Management of Abiotic Stresses in Coconut

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Coconut (*Cocos nucifera* L.) is one of the important perennial crops belonging Palme. The coconut palm is widespread in the coastal area of the tropics. In fact 90% of the worlds total acreage and production of the crop lie in between 20° N and 20° S latitude. In extreme latitudes the palms vegetative growth is good but with poor bearing of nuts.

In India, coconut is grown at different altitudes within 26°N latitude. However, at different latitudes, it is the temperature that determines the limit to altitude up to which the palm can be grown successfully. Thus, nearer to equator where the temperature would be favorable, the palm can be grown at higher elevation of even up to 1000 m above the sea level. Moving further from the equator the temperature tends to drop and becomes less favorable and, consequently the cultivation is to be confined to low altitudes.

It is important to have an integrated approach for getting better yields under stressful conditions. Any attempt to increase the drought tolerance in crop plants should essentially include i) high water use efficiency ii) high dry matter production efficiency iii) revival capacity and iv) developmental plasticity. Reasonably stable harvest index even under stressful condition is one important factor that has to be given importance.

Response of coconut to drought stress

In the rainfed areas, drought is the major constraint for the crop productivity, more so in plantation crops since they are widely grown in different soil types such as sandy, sandy loam, laterite and forest soils in the states of Kerala, Karnataka, Tamil Nadu and Andhra Pradesh. As these crops are mainly grown under rainfed condition, productivity is affected due to the dry summer months starting from December/January to April/May. Drought research in coconut stated in 1983 when drought affected the coconut yields. Drought in 2002 adversely affected the coconut plantations in Tamil Nadu. In many districts palms lost major portion of canopy or fully dried up. These palms take at last 2 to 3 years to recover fully. During the period the soil water deficits coupled with the changes in atmospheric parameters aggravate the situation leading to soil as well as atmospheric drought. Generally, this is the time when they should receive adequate water supply in order to get better yields. The type of light soils on which most of the perennial crops raised also contribute to the synergism effect. Increasing the crop area under irrigation has several limitations, the major one being the water resources. Being perennial in nature the water requirement of plantation crops is also fairly high. Since the water availability is becoming scarce, further increase in crop area under irrigation is difficult. The approach then has to be to use the available water source with high productivity efficiency. Thus it is important to identify the varieties, which can withstand moisture stress conditions in the field, and to evolve management strategies for conserving available water sources in order to mitigate adverse effects of drought.

Most of the plantation crops grow well in tropical climate with abundant sunlight, well distributed rainfall, with moderate temperature. As indicated earlier, for coconut the ideal conditions will be an annual rainfall between 130 and 230 cm mean annual temperature of 27° C and sunlight ranging from 250 to 350 wm^{-2} with annual sunshine of 2000 hrs (at least 120 hrs per month). (Child, 1974; Murray, 1977). Among the meteorological variables rainfall is one of the important parameters, which affect the production of crops. Hence conservation of available soil moisture is important for mitigating the water deficit during prolonged drought periods, at least to a certain extent. Various methods like contour bunding, trenching, pitting and construction of check-dams are used for the conservation of soil water. However for managing the atmospheric drought, crop plants which can adapt to the changing soil and atmospheric conditions and yield satisfactorily have to be recommended. Hence, before crop area expansion, a thorough knowledge of hydro-physical characteristics of soil as well as atmospheric condition of the locality is essential.

Soil-water plant relationship in coconut has been worked out and critical levels for stress development are delineated Based on the physiological and environmental variables a drought index has been worked out in coconut (Table 1).

In sandy loam soil water deficit of 110 mm is the critical level at which coconut suffered most due to moisture stress. During extreme water scarcity palms shed most of the leaves except the spindle leaf, thus protecting the meristematic region. However, the severity of the morphological symptoms depend on the intensity of drought (Pomer and de Taffin 1982; Rao, 1985). As the same weather conditions do not always occur in any given location, the yield of coconut fluctuates depending on the intensity of the factor involved. Water deficit caused by the inadequate rainfall with poor distribution deserve special mention. These dry spells vary with the location and year. The agro-climatic variables in the tropical areas varied significantly between the non-stress and stress period.

Table-1 Drought index in coconut as a function of soil moisture content, weather variables and plant parameters

Parameter	Critical levels
Air temperature	33 °C
Radiation	$265/wm^2$
VPD	27 m bar
Soil moisture content	9 %
Stomatal resistance	9.0 Sec/cm
Transpiration rate	$2.5 ug/cm^2/sec$
Leaf water potential	1.20 MPa

Source: Kasturi Bai and Rajagopal, 1996.

Even the rainfall pattern in different parts of same place is found to vary significantly. For example the rainfall in Southern Kerala is evenly distributed whereas the Northern Kerala, although annual rainfall averages 360 cm, 85% of it is received during the South-West monsoon (June to September), while 7.5% is received during the North-East monsoon, (October-November) and the remaining 8.5%. of it is received as non-seasonal rainfall. Thus the rainless period ranges from 5 to 7 months in Northern Kerala as compared to 4 to 5 months in Southern Kerala due to early cessation of South West monsoon or failure of North-East monsoon. Coconut palms also respond differently to these changing environmental condition in terms of growth and nut production.

Varietal differences in nut yield in response to severe stress conditions have been reported by Ramadasan *et al.* (1991). Bhaskara Rao *et al.* (1991) have explained the performance of same hybrids during good and drought influenced years in which some of the hybrids like LCT x COD and LCT x GBGD maintained high female flower production and high nut set than COD x WCT during drought years. The drought susceptible nature of COD x WCT and drought tolerant nature of LCT x GBGD and LCT x COD were also reported by Rajagopal *et al.* (1990) based on water relation components and cuticular wax content.

Physiological responses to drought stress: Water transport in coconut is carried out mainly by a negative pressure gradient with only a minor role by the root pressure (Milburn and Davis, 1973) 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 (*LA VPD*) and leaf to air temperature difference (ΔT) influenced the photosynthetic efficiency of coconut in irrigated and rainfed conditions via., the *gs* and water relations during day time (Rajagopal *et al.*, 2000). Seasonal variations in the Ψ_{leaf} occurs depending on the weather, type of soil and soil water availability (Shivashankar *et al.*, 1991; Voleti *et al.*, 1993a). A rapid screening method was developed based on Ψ_{leaf} in excised leaflets (Rajagopal *et al.*, 1988) for easy handling of a large number of genotypes. The physiological age of palms and of leaves influence the formation of wax and its composition on leaf surface. Leaves of coconut seedlings have almost 50% less ECW than those from adult palms even at same degree of stress. Major components of ECW identified are hydrocarbons and esters (Kurup *et al.*,1993). Role of K^+ and Cl^- nutrition in relation to drought tolerance in coconut has been explained on the basis of stomatal regulation. Probably Cl^- replaces malate as an osmoticum for maintaining the turgidity and thereby resisting the effects of water stress. (Braconnier and D'Auzac, 1985). Cl^- has been shown to increase water absorption and reduce transpiration by stepping up osmotic pressure within the cells in coconut (Ollagnier *et al.*, 1983). Increase in drought tolerance and higher stomatal regulatory capacity of palms under dry conditions with the addition of KCl was reported (Ollagnier *et al.*, 1983; Lubina, 1990). Inadequate supply of K^+ and Cl^- result in symptoms like yellowing and drying of leaves caused by an imbalance in the water relations of palms.

Biochemical responses to drought stress: The biochemical responses of coconut palm to drought stress include upregulation or synthesis of scavenging enzymes to maintain cell membrane integrity thus enabling cells to tolerate stress. Drought stress caused an increase in the activities of some of the stress sensitive enzymes, *viz.*, peroxidase (POD), polyphenol oxidase (PPO), superoxide dismutase (SOD), acid phosphatase (APH) and L-aspartate :2-oxoglutarate amino transferase (AAT) in adult WCT palms, while activities of malic dehydrogenase (MDH) and nitrate reductase (NR) were decreased

(Shivashankar,1990; Shivashankar *et al.*, 1991, Kasturi Bai *et al.*, 1996b; Rajagopal *et al.*, 1988; Shivashankar,1992). Changes in isozymes patterns of the peroxidase PPO (Shivashankar,1988) and APH (Shivashankar and Nagaraja,1996) has also been reported in stressed coconut leaves.

At the cellular level, the impact of stress is generally seen on the integrity of membranes and extent of solute leakage is regulated by the cell membrane stability, which differed among the cultivars and with the maturity of leaf - (Kurup,1989). Normal cell functions are affected due to changes in peroxidation of cell wall lipids (LP) during stress resulting in increased cell permeability and solute leakage. In coconut lipid peroxidation was high in drought susceptible cultivars as compared to tolerant ones (Chempakam *et al.*, 1993). Since the peroxidase, in combination with SOD and catalase is involved in the defense of aerobic cells against the superoxide radical and hydrogen peroxide in tissues, they are expected to protect the cell against oxidative damage. Drought tolerance is thus characterized by higher activities of the protective enzymes like SOD, catalase and peroxidase and consequently coupled with lower levels of lipid peroxidation and higher membrane integrity. (Chempakam *et al.*, 1993; Kasturi Bai *et al.*, 1996; Kasturi Bai *et al.*, 2001).

Screening for drought tolerance in coconut

Cell size and number, sub-stomatal cavity size, stomatal frequency, epicuticular wax content and thickness, leaf thickness, stomatal resistance water potential components, cell membrane stability are the essential anatomical and physiological traits for assessing moisture stress in plants (Rajagopal *et al.*, 1991; Kasturi Bai, 1993; Naresh Kumar *et al.*, 2000). Based on these, coconut germplasm collections comprising of talls, dwarfs and hybrids were screened under field conditions for drought tolerance.

Under stress conditions, where high evaporative demand in the atmosphere prevail, genotypes exhibited differential adaptability through stomatal regulation. *rs* was high in the hybrids followed by talls, whereas in dwarfs *rs* was almost 50% less than that in hybrids. This reflects on higher loss of water in dwarfs through transpiration than in talls and hybrids. The sensitivity of stomata affected Ψ_{leaf} to a great extent. The low *rs* resulting in high *E* led to lowering of Ψ_{leaf} in dwarfs, conversely high *rs* was associated with high Ψ_{leaf} among hybrids like WCT x WCT. Instantaneous and intrinsic WUE increased under mild water deficit conditions (Rajagopal *et al.*, 2000). The *E* was inversely proportional to the content of ECW on the leaf surface

Leaflet anatomy in relation to drought tolerance: Anatomical basis of physiological efficiency for drought tolerance in coconut is delineated (Naresh Kumar *et al.*, 2000). The leaflet thickness increased mainly due to increase in parenchyma cell size. It is also associated with lowered stomatal frequency, an indication of adaptation to drought. Increased leaf thickness and thick cuticle are some of the xeromorphic characters, which causes decrease in the ratio of the external surface to its volume. Correlations between anatomical features and physiological parameters also indicated thick cuticle lowers the cuticular transpiration. Water in leaves is conducted not only by the veins and bundle sheath extensions but also by the mesophyll cells, epidermis and through intercellular spaces. Water transport towards the epidermis is much higher through the palisade tissue than the spongy parenchyma. Increased parenchyma cell size (less intercellular space/ unit area) as observed in tolerant types. This may help in reducing the water conductance towards epidermis thus reducing the transpirational rates and maintaining high water potentials. The volume of intercellular spaces in xeromorphic leaves is low thus reducing the water transport to epidermal cells. The surface area of palisade parenchyma/ unit area, thus decreased, lowered photosynthetic rates. The ratio of internal to external surface is positively correlated with the rate of transpiration. Thus, the structure favorable to high photosynthetic rates (large palisade parenchyma tissue surface, i.e., small parenchyma cells) induces at the same time high transpirational rates due to higher intercellular space (Naresh Kumar *et al.*, 2000).

The study indicated marked influence of leaflet anatomy on photosynthesis and transpiration (Table-2). It is suggested that a leaf anatomy which favours high photosynthetic rates also favour high transpirational rates thus the drought susceptible types had higher photosynthetic rates associated with high transpirational rates compared to the tolerant ones. The reason for such trends can be explained on the basis of leaflet anatomy (Naresh Kumar *et al.*, 2000).

The cultivars tolerant to water stress, had thick leaflets, thick cuticle on both sides, larger parenchyma, hypodermal and water cells compared to less tolerant (Naresh Kumar *et al.*, 2000). The water storage tissue supply water to other tissue when water is limiting. Cultivars having thick cuticle are able to maintain higher leaf water potentials. Drought tolerant types also had more scalariform thickening on xylem trachieds in vascular bundles and large sub-stomatal cavities. Large sub-stomatal cavities will help in maintaining enough internal CO_2 concentrations required for sustaining the photosynthetic rates during the stress period when the stomata are partially closed. High internal CO_2 concentrations may help in reducing the water loss through stomata. Certain parameters like epidermal cell size (upper and lower) and guard cell size are related to the drought tolerance character of a cultivar. It is possible that cumulative effect of all these traits contribute to the adaptation to drought stress (Naresh Kumar *et al.*, 2000).

Table-2 Correlations between leaflet stress studied anatomical features and physiological parameters in coconut

Parameters		R value
Leaflet thickness	Palisade cell size	0.73
	Spongy cell size	0.82
	Stomatal frequency	-0.67
	Photosynthetic rate (Pn)	-0.41
	Transpiration rate	-0.12
Cuticle thickness Adaxial	Cuticular wax (ECW)	0.86
	Transpiration rate	-0.69
	Pn	0.13
	Leaf Water Potential	0.64
Abaxial	ECW	0.72
	Transpiration rate	-0.79
	Pn	0.13
	Leaf water potential	0.50
Sub-stomatal cavity (size)	Stomatal frequency	-0.54
	ECW	0.61
	Transpiration rate	-0.15
	Photosynthetic rate	-0.11
Palisade cell size	Pn	-0.77
	Transpiration rate	-0.38
	Leaf water potential	0.11
Spongy cell size	Pn	-0.67
	Transpiration rate	-0.05
	Leaf water potential	0.10

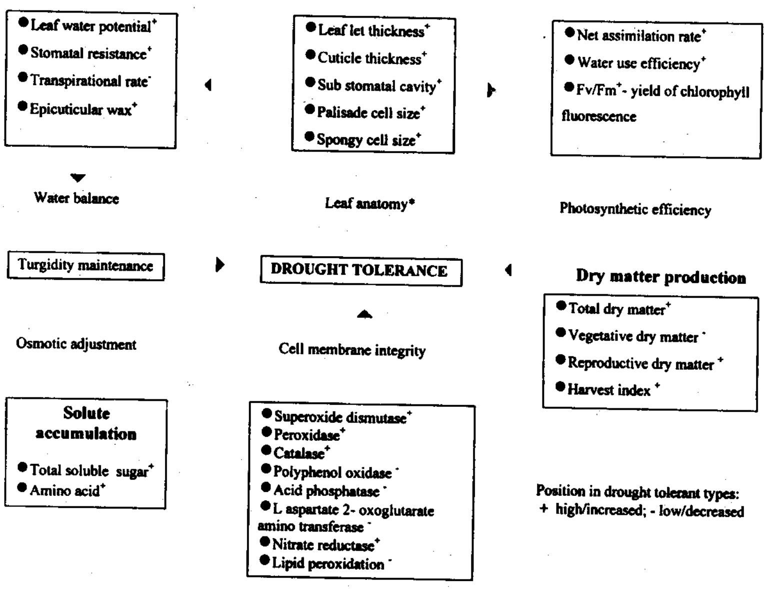
Source: Naresh Kumar *et al.*, 2000.

Drought tolerance mechanism in coconut

All the above mentioned research results 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 inductive morphological, anatomical, physiological and biochemical mechanism (Naresh Kumar *et al.*, 2000; Rajagopal and Kasturi Bai, 2002). 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.

Traits related to drought tolerance in coconut: Long gestation period and large area requirement of plantation crops pose challenge to researchers for any large scale and rapid field screening for any trait. The problem is further complicated by slow response of these crops with regard to any adverse effect on yield. Drought tolerant types can be identified by screening the germplasm for specific traits sensitive to stress conditions. Investigations have been carried out on physiological and biochemical mechanism of drought tolerance in plantation crops and identified the varieties with drought tolerant characteristics. Some of the desirable traits identified are large paranchyma cells, thick cuticle on leaf surface, high water use efficiency, high stomatal resistance, high leaf water potential, low transpiration rate, high epicuticular wax content and higher activities of the stress sensitive scavenging enzymes.

MECHANISM OF DROUGHT TOLERANCE IN COCONUT



(Source: Rajagopal and Kasturi Bai, 2002; *Naresh Kumar *et al.*, 2000)

The exploitation of the identified varieties, with not only drought tolerance but also with the potential for high yield under limited water availability, in the breeding strategies would be an important step for the overall improvement of crops productivity in drought prone areas. Mechanisms and strategies to be adopted in selection and breeding programmes depend not only on their effect on traits related the productivity, but also on the type of drought likely to be encountered by the crop. Plants adapt to stress condition by the intervention of several inductive phenological, morphological, anatomical, physiological, and biochemical mechanisms.

Influence of drought stress on photosynthetic efficiency and water use efficiency of coconut

The photosynthetic rates (*Pn*) were reduced by water stress mainly due to increase in stomatal or mesophyll resistance. Due to stress, more reduction in *Pn* was noticed in susceptible types than in tolerant types. The potential of palms for higher DM production is reflected on WUE. WUE can be determined based on dry matter accumulation (gm. DM. $mmwater^{-1}$ used) as well as by gas exchange measurements ($\mu mol\ CO_2.\ mmol^{-1}\ H_2O$). WUE based on dry matter accumulation ranged between 28.8 to 69.3 gDM. mm $water^{-1}$ used among the cultivars/hybrids. WUE was high in un-irrigated palms than in irrigated palms (Rajagopal *et al.*, 1989). A close relationship between the measurement of single leaf WUE and the whole canopy WUE has been indicated. WUE correlated with and the dry matter production and HI (Kasturi Bai *et al.*,1996).

In coconut, the day time leaf surface to air VPD (LAVPD), ΔT influence the photosynthetic characteristics and water relations. Under mild stress conditions, WUE increases, where as overall carbon assimilation efficiency is low in rainfed palms (Rajagopal *et al.*, 2000a). The day time trends in gas exchange characteristics, WUE and Ψ_{leaf} show two peaks, one at 9:00 and another at 15:00 hrs under rainfed condition. High Ci and Ci/Ca in rainfed palms indicate the predominance of non-stomatal inhibition of Pn rates. *Increased photo-respiration, impaired chloroplast functioning, Hill activity,* high ΔT under stress conditions also contribute towards inhibition of Pn. (Rajagopal *et al.*, 2000a).

During the moderate water deficit periods, the *WUE* is maintained high as the decrease in *E* was more than the decrease in *Pn*. However, when *LAVPD* increased further, the stomata started closing, decreasing *Pn* rates and increasing *Ci* and *E* thus the *WUE* reduced drastically under such situations. (Rajagopal *et al.*, 2000a).

Lower Ψ_{leaf} due to high *LAVPD* driven high *E* and also due to low water supply from the roots led to stomatal closure consequently reducing the thermo- regulatory efficiency leading to increase in ΔT. These conditions adversely affected the photosynthetic efficiency of rainfed palms. This ultimately led to the lower assimilation and production of dry matter and thus resulting in lower nut yield under rainfed conditions. However, irrigation keeps the palm leaflets cooler as the continuous and adequate supply of water from the root system ensure the maintenance of high Ψ_{leaf}. Thus the *LAVPD* did not increase much and stomata are kept open resulting in high *gs*. These conditions resulted in efficient thermo-regulation of leaflet as the *E* was maintained to check the increase in ΔT. These situations are favorable for high *Pn* rates under irrigated conditions .This led to higher dry matter production and higher nut yields under irrigated conditions. The stomatal response to microclimatic variations are suggested to change to maximize the *WUE*, particularly under mild water deficit conditions. Increase in *Ci* during mid day -closure of stomata may help plants to avoid photo-inhibition by dissipating a part of light energy for CO_2 fixation to maintain *Pn* rates, even though at lower rates. (Rajagopal *et al.*, 2000a).

Nut yield in relation to intensity and length of drought stress

The coconut palm is influenced considerably by the environmental variables in its productive features especially under rainfed condition. Of all the climatic factors rainfall has the maximum influence on the seasonal fluctuation in yield (Abeywardena, 1968). The summer irrigation is found to improve the productivity of the palms (Nelliat and Padmaja, 1978).

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. Hence, the impact of drought occurring during any of the critical stages of the development of inflorescence affects nut yield (Marar and Pandalai, 1957; Rao, 1986; Rajagopal *et al.*, 1996; Rajagopal *et al.*, 2000c). The impact of drought on the ontogeny of coconut inflorescence integrating the overall occurrence of dry spell and growth stages of the developing nut has been delineated (Rajagopal *et al.*,1996). 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, Rao,1991, 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, has indicated that the impact of such variations in dry spell on nut yield was discernible (Rajagopal *et al.*, 2000c). 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 are more important than the total rainfall *per se* which influence the nut yield (Rajagopal *et al.*, 2000b and 2000c). The total rainfall, number of rainy days and the total rainfall are not as crucial as the length and number of dry spells coinciding with the critical stages such as primordium initiation, ovary development and button size nuts which ultimately determine the yield potential of coconut palms under rainfed conditions. 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

Sensitive critical stages to drought stress

The sensitive critical stages which affect the yield in many crops are seedling establishment, inflorescence initiation, flowering, fruit set and fruit development stages. In addition to these in coconut spike let initiation and female flower primordia formation are also found to be stress sensitive stages. Depending on the severity of the stress and coincidence with sensitive stage, yield will be affected. Rajagopal *et al.* (1996) have explained the impact of drought on inflorescence and nut development in coconut by integrating the overall occurrence of dry spell during the ontogeny of inflorescence and nuts.

Ranking of cultivars for drought stress tolerance

Based on the aforesaid parameters cultivars like WCT, LCT and hybrids WCT x COD, LCT x GBGD, LCT x COD were identified as drought tolerant types. Ranking for drought tolerance was done based on all stress sensitive parameters using parametric relationships. Thus, coconut cultivars could be identified for their degree of tolerance to drought stress based on the desirable traits, which reflect on the overall water relations of palms (Rajagopal *et al*., 1990). An exhaustive list of drought tolerant crop varieties is available in India (Rajagopal, 1997). Using tolerant parents, hybrids have also been evolved. These are now being adapted by farmers for wide cultivation

Characterization of Drought in coconut growing areas

Weather variables like rainfall, day/night temperature regimes, relative humidity, sun shine duration, vapour pressure deficits play pivotal role in determine the crop growth and development and yield. As mentioned earlier, coconut palm, for good growth and nut yield, requires a well-distributed rainfall (130 to 230 cm/year), mean temperature (27 °C with diurnal variation of 5 °C) and sun shine (250 to 350 Wm^{-2}) with 2000 h duration (at least 120 hrs/month) (Child, 1974; Murry, 1977). Earlier studies indicated relationship between rain fall and other weather variables and nut yield in coconut (Vijayakumar *et al.*, 1988; Rajagopal *et al.*, 1996).

The influence of weather on nut yield in coconut in fact starts from inflorescence initiation and lasts till nut maturity (Rajagopal *et al.*, 1996). The time lag between inflorescence initiation to nut maturity is 44 months. Coincidence of critical sensitive period with unfavourable weather results in drastic reduction in yield. Coconut being a perennial crop is more influenced by the weather variables and also long lag period emphasizes the importance of weather on realizing the higher nut yields.

The nature and length of drought in different coconut growing areas was worked out based on the weather data for last 15 to 20 years from different agro-climatic zones viz., Western coastal area - hot sub-humid-per-humid (Kasaragod - Kerala; Ratnagiri - Maharashtra), hot semi arid (Arisikere - Karnataka) and Eastern coastal plains- hot sub-humid (Veppankulum- Tamil Nadu; Ambajipeta- Andhra Pradesh). These represent the major coconut growing areas in India. Our results indicate that the length of dry spell determines the impact on coconut yield.

The mean annual rainfall varied from a maximum of 3337.7 mm in Kasaragod to a minimum of 718.23 mm in Arsikere. Kasaragod, Kidu and Ratnagiri had similar rainfall pattern with peaks during June, July and August whereas Veppankulam, Ambajipeta and Arsikere had different patterns for rainfall with peaks during October-November. Dry spell was longer in Ratnagiri (216 days) and Arsikere (202 days) and shorter at Kidu (146 days) (Fig-1). Impact of such variations in dry spell on nut yield was discernible.

In general, all the centres exhibited 2 or 3 years of consecutive drought as also alternative drought during a 15 year cycle. An attempt has already been made to work out the dry spell based on the beginning and end of rainfall during the cycle. Dry spell showed marked fluctuations over the years in each centre. When expressed as number of days, Ratnagiri and Arsikere had more than 200 days of dry spell compared to other centres.

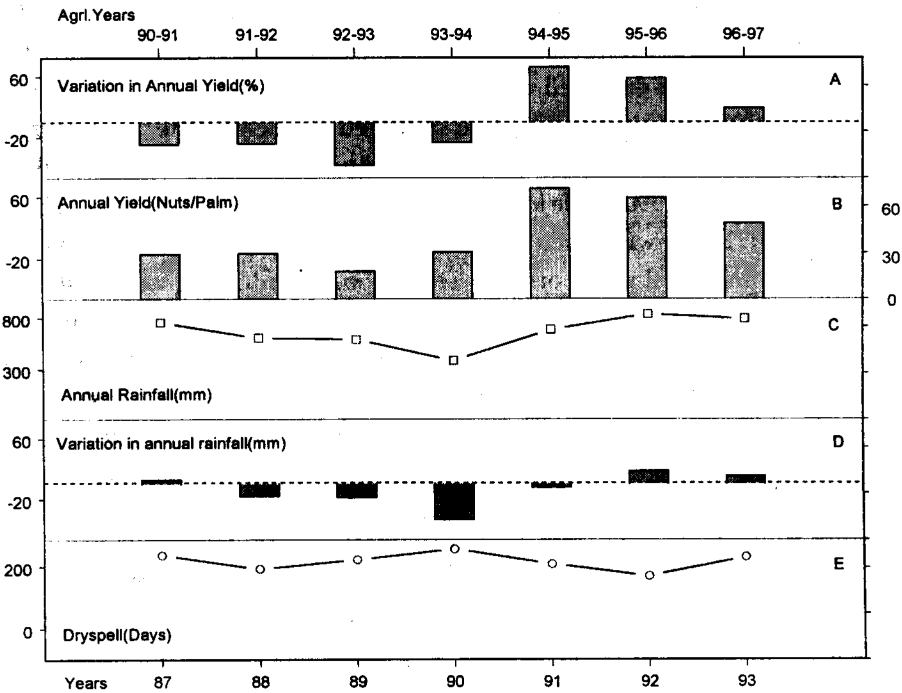


Fig-1 Impact of rainfall and dry spell on the nut yield in coconut after 4 years at Arsikere (Karnataka). Note the time gap in data of meteorological parameters and nut yield

The nut yield exhibited large variations over the years in all the centres. the significant reduction in nut yield in each centre during 1 or 2 years either consecutively or alternatively. In view of long duration of 44 months between the initiation of inflorescence primordium and ultimate nut yield, with about 70% period of pre-fertilization and only 30% represented by fertilization/post-fertilization phases, any fluctuations in dry spell occurring during important stages of floral/fruit development would reflect on net yield. Rajagopal *et al.* (1996) reported the close relationship between dry spell and nut yield and identified three critical stages during the ontogeny of nut development, namely initiation of inflorescence primordium, ovary development and button size nut. The study revealed that the rainfall/dry spell during these stages ultimately determine nut production.

The agricultural year yield data was compared with the corresponding rainfall/dry spell data of earlier 2-3 years because of long developmental periods (Fig-2). For instance, in Kasaragod the low nut yield in 1986-'87, with high percentage variation could be traced to longer dry spell in1982-'83. Conversely lower dry spell in1984-'85 resulted in relatively high nut yield in 1987-'88. A similar trend could be observed in each centre. For example, in Veppamkulm high nut yield was recorded in 1993-94 corresponding with the dry spell during 1990,while lower yield in 1994-95 coincided with increased dry spell in 1991. Likewise, each centre had a distinct pattern in the occurrence of dry spell and production of nuts. The coconut production varied in different centers and depending on the rainfall pattern the yield showed fluctuations. Longer dry spell was found to affect nut yield in the fourth year. Further evidence on the three critical stages namely, inflorescence primordium, ovary development and button size nut sensitive to moisture stress was obtained.

Management of drought stress in coconut plantations

Studies revealed occurrence of drought occurs once in three to four years with different intensities in major plantation areas. Depending on the length of dry spell and its coincidence with the critical stages of crop growth the yield will be affected. In order to have sustained yields it is important to have strategies to manage drought, which includes the soil, as well as atmospheric droughts.

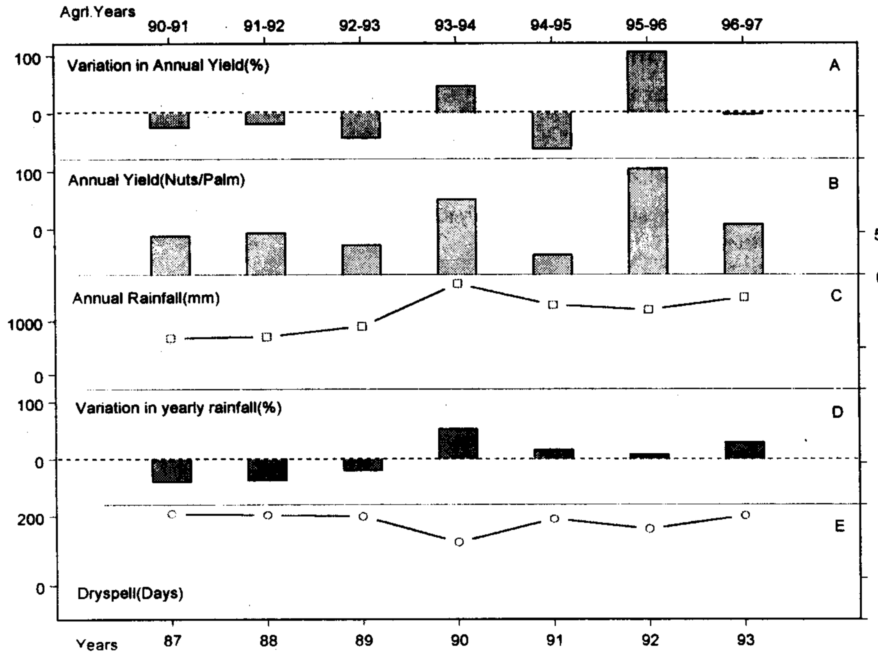


Fig-2 Impact of rainfall and dry spell on the nut yield in coconut after 4 years at Veppankulum (Tamil Nadu). Note the time gap in data of meteorological parameters and nut yield

Drought management strategies mainly include the conservation of available soil moisture and efficient use of available water resources for high production. As the plantation crops are grown under different soil types having variation in hydrophysical characteristics different methods have to be adopted to conserve soil moisture. The following agronomic practices can be used for soil management for conservation of water during drought periods such as adoption of organic farming technologies and tillage practices like summer ploughing, soil mulching and addition of soil stabilizers.

Soil moisture conservation and irrigation management to mitigate drought effect: 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., Kasturi Bai *et al.*, 1997). Soil moisture conservation practices like husk burial in basins, leaf mulching, glyricidia culture, application of compost and farm waste in basins increase nut yield in coconut (Rajagopal *et al.*, 2000d; Rajagopal and Naresh Kumar, 2001). Potassium nutrition also plays important role in drought tolerance in coconut (Quencez and de Taffin, 1981; Rajagopal *et al.*, 2000d; Rajagopal and Naresh Kumar, 2001).

The increase in yield due to irrigation predominantly is a result of increases in source (the Pn rates) and sink (female flower production) efficiency. In such a situation the final nut yield is directly proportional to the number of female flowers produced with translocation of photosynthates is not a limiting factor as indicated by the increased nut retention.

Table-3 Summary of physiological conditions of source and sink as influenced by the type of irrigation

Source	Sink	Condition	Yield/WUE (instantaneous)	Remarks
Low Ψ_{leaf} *E*, *gs* and *Pn*	Less female flower production, nut retention	Rainfed	Low/Low	Less available water in root zone
Low Ψ_{leaf} high *E*, *gs* and *Pn*	More female flower production, nut retention	Basin irrigation	High/Low	Adequate availability of water; no dry pockets in root zone
High Ψ_{leaf} medium *E* and *gs* and high *Pn*	More female flower production, nut retention	Drip irrigation	High/High	Availability of water in optimum; dry pockets in root zone

Under rainfed conditions, the palms grown on sandy soil produced less number of female 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-3). The drip irrigation provided conditions for better physiological efficiency of source and sink for high WUE and yield. They also indicated that the drip irrigation increased WUE at field and at plant and leaflet level. The drip irrigation is a system where not only the available water is used to the optimum with negligible losses, but also because of presence of dry zones in root system possibly though root-shoot signals act as the stomatal regulation system to provide optimal physiological efficiency for higher WUE and better yields. 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).

Soil management in coconut gardens include

i) Mulching with composted coir dust, 50 kg/palm,

ii) Burial of husks in 3 or 4 layers,

iii) Application of green manures and organic manures (FYM) - 50 to 100 kg/palm,

iv) Spreading dried coconut leaves and other organic residues (mulching effect),

v) Addition of tank silt at 100 to 200 kg/palm (improves organic matter, water holding capacity),

vi) Spreading of 2 kg NaCl around the palm basin

Water management in coconut gardens include

i) Bury 2 or 3 earthen pots/hollow bamboos and fill with water (sub-soil moistening),

ii) **Drip irrigation:** 3 or 4 drippers may be placed per palm, (drippers to wet sub-soil layer), Drip irrigation is shown to increase not only field WUE but also the physiological WUE of plant (Naresh Kumar *et al.*, 2000b).

iii) If adequate water is available, irrigate with 200 lit. water/palm once in 4 days and mulch with dry leaves,

iv) Avoid flooding the basins. If water resources are good, save for facing prolonged drought,

v) Effective recycling of used water from backyards.

At large scale, some of the following are desirable to follow to conserve soil and water.

i) In sloppy lands, terracing the palm basins may be undertaken (intercepts run off water and enhance soil moisture),

ii) Water harvesting devices in mildly slopped area to enable water to collect in between row,

iii) Prepare bunds dividing the field into plots to prevent run off of water.

These measures would help to increase the ground water table and the increase the soil water availability.

Crop management also offers scope to reduce drought impact on crop mainly by the removal of senescent leaves to reduce transpiration loss. If late rains occur, pulses or fodder crops can be sown in between coconut rows. After harvest, these plant residues can be used as mulches. So also green manure crops can be raised in the plantations. Application of higher doses of fertilizers (eg. for each coconut palm 1 kg urea, 2 kg Super phosphate, 1.2 kg muriate of potash, 0.5 kg $MgS0_4$, 50 kg green leaf or FYM) will also help in alleviating the impact of water stress on production, by increasing the soil water holding capacity. Ploughing back tender *Glyrecedia* has given encouraging results.

The above practices which lead to soil-water-plant management can be synerzised by planting suitable varieties/cultivars which can adapt to the changing environmental conditions. The nature of generation governing drought sensitive traits can be exploited by selecting proper breeding strategies.

Temperature stress

Coconut palms grow well in very narrow range of temperatures. Low temperatures cause seedling death, delayed flowering, low inflorescence production per year, floret abortion, low fertilization and low yields in coconut. On the other hand high temperatures cause seedling death, floret abortion, low fertilization and low yields even though inflorescence production per year remains normal. Extreme temperatures cause inflorescence abortion also. Efforts are on to identify the field tolerant palms. Planting of seedlings of 2 to 3 year old may solve the problem of seedling death due to very high or low temperatures. To overcome the seedling damage due to high temperature and high light intensities, shade should be provided by placing dried coconut leaves on the western side of seedling pit.

Cyclone, flooding and high wind speed stress

East coast of India is prone to cyclones and floods. The coconut plantations were badly affected by the recent cyclones that occurred in 1996 and 1998 in Andhra Pradesh and Orissa states (Dash *et al.*, 2002). Many places palms were uprooted or lost the crown leaving stm on the grounds. In places, where the impact was less palms were seen either tilted one site or with partial damage to the crown. These occurred due high wind speed. Palms take 2 to 3 years to recover and come to yielding again. The damage was severe where surface planting was practiced and also where exposed roots were cut. In surface planting condition, one can see the exposed roots on the base of stem. Cutting of these roots is a general practice in certain pockets of Andhra Pradesh. During high wind speeds and cyclone rains, pollination also is hampered leading to low fruit set. Apart from this falling of button size, fist size, immature nuts is common due to mechanical force.

To with stand the impact of cyclone or high wind speed damage, it is advised to plant seedlings as per recommended practice of placing in 1 m3 planting pit with planting the seedling 50 cm below the ground level and filling the pit to surface level in subsequent years. By doing so, exposure of roots at the base of stem can be avoided. In old plantings where roots are exposed, practice of cutting of roots should be discontinued. Planting of *Casurina,* etc. can serve as wind shield in coastal areas in long run. Cyclone affected coconut palms can be revived fast by proper management. Application of FYM or burial of farm waste in the basin, application of recommended dose of fertilizers, providing irrigation (with sea water, where ever it is available) can rescue and revive palms much faster. In coasts Andhra Pradesh, the cyclone hit gardens revived faster in cases where proper management is done.

Flooding for shorter duration will not cause much damage to the palm. But if water stagnation prolongs palms suffer from physiological drought, where palms will not be able to uptake water or nutrients due to hampered root function because of lack of O_2 for respiration. Apart from this during flooding leaf eating caterpillar damages the entire photosynthetic area of coconut by scrapping chlorophyll. This causes sever loss in terms of nut yield. Coconut palm do not perform well in soils with poor drainage. In such soils occurrence of *Ganoderma* stem bleeding disease is very common. Hence it is suggested to make good drainage provision in coconut gardens.

Abiotic stress – what makes it so complex?

In nature, abiotic stresses vary to grate extent in its intensities. Occurrence of drought also coincides generally with high light intensities and high temperature regimes. Further, length and severity of these stresses vary with place to place and time to time in a place. This special and temporal variations make the issue more complex. More over the response of a plant to abiotic stress is a multidimensional one with responses starting at inter cellular level to organ and developmental stage level varying with space and time. Also, The transgenics so far tested are successful under controlled conditions for stress tolerance However, in field conditions, the nature and degree of abiotic stresses are complex. So, it is desirable to have more than one gene to combat stress. In future, the biotechnological research may emphasize on accumulating as many desirable genes as possible in one genotype (gene pyramiding) in order to get a much-dreamt "Ideotype"

Challenges ahead

Defining IDEOTYPE for drought situations is a big challenge simply due to the complexity of problem. Any definition of such ideotype will integrate the knowledge on abiotic stresses and plant potential to respond to such situations. An ideotype, which can withstand any type of abiotic stress of any intensity and duration is a thing which all researchers would like to have. But so far, this is not accomplished. Moreover, in nature, multiple stresses occur at time and the degree and time of occurrence of stresses vary in space and time. Integration of all plant responses is very important for overall understanding and improvement of yields in stressful conditions.

Development of integrated disastrous management strategies suitable for different situations is a Herculean task. However, it is possible to

Future thrust should be on

- Integration of stress signal transduction and metabolic responses in plants.
- Overall integration of plant responses at various levels i.e., molecular, physiological, anatomical, morphological and phonological levels.
- Development of marker assisted rapid screening methods.
- Understanding the stability of drought tolerance at different phonological stages
- Characterization of drought for specific areas and specific crops for effective drought management
- Evolving hybrids or cultivars with high stable yields coupled with high quality under rainfed conditions through innovative techniques (Gene pyramiding)
- Identification and conservation (*in situ* or on farm) of field tolerant high yielding plants for further use in crop improvement programmes.
- Implementation of already available management strategies for mitigation of different abiotic stresses in affected areas
- Mapping of areas prone to different abiotic stresses for effective monitoring and management
- Development of early warning systems may be useful particularly for annual crops

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