National Seminar on Role of Plant Physiology for Sustaining Quality and Quantity of Food Production in Relation to Environment

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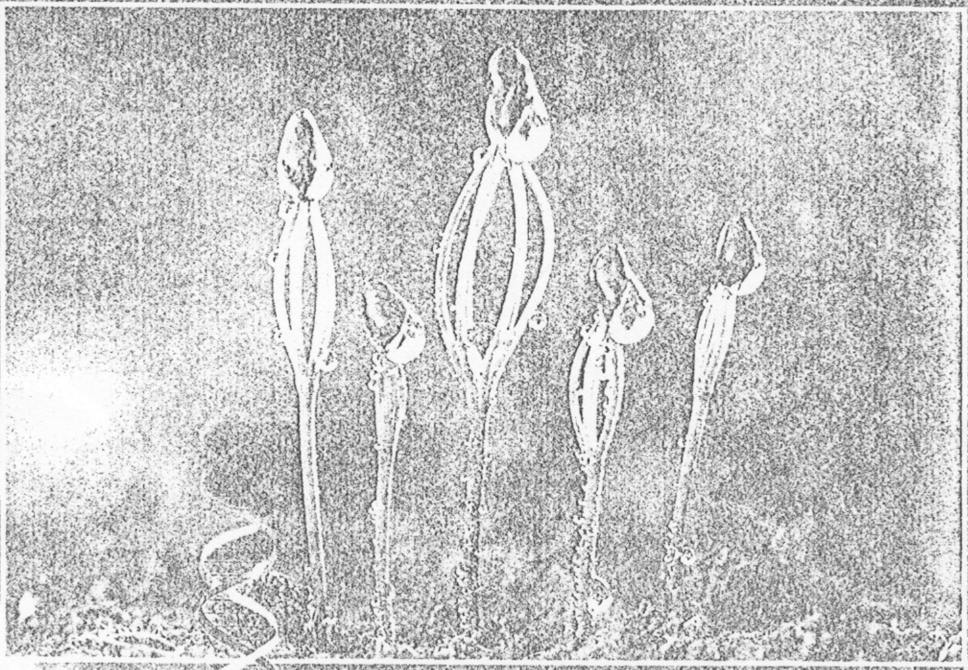
Abstract & Souvenir



Edited by : M. B. Chetti

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DEPARTMENT OF CROP PHYSIOLOGY,
UNIVERSITY OF AGRICULTURAL SCIENCES,
DHARWAD-580 005, KARNATAKA
AND
INDIAN SOCIETY FOR PLANT PHYSIOLOGY
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Avenues to improve productivity potential under drought condition - a case study on coconut

V. Rajagopal and S. Naresh Kumar
Central Plantation Crops Research Institute, Kasaragod, 671 124, Kerala

Introduction

It is important to have an integrated approach for getting better yields under stressful conditions. It is known fact that water is essential for plant not only for metabolic needs but also for its architectural up-liftment, as near-turgid cells are required for plant structure. Hence, 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 an important factor.

Drought stress is the most prevalent abiotic stress which affects the plant growth and crop productivity. In fact, 1/7 of global surface is occupied by deserts. According to FAO, among the cultivated land world wide, only 16% of land is irrigated. In India, about 70% of agricultural land is under rainfed condition. In spite of the development of irrigation facilities, it is expected that still 60% of land has to remain under rainfed condition (Table 1).

Table 1: Cultivable land in rainfed area in the World and in India

Land	World	India
Cultivable land	1474 m ha	142 m ha
Irrigated area	227 m ha	39.2 m ha
Rainfed area	1247 m ha	102.8 m ha
Irrigated area (%)	17.6%	28%
Rainfed area (%)	82.4%	72%

(Source: II International Crop Science Congress Proceedings (1998)

Drought stress and plant responses

Water stress is an important main factor which affects plant growth and development. In general, lack of adequate water in cells lead to loss of turgor thus causing closure of stomata, which in-turn adversely affects the photosynthetic rates, decreases root growth, increases respiration and denaturates enzymes and excess photons is driven towards the formation of superoxide radicles which damage the membrane integrity. To overcome water stress, plants have certain adaptative mechanisms at different levels i.e., molecular, biochemical, physiological, anatomical, morphological and phenological levels.

Effect on anatomy: reduced rates of cell expansion due to loss of turgor, xylem cavitation, leaf scenescence, etc.

Responses at anatomical levels: Thick cuticle, sunken stomata, xylem vessel modifications, large parenchyma cells, dormant growing buds, seed dormancy, etc.

Effect at morphological level: Death of growing tips, leaf scenescence, decrease in economic sink, tiller degeneration, flower drop, pollen abortion, ovule abortion.

Responses at morphological level: leaf modifications, hairyness on leaf surface (pilosity of leaves), thick leaves, leaf rolling, succulent leaves, smaller leaf area, deep and vigorous root system, modified root/shoot ratio, early plant vigour, canopy architecture, etc.

Effect on phenology: Hasten the plant maturity, decrease in rate of leaf appearance, increase in time duration to panicle initiation and flowering, etc.

Responses at phonological level: Developmental plasticity, etc.

Gene regulation under drought stress: It has been shown that many ABA responsive genes (RAB), HSP genes, early response to dehydration (ERDs) gene expression, are some of the genes which are up-regulated. Cis-acting regulatory promoters like dehydration responsive element (DRE) which are ABA sensitive have also been found.

Signal transduction: It is important to know the stress signal mechanism in order to develop genetically engineered stress tolerant crops. For Ex : the environmental signals are first perceived by the specific receptors, which upon activation initiate the cascade of signals, finally triggering the activation of gene expression and consequently synthesis of specific products. The role of root to shoot ABA signals in bringing out the plant responses to drying conditions is well documented. The ABA responsive elements (ABARE) are the transcriptional regulators for ABA responsive gene expression. Receptors like protein kinases, phosphatases, histidine kinases, G-protein associated receptors, Ca-calmodulin complex (CDPKs), inositol phosphates are some of molecules which are involved in signal transduction in plants. MAP kinase (MAPK) are intracellular signal systems which transmit signals from cell membrane to nucleus. Apart from these molecules, certain protein modifiers, scaffolds and adaptors play a role in the regulation of signal transduction and also a protein lipidation, protein methylation, protein ubiquitination are important protein modification events during signal transduction. Still a lot of insights are in offing in this relatively new area of research.

Selection for drought tolerance: Germplasm should be screened for targeted traits under the targeted environments varying in time and space. In perennials, the stability of such tolerance over a period of time is the key factor for realizing stable yields even during stress years. Special emphasis should be given for field tolerance and *in situ* tolerant plants. Selection criteria for drought tolerance are not clearly defined. This makes the selection more vulnerable towards failures. However, high WUE types with high dry matter production efficiency and HI perform better under stress conditions. Early vigor and high revival capacity are very significant factors that should take pivotal place. Selecting such genotypes should be based only on field stress.

In recent years, the emphasis is on MAS for desirable traits under stress by using molecular marker techniques like RAPDs, RFLPs, AFLPs, microsatillite analysis (SSRs) and the QTLs, for many desirable traits viz., root morphology, osmotic adjustment and WUE for drought tolerance may offer more consistent results in the near future.

Characterization and management of drought prone areas

It is important that drought prone areas may be characterized for the nature, intensity, frequency, length of dry spell, onset and off set of critical dry spell. Since the sensitivity of plant to dry spell varies with the crop type, a close coordination between these two areas is essential for furthering the yields in drought prone areas and any specific recommendation to improve the yield should include resource characterization. Based on the resources available, production zones can be made so as to enable to achieve maximum yield in a given situation. The water balance and regional hydraulic cycle plays an important role apart from the soil characteristics.

Drought stress on perennial crops – A case study on coconut response

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 in the states of Kerala, Karnataka, Tamil Nadu and Andhra Pradesh. The productivity is affected due to the dry summer months starting from December/January to April/May. During this period, the soil water deficits coupled with the changes in atmospheric parameters aggravate the situation leading to soil as well as atmospheric drought. Being perennial in nature, the water requirement of plantation crops is also fairly high. Thus, it is important to identify the varieties which can withstand moisture stress conditions with higher productivity efficiency in the field and to evolve management strategies for conserving available water sources in order to mitigate adverse effects of drought.

Agro-climatic variables

Most of the plantation crops grow well in tropical climate with abundant sunlight, well distributed rainfall, with moderate temperature. 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 an annual sunshine of 2000 hrs (at least 120 hrs per month). (Child, 1974 and 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. 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 2).

Table 2: 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^{-1}
Transpiration rate	2.5 mg cm^{-2} sec^{-1}
Leaf water potential	1.20 MPa

(Source: Kasturi Bai and Rajagoapl, 1996)

In sandy loam soil, water deficit of 110 mm is the critical level at which coconut sufferes 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 (Prasada Rao, 1985, Pomer and de Taffin 1982). 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.

The rainfall pattern in different parts of the same place is found to vary significantly. For example, the rainfall in southern Kerala is evenly distributed, whereas in 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 (Table 3).

Table 3. Response of coconut palms to high (North Kerala) and low (South Kerala) drought intensities

Characters	WCT		COD x WCT	
	NK	SK	NK	SK
No. of days for leaf opening	55	52	57	54
No. of days for spathe opening	72	66	55	77
Nut yield $palm^{-1}$	78	96	106	116
Copra weight (g)	133	167	135	169

NK=N. Kerala SK=S. Kerala

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 reported by Rajagopal *et al* (1990) based on water relation components and cuticular wax content.

Drought tolerant characters

Longer gestation period and larger area requirement of plantation crops pose challenge to researchers for 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 mechanisms of drought tolerance in plantation crops and identified the varieties with drought tolerant characteristics. Some of the desirable traits identified are large parenchyma 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. The exploitation of the identified varieties, with not only drought tolerance but also with the potential for higher yield under limited water availability, in the breeding strategies would be an important step for the overall improvement of productivity in drought prone conditions. Mechanisms and strategies to be adopted in selection and breeding programmes depend not only on their effect on traits related to 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. Some of the desirable traits for drought tolerance are listed in (Table 4).

Table 4: Desirable traits for drought tolerance

Agronomical	Stability in yield
	Quality yield
Phenological	Earliness, developmental plasticity
Morphological	High root penetration
	High root: shoot ratio
	Optimal leaf area index
	High harvest index
	Leaf modifications (species specific)
	Thick leaflets
Anatomical*	Larger sub stomatal cavity
	Low stomatal frequency
	Thicker cuticle
	Large hypodermal cells
	Large parenchyma cells
Physiological	High WUE
	High leaf water potential
	High relative water content
	High membrane integrity
	High photosynthetic rate
	High photosystem II efficiency
	Osmatic adjustment
Biochemical	High wax content
	High proline content
	Low lipid peroxidation
	High activity of superoxide dismutae, peroxidase and catalase
	Stable RNA
	Stability of nitrate reductase activity
	Stress protein synthesis
Molecular	Fast signal transduction
	Expression of desirable genes under stress

* Source: Naresh Kumar et al., 2000

Naresh Kumar *et al.* (2000) have studied the leaflet anatomical adaptation to drought tolerance in coconut and the relation between the anatomical features and physiological parameters (Table 5). The study indicated marked influence of leaflet anatomy on photosynthesis and transpiration. It is suggested that a leaf anatomy which favours higher photosynthetic rates, also favours higher transpirational rates and 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.

Table 5: 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	-0.41
	Transpiration rate	-0.12
Cuticle thickness (Adaxial)	Cuticular wax	0.86
	Transpiration rate	-0.69
	Photosynthetic rate	0.13
	Leaf water potential	0.64
Cuticle thickness (Adaxial)	Cuticular wax	0.72
	Transpiration rate	-0.79
	Photosynthetic rate	0.13
	Leaf water potential	0.50
Sub-stomatal cavity (size)	Stomatal frequency	-0.54
	Cuticular wax	0.61
	Transpiration rate	-0.15
	Photosynthetic rate	-0.11
Palisade cell size	Photosynthetic rate	-0.77
	Transpiration rate	-0.38
	Leaf water potential	0.11
Spongy cell size	Photosynthetic rate	-0.67
	Transpiration rate	-0.05
	Leaf water potential	0.10

Source: Naresh Kumar *et al.* (2000)

Critical stages to drought stress

The 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 and arecanut, spikelet initiation and female flower primordia formation are also found to be stress sensitive stages, whereas in black pepper, it is the spiking stage. Sucker and panicle initiation stages are sensitive in cardamom and in tea, it is the vegetative growth, which is sensitive to moisture stress. 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.

Drought tolerant types

By employing screening techniques for desirable traits for drought tolerance, varieties have been selected and released for planting in drought prone areas. An exhaustive list of drought tolerant crop varieties are available in India (Rajagopal, 1997). Using tolerant parents, hybrids have also been evolved. The important drought tolerant varieties/hybrids are:

Coconut : WCT, LCT, FMS, WCT x COD.

LCTxGBGD, LCTxCOD

Cocoa : NC23, NC29, NC 31, NC 39

Cashew : BPT1, BPT2, H-2/16, H-1608

Black pepper : Arakalamunda, Kalluvally

Cardamom : Malabar

Tea : UPASI-1, 2, 20, 26, 27

Coffee : Sanramon hybrid

Rubber : GI 1, GT1, RRIM 600, RRII 18, RRII 105

Drought management

Studies have revealed that 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 is 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, which 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.

Some of the following are desirable to follow to conserve soil and water.

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

ii) Water harvesting devices in mildly sloped area to enable water to collect in between row and preparing bunds dividing the field into plots to prevent run off of water.

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

Some of the palms yielding very high compared to others in their vicinity have desirable canopy shape, leaf number apart from being better yielder. The physiological water use efficiency of these palms is also high (Table 6). This type of *in situ* tolerant plants with desirable traits should be used in breeding programmes.

Table 6: Photosynthetic rates and WUE of *in situ* field tolerant palms identified during survey (compared with other palms growing in the vicinity)

Center/ palm type	Pn (µmol/m²/s)	gs (mol/m²/s)	E (mmol/m²/s)	WUE (µmol/mmol)
Arisikere				
Tolerant	4.07	0.047	2.02	2.01
Susceptible	3.51	0.047	2.14	1.64
Ambajipeta				
Tolerant	6.24	0.06	2.28	2.74
Susceptible	5.60	0.07	2.28	2.46

Challenges ahead....

Defining **Ideotype** for drought situations is a big challenge due to the complexity of problem. Any definition of such ideotype will integrate the knowledge on drought stress and plant potential to respond to such situations. An ideotype which can withstand any type of drought 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 the plant responses is very important for overall understanding and improvement of yields in stressful conditions.

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
- Evolving hybrids or clones 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
- Characterization of drought for specific areas and specific crops for effective drought management

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