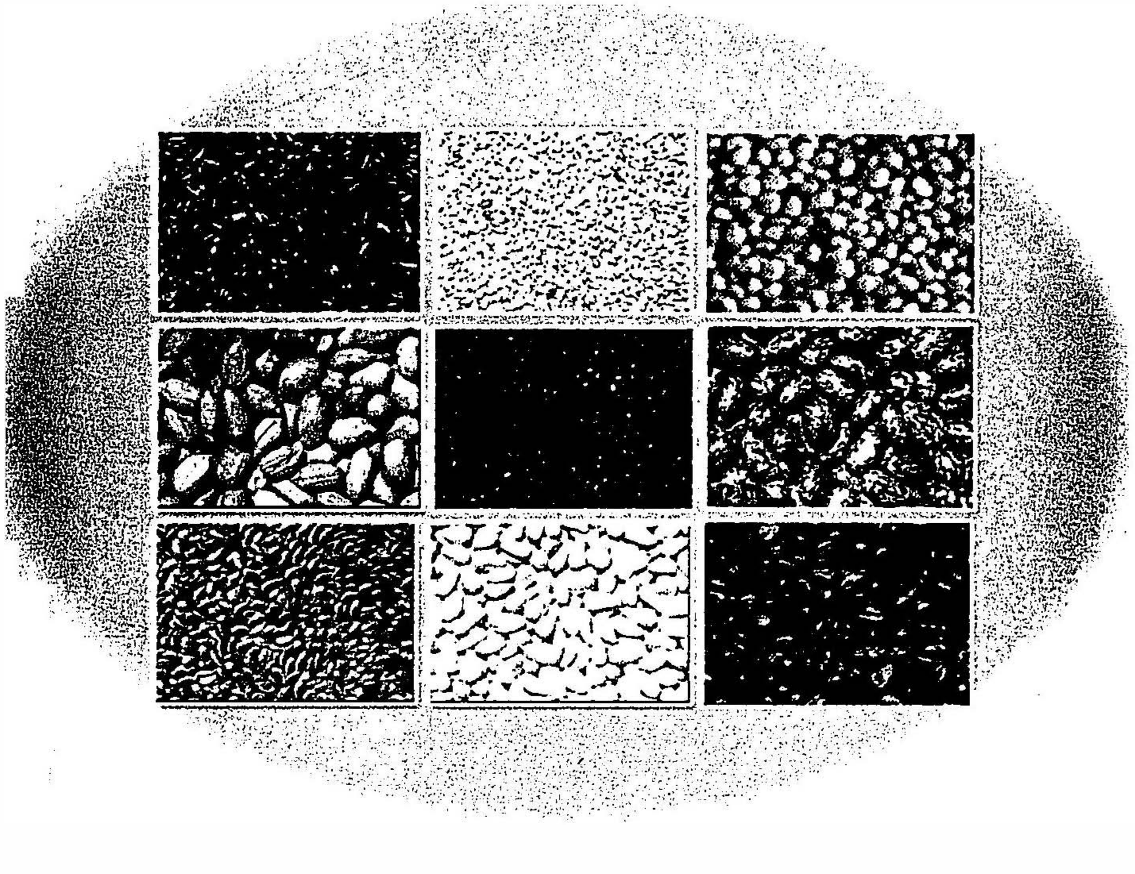
THEMATIC PAPERS

National Seminar
On

STRESS MANAGEMENT IN OILSEEDS FOR ATTAINING SELF-RELIANCE IN VEGETABLE OILS

January 28-30, 2003



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National Seminar
on

Stress Management in Oilseeds for Attaining Self-Reliance in Vegetable Oils

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EDITORS

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Breeding for Increased Water-use Efficiency in Groundnut

S.N. Nigam, R.C. Nageswara Rao and Graeme C. Wright

Drought is a major abiotic stress affecting yield and quality of rainfed groundnut worldwide. Yield losses due to drought are highly variable in nature depending on its timing, intensity, and duration coupled with other location specific environmental factors such as irradiance and temperature (Nageswara Rao and Nigam, 2001). Drought effects on groundnut are manifested in several ways both on quantity and quality. Water deficits depending on the timing of occurrence can cause significant reduction in yield by affecting physiological processes i.e., N_2 fixation (Devries et al., 1986; Venkateswarlu et al., 1989), photosynthesis (Williams and Boote, 1995), and calcium uptake by developing pods (Rajendrudu and Williams, 1987). The unpredictability of drought events causes enormous variability in production and hence problems for continuity of supply, which directly affects domestic and export-market requirements. It is well documented that end-of-season drought can predispose the crop to aflatoxin contamination which can severely impact the economic value of the crop (Mehan, 1989). It is estimated that an annual estimated loss in groundnut production caused by drought alone is equivalent to US $ 520 million (at the prevailing price of 1994). International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)'s mid-term plan (1994-98) analysis projected that almost half of the losses (US $ 208 million) could be recovered through genetic enhancement for drought resistance with a benefit: cost ratio of 5.2 (Johansen and Nigam, 1994). It is now recognised that "water" is a finite resource on the planet earth and agriculture has been the biggest user and abuser of this resource. Developed countries are already responding to this situation by implementing strategic plans to preserve and rationalise water use in agriculture by management and genetic improvement. Genetic improvement for water-use efficiency has been a major research thrust in most of the arable crops. The importance of genetic enhancement for improved adaptation to water-limited conditions and efficient water use has been long recognised by ICRISAT. The groundnut breeding program has adopted three major strategic approaches to enhance adaptation of groundnut to drought prone environments:

i) Development of short-duration genotypes that can escape the end-of-season drought

ii) Development of genotypes with superior yield performance in drought prone regions following conventional breeding approach

iii) Development of drought resistant genotypes following physiological breeding approach

The progress made under each of the above listed strategies is described in detail by Nageswara Rao and Nigam (2001). ICRISAT has made considerable progress in shortening crop duration of groundnut without unduly penalizing realized yield (Vasudeva Rao *et al.*, 1992). However, it is still necessary to screen genotypes in a given maturity group for resistance to end-of-season drought because of two reasons. Firstly, to identify genotypes with reasonable pod yields and better vegetative growth (in view of groundnut haulms being the valuable fodder in most of the semi-arid environments) under severe end-of-season droughts. Secondly, end-of-season drought is closely linked with aflatoxin contamination of the produce and that the screening for end-of-season drought also provides scope for identification of genotypes with resistance to *Aspergillus flavus* infection and aflatoxin production (Mehan *et al.*, 1988).

This paper briefly describes the approaches followed by the Genetic Resources and Enhancement Program at ICRISAT to improve adaptation to drought and water-use efficiency of groundnut. It is recognised that water-use efficiency is an important trait contributing to groundnut productivity under both irrigated and rainfed conditions.

Drought patterns and genetic options

Drought is a complex syndrome with three major and widely varying components, i.e., timing of occurrence during the season, duration, and intensity. Occurrence of high radiation and temperatures and soil characteristics significantly influence the effects of drought and add to the complexity of defining the problem. The extreme variability in the nature of drought has made it difficult to define plant attributes required for improved performance under drought, consequently, limiting the plant breeding efforts to enhance drought tolerance in groundnut. Most frequently encountered drought patterns can be grouped into three types i.e., early-season drought, mid-season drought, and end-of-season drought. Genetic options for improvement in drought resistance vary with the most drought patterns experienced in a given environment.

Early-season drought: Once the crop is established, early-season drought in groundnut is not of much consequence. As a matter of fact, a 20-25 day moisture stress early in the season and subsequently its release by applying irrigation is encouraged to induce heavy and uniform flowering leading to increased productivity in groundnut (Nageswara Rao *et al.*, 1985; Nautiyal *et al.*, 1999)

Mid-season drought: Mid-season droughts affect the most vulnerable stages (pegging and pod and seed development) of plant growth in groundnut. A poor relationship between the yield potential (achieved under adequate water availability) and the sensitivity of genotypes to mid-season drought (Fig-1) suggested a possibility of identifying/or developing genotypes with high yield potential and relatively low sensitivity to mid-season droughts (Nageswara Rao *et al.*, 1989).

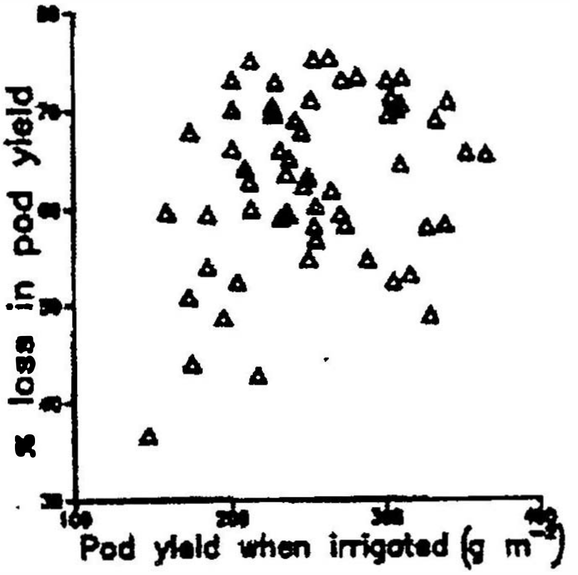

Fig-1 Relationship between yield loss due to mid-season drought and pod yield potential under irrigated conditions in 60 groundnut genotypes (Source: Nageswara Rao *et al.*, 1989)

End-of-season drought: End-of-season drought affects the seed development most. It also predisposes the produce to aflatoxin contamination. Genotypic yield accounts for 90% of the variation in pod yield sensitivity to water deficit during seed filling stage (Fig-2) (Nageswara Rao *et al.*, 1989). Where the growing season is short and terminal drought predominates, matching of phonological development of a cultivar with the period of soil moisture availability is an important drought escape strategy to minimize the impact of drought stress on crop production.

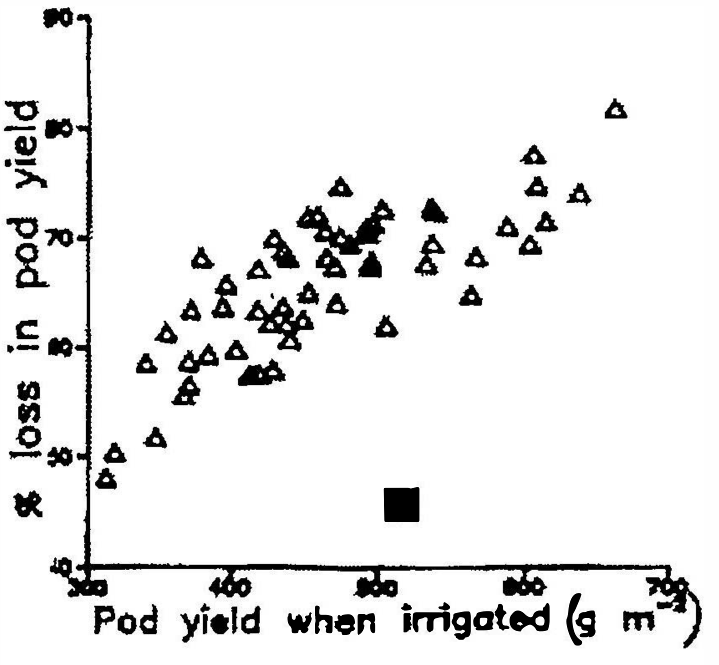

Fig-2 Relationship between yield loss due to end-of-season drought and pod yield potential under irrigated conditions in 64 groundnut genotypes (Source: Nageswara Rao *et al.*, 1989)

Given the understanding of these drought patterns and availability of vast germplasm resource, the groundnut breeding group has been generally relying on empirical selection methods to increase the seed yield in a given environment. While the direct selection for yield can be effective (White *et al.*, 1994), major limitations of this approach are its high resource investment and poor repeatability of the results in different environments. An effective and efficient genetic enhancement for drought resistance requires identifying and combining appropriate genetic traits that can potentially contribute to the superior performance of a genotype across a range of drought environments. The success of this physiological breeding approach relies on close interaction between breeding and crop physiology disciplines where both require a clear understanding of each other's work.

Development of drought resistant genotypes at ICRISAT

Most of the drought resistance breeding activities at ICRISAT Center, Patancheru are conducted in the postrainy season (Nov-April) when there is least interference from the rains. The approach and methodology followed at ICRISAT for enhancing drought resistance in groundnut are described in detail by Nageswara Rao (1994). Briefly, ICRISAT adopted a holistic approach in screening and selecting groundnut genotypes with superior performance under two most critical droughts i.e., mid-season and end-of-season.

For the development of genotypes with superior yield performance under drought conditions, germplasm and segregating populations are evaluated/ selected in the postrainy season under simulated drought conditions (Table-1). In addition to simulated drought conditions, the advanced breeding lines are also evaluated under rainfed conditions in the rainy season (June-October).

Table-1 Drought patterns and selection criteria used in drought resistance breeding in groundnut at ICRISAT Centre, Patancheru, India

Germplasm	Segregating populations	Advanced breeding lines in replicated yield trials
A) Drought patterns		
Early-season	Mid-season	Mid-season
Mid-season	End-of-season	End-of-season
End-of-season		Under rainfed conditions (only in the rainy season)
Intermittent		Under normal irrigated conditions (control)
B) Selection criteria		
Harvest index (HI), Biomass	High pod and seed yields	High pod and seed yields under both normal and drought conditions

Early-season drought = After the first irrigation for germination, irrigation withheld upto 40 days after sowing (DAS)
Mid-season drought = Irrigation withheld from 40 to 80 DAS
End-of-season drought = Irrigation withheld 80 DAS to harvest
Intermittent drought = Irrigation withheld at different stages and for varying durations

Germplasm screening: Using line-source sprinkler system of irrigation, germplasm lines are screened for early-season, mid-season, end-of-season, and intermittent droughts in the field. Based on HI and biomass production, germplasm lines are selected for resistance to different kinds of drought. Several lines with superior performance under different kinds of drought (ICG# 3086, 3141, 2738, and 1163, and ICGV# 91151, 94127, 92209, and 91109 for mid-season drought; ICG 2213, ICGS 76, ICGV# 90226, 91074, 91185, 91192, 92004 92022, 92023, 92028, 92029, and 92033 among others for end-of-season drought) are now available for use in breeding programs (ICRISAT, 1997).

Development of breeding materials: Following the above empirical approach described in Table-1 for segregating populations and advanced breeding lines, several drought resistant advanced breeding lines have been developed and distributed to national programs in the form international drought resistance groundnut varietal trials.

Performance of the selected drought resistant lines is given in Tables-2 and 3.

Table-2 Performance of some drought resistant varieties under imposed mid-season drought condition, 1998-99 postrainy season, ICRISAT Centre, Patancheru, India

Variety	Pod yield (t/ha)	Shelling percentage	100 seed weight (g)
ICGV 95391	4.3	65	60
ICGV 96304	4.1	66	50
ICGV 94148	4.0	66	49
ICGV 95386	3.8	74	61
Control			
TMV 2	2.7	73	39
Trial mean	3.5		
SEm±	0.27		
CV (%)	10.7		

The mid season drought was imposed by withholding irrigation from 40 to 80 DAS.

Table-3 Performance of selected varieties in an International Drought Resistance Groundnut Varietal Trial, 1998-99 rainy season, Malekutu, South Africa

Variety	Pod yield (t/ha)	Shelling percentage	100 seed weight (g)
ICGV 92116	3.2	74	43
ICGV 93261	3.0	63	36
ICGV 92121	3.0	74	50
ICGV 93233	2.7	71	50
Control			
ANEL	2.4	70	38
Trial mean	2.3	70	42.
LSD (P=0.05%)	0.81	8.2	7.0
CV (%)	21.27	7.1	10.7

In addition to other desirable characteristics, some of the groundnut releases in India ((ICGS 44, ICGS 76, and ICG (FDRS) 10 for mid-season and ICGS 11and ICGS 37 for end-of-season droughts) and Indonesia (ICGV 86021 released as Terapah) carry resistance to drought.

Notwithstanding these success stories, the empirical approach to drought resistance breeding remains resource extensive and tardy. Because of larger genotype (G) x environment (E) interaction for kernel yield in groundnut, its heritability is low (Blum, 1988; Williams, 1992). Unfortunately, the phenotypic model for yield provides little understanding of biological significance and reasons for G x E interactions. However, the empirical breeding approach continues because so far there are no tools to obtain better information about genotypic traits contributing to yield under drought conditions in a large scale breeding program.

Physiological approach to drought resistance breeding

W [illegible] potential merits of the physiological traits that could be used to improve selection efficiency (Ludlow and Muchow, 1990), there is limited information on the development and application of such indirect selection approaches in the groundnut breeding programs (Wright *et al.*, 1996). There are even fewer studies of objective comparison of empirical and indirect selection methodologies for enhancing drought resistance in groundnut. A better understanding of the basis of the performance of genotypes in variable environments via use of simple physiological models should improve the efficiency with which a breeder can characterise material for its G and G x E interaction, and hence increase the speed at which superior genotypes can be developed.

In recent years, there has been significant improvement in our understanding of physiological basis of genotypic response to drought in groundnut. The traits contributing to superior performance under drought conditions in groundnut have been identified and substantial genetic variation observed for them. These include HI (Mathews *et al.*, 1988; Nageswara Rao *et al.*, 1993), total amount of water transpired (T), and transpiration efficiency (TE, defined as amount of dry matter produced per unit amount of water transpired) (Hubick *et al.*, 1986 and 1988; Mathews *et al.*, 1988; Wright *et al.*, 1988 and 1994). These studies made it possible to analyze the yield variation under drought conditions using a physiological model proposed by Passioura (1977), where: Pod yield = T x TE x HI.

Although a large variation has been found for each of these physiological traits in groundnut, under both irrigated and water limited situations, there are substantial difficulties in accurately measuring them in large number of plants/populations needed for selection programs (Hubick *et al.* 1986 and 1988; Wright *et al.* 1988,1993, and 1994).

Earlier studies indicated that TE and HI were negatively correlated (Hubick *et al.*, 1988; Wright *et al.*, 1993). However, a more strategic and comprehen selection program, funded by The Australian Centre for International Agricultural Research (ACIAR), involving collaboration among Indian Council for Agricultural Research (ICAR), Queensland Department of Primary Industries (QDPI), and ICRISAT has been implemented to identify genotypes with high levels of the physiological model traits (described above), in the vast germplasm pool at ICRISAT (Wright and Nageswara Rao, 1994). These results suggested that the negative association between TE and HI, observed in earlier experiments, could be broken and there was scope for selecting for and combining TE and HI traits concurrently to improve yield performance (Nageswara Rao and Wright, unpublished data). Table 4 lists performance of selected genotypes in terms of their trait levels in a large multilocation trial conducted during 1994- and 95 rainy seasons in India.

Table-4 Performance of selected genotypes for T, TE and (as %) in 1994-95 rainy season, ICRISAT Centre, India

Genotype	± % change from the mean			
	Pod yield	T	TE	HI
CSMG 84-1	28.8	29.3	0.3	-0.4
DRG 101	10.5	1.2	1.0	10.8
DRG 102	12.7	8.8	1.0	6.1
ICGS 44	13.0	-16.5	2.2	31.7
ICGS 76	27.0	7.7	5.5	11.8
ICGV 86754	15.5	6.5	2.5	4.9
ICGV 87354	22.5	5.0	1.8	10.5
Kadiri 3	19.6	12.8	-0.8	10.2
NC Ac 343	13.9	8.5	0.3	5.4
Somnath	12.9	0.5	0.5	10.8
TAG 24	16.6	-10.1	1.7	30.1
Exp. Mean	2.23 (t/ha)	290.5 (mm)	2.7 (g/kg)	0.31

Source : Wright *et al.*, 1998.

It was apparent that high levels of at least two out of the three physiological traits were necessary for superior performance of a genotype. Interestingly, genotypes involving parents selected form drought screening at ICRISAT (e.g.

ICGS# 44 and 76, ICGV# 86754 and 87354) had superior yield performance because of higher TE and HI or all the three traits, while for the other cultivars, dominant contribution to the yield was from T and /or HI. This analysis indicated scope for developing new cultivars by pyramiding the traits or identifying the deficient trait(s) in the popular cultivars so that the parental selection and genetic enhancement can be focussed to improve levels of deficient trait in the required agronomic background (Wright *et al.,* 1998). Recent progress in developing new and novel indirect methodologies to assess the model parameters with minimum and cost effective measurements on the crop created new avenues for selecting groundnut genotypes with high levels of T, TE, and HI (Wright *et al.,* 1996).

It was interesting to note that the yield performance of some these selected genotypes was superior even under irrigated conditions suggesting that the physiological traits such as TE and HI could be used as selection criteria for the crop improvement under irrigated conditions also.

Use of indirect selection tools: Recent studies have identified surrogate traits, carbon isotope discrimination in leaf (Δ) (Fig-3) and specific leaf area (SLA) (Fig-4), which are associated with TE in groundnut (Wright *et al.,* 1994).

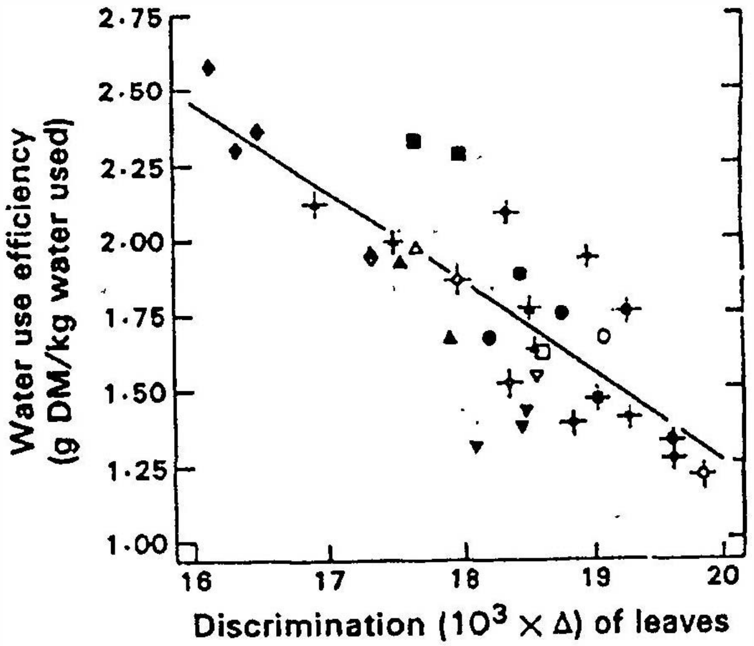

Fig-3 Water use efficiency (TE) versus carbon isotope discrimination (Δ) in a range of groundnut cultivars (water use efficiency (TE)=7.347-0.307Δ; r=-0.81, P<0.01) (Source: Hubick *et al.,* 1986)

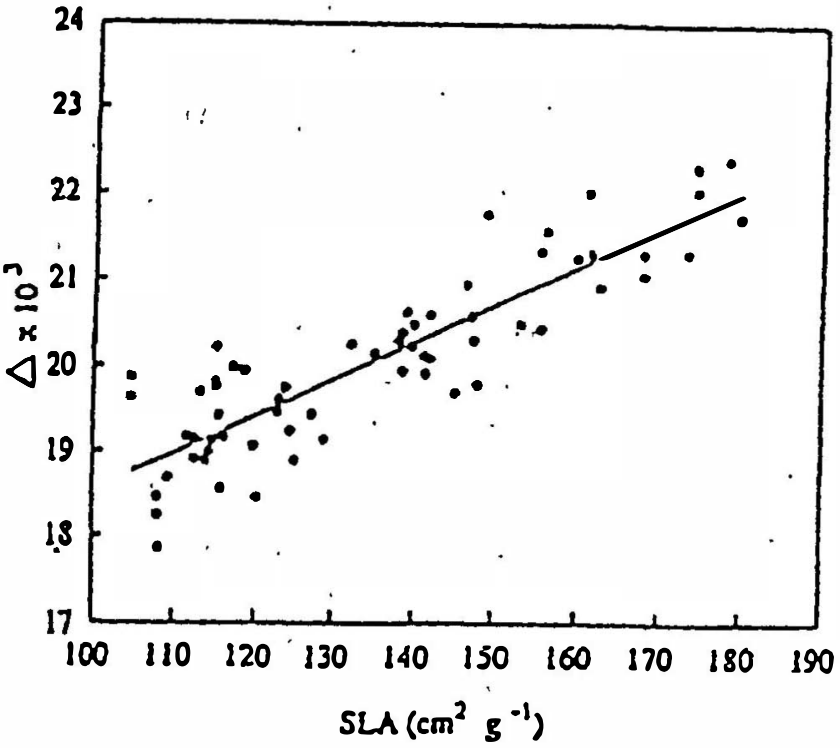

Fig-4 Relationship between the mean SLA and Δ in leaves of four groundnut cultivars under two drought treatments (Δ=14.2+0.04 SLA, r^2=0.81, P<0.01) (Source: Wright *et al.*, 1994)

Further, SLA, which is a crude but easily measurable parameter, can be used as a rapid and inexpensive selection criterion for high TE (Wright *et al.*, 1994; Nageswara Rao and Wright, 1994).

Screening of groundnut germplasm for SLA indicated significant variability within and between taxonomic groups. It was interesting to note that the genotypes belonging to variety *hypogaea* (virginia bunch and runner types), had a lower mean SLA than those of variety *fastigiata* (valencia and spanish types) suggesting a likelihood of higher TE (Nageswara Rao *et al.*, 1994). However, the former had lower partitioning ability than the latter. There is new evidence that the groundnut genotypes having lower SLA (high TE) showed more stability in dry matter production under drought (Nautiyal *et al.*, unpublished data).

Nageswara Rao *et al.*, (2001) have recently shown that a hand-held portable SPAD chlorophyll meter can be used effectively following necessary protocols for rapid assessment of SLA and specific leaf nitrogen, the surrogate measures of TE in groundnut (Fig-5). This would facilitate screening of large number of segregating populations in the field with ease.

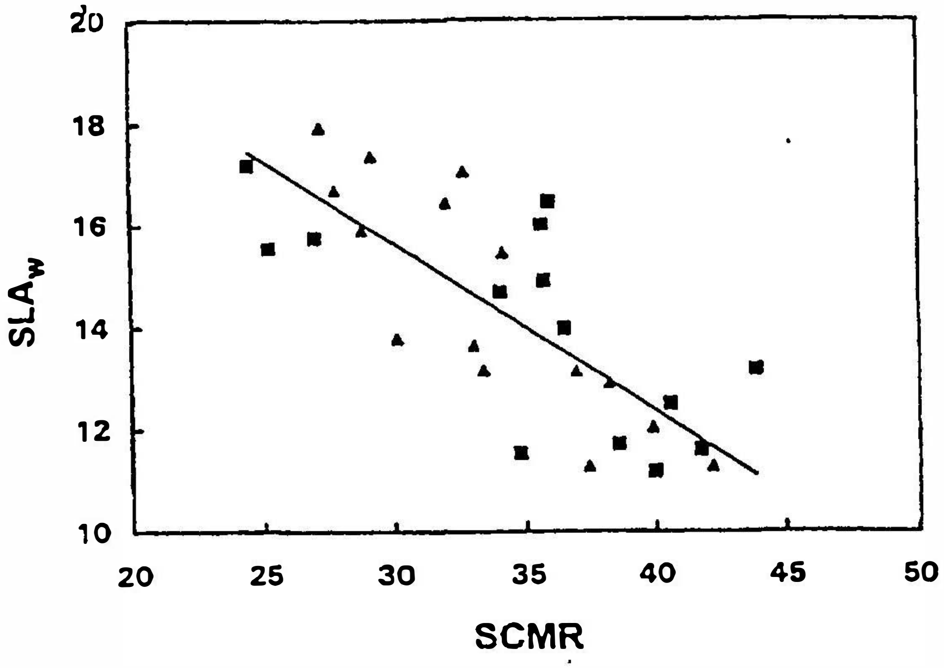

Fig-5 Relationship between SLA and SPAD chlorophyll meter reading (SCMR) in 15 groundnut genotypes in a field experiment ($SLA=-0.33\ SCMR+25.46$; $r=-0.80$, $P<0.01$)
(Source: Nageswara Rao *et al.*, 1986)

Application of indirect selection tools in a large breeding program

An on-going ACIAR-funded ICAR-QDPI-ICRISAT collaborative project is currently assessing the value of indirect selection tools in improving the efficiency of selection in a large-scale groundnut breeding programs in India and Australia.

In this project the crosses were made with specifically selected parents (Table 4) and progenies were selected based on the levels of three model components (T, TE, and HI). The model components for large segregating populations were derived from the simple measurements of SLA, total dry matter, and pod and kernel yields at the final harvest following the methodology described by Wright *et al.*, (1996). The progenies were assessed for their performance and ranked using a "Selection Index", which gave an equal weighting to each of the model parameters (Subash Chandra *et al.*, Unpublished data). A multi-location study is currently under way to evaluate the performance of progenies along with their parents and local checks in a wide range of rainfed environments in India (13 environments) and Australia (7 environments). It will be interesting to see if the concurrent selection for the drought resistance traits (T, TE, and HI) in a selection program would lead to development of genotypes with stable yields across erratic rainfall seasons. Results obtained to date have shown that progenies with high levels of drought resistance traits as well as high yield could be selected following a "Selection Index" approach. The selected progenies have shown a yield advantage up to 30% over the parents at the end of two selection cycles.

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