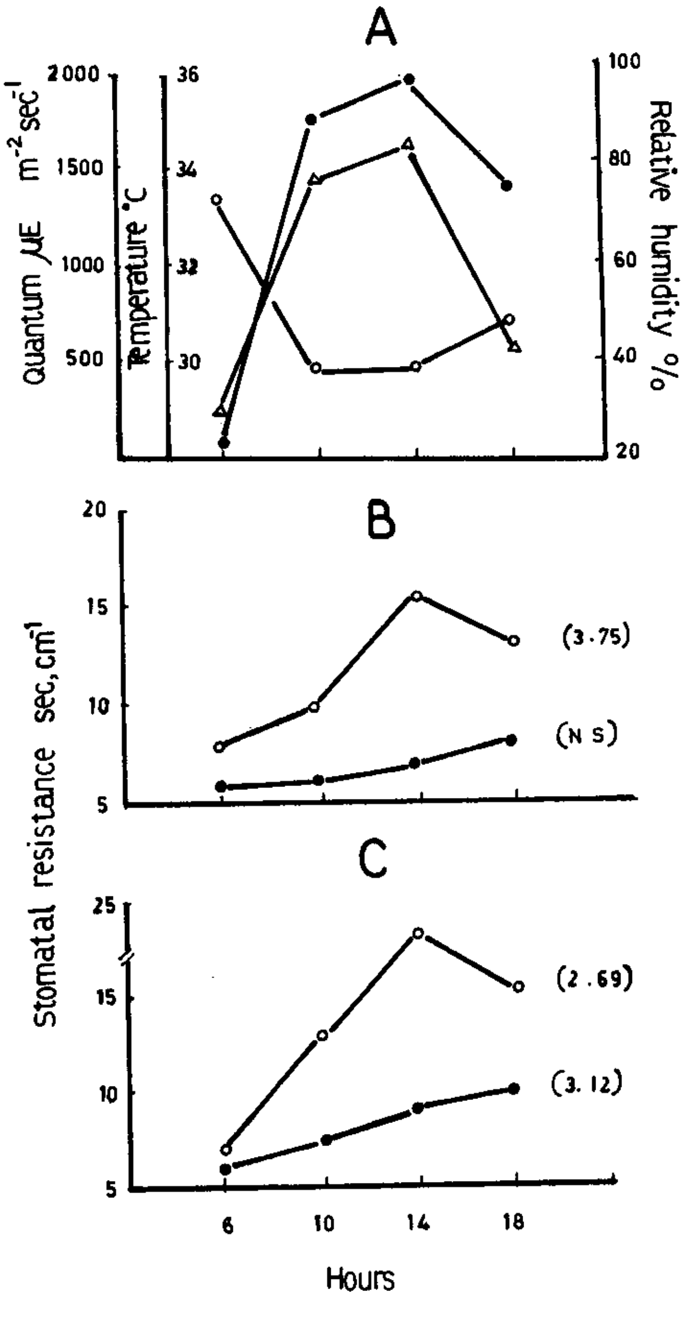

Fig. 3. Stomatal resistance in coconut plantation during a day. (A) Agro-climate at the experimental site - ● : light; Δ : temperature; o : relative humidity. Stomatal resistance was measured on first (B) or middle (C) leaves of apparently healthy (o) and diseased (●) palms. Values are means of nine palms, C.D. at 1% level are given in brackets.

TABLE 9

Carbonic anhydrase activity in healthy and root (wilt) diseased coconut palms.

Leaf position	Healthy	Apparently healthy	Diseased
		mg CO_2 mg (protein)$^{-1}$ h^{-1}	
Spindle leaf	9.8	6.2	5.5
First leaf	5.3	1.7	1.1
Middle leaf	3.6	1.7	0.9
Outer leaf	2.4	1.2	1.1

TABLE 10

Nitrate reductase activity in the leaves of different whorls of apparently healthy and root (wilt) affected coconut palms. Values are mean of six palms.

Leaf position	Apparently healthy		Diseased	
	nmoles h^{-1} g (fresh wt.)$^{-1}$	nmoles h^{-1} g (dry wt.)$^{-1}$	nmoles h^{-1} g (fresh wt.)$^{-1}$	nmoles h^{-1} g (dry wt.)$^{-1}$
Spindle	52.5	214.6	60.2	405.1
Inner whorl	58.3	168.9	81.2	260.0
Middle whorl	123.7	323.3	126.8	332.6
Outer whorl	73.1	185.3	101.7	235.7

palms. The leaves of diseased palms showed higher content of soluble sugar fractions (Mathew, 1977), an increase in non-protein nitrogen content and a decrease in water soluble nitrogen and protein nitrogen fraction and higher total and organic phosphorus (Varkey et al., 1969) compared to healthy palms. Michael (1978) observed an enhanced respiration rate (5 to 21%) in the diseased leaves. Radioisotope studies with ^{32}P indicated that although total P was more in diseased palms, the organic P, especially nucleic acid P was significantly less than that of healthy palms (Dwivedi et al., 1979). Accumulations of certain amino acids (Pillai and Shanta, 1965) and tannins (Lal, 1968) and decrease in polyphenols (Joseph and Jayashankar, 1973) were observed in the diseased leaf tissues. The levels of carbonic anhydrase in the leaves of diseased palms were lower (Table 9) while nitrate reductase activity was higher (Table 10) than those in apparently healthy palms (Dwivedi et al., 1977).

Flowering

A healthy coconut (WCT) palm commences flowering by 7th year after transplantation or at the age of attainment of 45th leaf stage of growth (Menon and Pandalai, 1958). In a study to determine the most susceptible age of the palm to the disease, Ramadasan et al. (1971) observed that (i) the young coconut palms are more susceptible to disease at the age of bearing, (ii) in the palms which contracted the disease before the commencement of bearing, the bearing age was delayed indefinitely and (iii) in the young palms that became diseased before the commencement of bearing, the yield was drastically affected when compared with the yield of those that were diseased after the commencement of bearing. Thus Table 11 demonstrates

TABLE 11

Annual yield of nuts in young healthy and root (wilt) diseased palms.

Age of the palms in years	Healthy	Diseased	% loss due to disease
7	16.4	11.8	28.0
8	25.5	16.0	37.3
9	38.7	17.6	54.5
10	42.9	17.2	59.9
11	56.7	22.9	59.6
12	65.6	21.9	66.6
13	87.6	25.7	70.7

that the yield of nuts in the diseased palms increased only twice from the 7th to 13th year, where as in the healthy palm, the yield increased over five times during the same period. In the healthy group, though the average annual increase in the yield per palm during this period was about 12 nuts, it was only 2 nuts per palm in the diseased group. It is felt that the greater susceptibility of young palms to the disease, at the time of commencement of bearing and the consequent postponement of flowering and subsequent yield reduction could possibly be attributed to the diversion of accumulated carbohydrates in the trunk (Ramadasan and Mathew, 1977) for the growth and multiplication of organism(s) involved in the disease.

CONCLUDING REMARKS

Being a tree crop of large size, long life, continuous bearing tendency and with a distant origin, the coconut palm exhibits wide variability. Hence, the studies on the physiological parameters as related to crop productivity in health and disease have been slow. Nevertheless, the results discussed in the present paper attempt to probe into the production characters responsible for limiting the productivity. Recent results have shown that the nitrogen use efficiency exhibited at seedling level, which can be detected by a relatively rapid method (Shivashankar, Personal communication) can possibly be used for predicting the high yield. This, together with the finding of heritability of efficiency of growth and dry matter production in one year old progenies of West Coast Tall palm (Ramadasan et al., 1985) can be made use of in the precise selection of planting material with high productivity potential. The wide yield gap can thereby be narrowed.

The physiological and bio-chemical studies on the root (wilt) disease of the palms indicated the extent of deranged metabolism caused by the disease. Studies on water relation aspects have shown that the internal water deficit developed in the diseased palm and the disfunction to the stomatal control leading to change in leaf water potential may be the steps leading to the flaccidity of the leaves, which is characteristic symptom of the disease.

Acknowledgements

We are thankful to Dr. K.V. Ahamed Bavappa, Director of the Institute for encouragement, Mr. S.M. Chettiar for typing the manuscript and to all our colleagues in the Division for their help.

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