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Studies on Water Relations of Groundnut

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Abstract

Approximately 70% of the world groundnut production comes from the developing countries, many of which lie in the semi-arid tropics (SAT). Yields in the SAT are low and variable due to erratic rainfall. Water deficits that are a consequence of the imbalance between water supply and plant-water needs affect groundnut growth depending on the stage of crop growth and the degree or intensity of the drought stress. In order to develop management strategies to increase and stabilize groundnut yields in the SAT it is necessary to study the effect of drought stress at different phenological phases on growth, water relations, and yield.

Total water use by groundnut is controlled by climatic, agronomic, and varietal factors. The role of some of these factors has been summarized with suitable examples. Drought stress effects at different phenological phases on the growth, water relations, and yield have been highlighted using the data collected in a series of experiments conducted over three postrainy seasons of 1980, 1981, and 1982 on a medium deep Alfisol at ICRISAT center in India employing the line-source sprinkler irrigation technique. The implications of research on water relations in developing strategies for improved groundnut production are discussed.

Résumé

Etudes sur les relations hydriques de l'arachide : *Environ 70% de la production mondiale d'arachide provient des pays en voie de développement, dont plusieurs se trouvent dans les zones tropicales semi-arides. Dans ces zones, les rendements sont faibles et variables en raison de l'irrégularité des pluies. L'effet des déficits hydriques (résultante du déséquilibre entre l'apport d'eau et les besoins hydriques des plantes) sur la croissance de l'arachide varie selon les stades de croissance de la culture et la gravité du stress hydrique. Pour développer des stratégies visant à accroître et régulariser la production d'arachide dans les zones semi-arides, il faut étudier les effets de la contrainte hydrique à différents stades phénologiques, les relations hydriques et les rendements de l'arachide.*

La consommation totale d'eau par l'arachide est fonction de facteurs climatiques, agronomiques et variétaux. Le rôle de certains de ces facteurs est illustré par quelques exemples. Les effets de la contrainte hydrique sur la croissance, les relations hydriques et les rendements sont résumés pour différents stades phénologiques. Pour ce faire, nous avons utilisé les données collectées lors d'une série d'essais conduits en 1980, 1981 et 1982, après la saison des pluies, sur des Alfisols de profondeur moyenne, au Centre ICRISAT en Inde. La technique d'irrigation par aspersion en ligne a été utilisée. Les implications de ces résultats sur le développement de stratégies de production d'arachide sont discutées.

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CRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1986. Agrometeorology of groundnut. Proceedings of an nternational Symposium, 21-26 Aug 1985, ICRISAT Sahelian Center, Niamey, Niger. Patancheru, A.P. 502 324, India: ICRISAT.

Introduction

At the end of an excellent compendium in Peanut Science and Technology reviewing the future needs of the groundnut industry, Pattee and Young (1982) suggested that future research on water-management technology should include basic studies of soil-plant- water relations of groundnut. This is important because groundnut has specific moisture needs due to the unique feature of developing the pods underground. The flower is borne above ground and after it withers, the stalk elongates, bends down, and forces the ovary underground. The seed matures below the surface. Hence both the quantity and the quality of groundnut seed is intimately related to conditions that favor the growth processes preceeding and during the development of the seed. Proper functioning of these growth processes requires a favorable balance controlled by the relative rates of soil-moisture uptake by the roots and the water loss by transpiration. Water deficits that are a consequence of the imbalance between water uptake and transpiration, affect groundnut growth depending on the stage of crop growth and the degree or intensity of the drought stress. It is hence imperative that studies on water relations of groundnut should include considerations of soil-water availability, and the influence of the adequacy or lack of soil water at different growth phases on plant-water status, plant growth, and yield.

Soil-Water Availability and Water Use

Groundnut yields are reported to be variable from year to year because of the large interannual variation in rainfall (Sindagi and Reddy 1972). Bhargava et al. (1974) reported that 89% of the yield variation over four regions in India could be attributed to rainfall variability in the Aug-Dec growing period. It is therefore not surprising that a large majority of the agronomic investigations conducted on groundnut, especially in the semi-arid regions, are concerned with irrigation aimed at stabilizing yields.

Depth of Water Extraction

One of the important considerations in the availability of soil water to groundnut plants is the rooting depth under normal conditions to fully exploit the profile water. Although the rooting depth groundnut plant is reported to extend up to 15 (Metelerkamp 1975) and even up to 200 cm (Hammond et al. 1978, Robertson et al. 1980), a majority of the roots are in the surface-soil layers. Robertson et al. (1980) reported 39% of the total rooting length in the top 15 cm of soil and 55% in the top 30 cm. Hammond et al. (1978) measured root densities of 1.5 cm cm^{-3} in the 0-30 cm soil layer while at greater depths the root densities were only 0.1-0.4 cm cm^{-3}. When the water supply is adequate, as under irrigated conditions, groundnut extracts up to 48% of the water required from the upper 30 cm (Mantell and Goldin 1964). Shalhevet et al. (1976) from the International Irrigation Centre using the data from two locations in Israel showed an average removal of 36% in the 0-30 cm depth, but only 7% in the 120-150 cm region. Under a limited-water situation, more water extraction occurred from the 90-150 cm soil layer. Avasarmal et al. (1982) and Hammond and Boote (1981) also concluded that maximum water extraction occurs in the 30-45 cm soil layer. Stansell et al. (1976) observed water extraction below 60-cm depth only 75 days after sowing.

Total Water Use

The total water use by a groundnut crop is controlled by climatic, agronomic, and varietal factors. A summary of the reported water use of groundnut is given in Table 1. The range of water-use values given reflects the variable soil-climatic conditions under which the crop is grown and the varieties used.

The total water use of groundnut could also be altered by agronomic practices irrespective of the rainfall or number of irrigations. Fertilizer application has been reported to increase the water use (Bhan 1973) and interactive effects of fertilizer and irrigation have also been shown (Babu et al. 1984, Narasimham et al. 1977). Row spacing was reported to affect water use although there was no unanimity on which spacing helps to increase water use. While Bhan and Misra (1970) and Bhan (1973) showed that groundnut grown in narrow rows of 30 cm used more water, Choy et al. (1977) reported less water use by the crop in 30-cm rows. Results of McCauley et al. (1978) also agreed with those of Choy et al. (1977). On the other hand, investigations of Reddy et al. (1978) showed highest consumptive water use with 45-cm row spacing in comparison to 30- or 60-cm rows. Row orientation (Choy et al. 1977, Davidson et al. 1983, McCauley et al. 1978) in these

e 1. Summary of reported values of total water use (mm) of groundnut.

Reference	Total water use (mm)	Remarks
Ali et al. (1974)	530	Irrigated at 60% water depletion
Angus et al. (1983)	250	Rainfed
Charoy et al. (1974)	510	Rainfed
Cheema et al. (1974)	337	Rainfed
	597	Irrigated at 40% water depletion
Kadam et al (1978)	342	Rainfed
Kassam et al. (1975)	438	Rainfed
Reddy et al (1980)	560	Irrigated, winter months
Reddy et al. (1978)	417	Rainfed
Reddy and Reddy (1977)	505	Irrigated at 25% water depletion
Panabokke (1959)	404	October-January
Keese et al. (1975)	500-700	Irrigated at 50% water depletion
Samples (1981)	450-600	Irrigated at 50% water depletion
Nageswara Rao et al. (1985)	807-831	Irrigated 7-10 day interval during winter months

spacing studies was reported to influence the water use.

The crop water-use requirements reach the maximum about midway through the growth of the crop when the canopy cover is complete (Davidson et al. 1973). Peak water-use values range from 5-7 mm d^{-1} (Mantell and Goldin 1964, Stansell et al. 1976, Henning et al. 1982). Soil-water availability exerts a controlling influence on the peak water use as reported by Vivekanandan and Gunasena (1976) who measured peak values of 6.1, 4.8, and 3.8 mm d^{-1} under high, intermediate, and low water potentials respectively.

Soil-Water Availability and Total Water Use as Influenced by the Stage at which Drought Stress Occurs

Rainfall in the semi-arid regions is erratic in duration and distribution, which could lead to droughts of varying intensities and durations during the crop season. Hence, the total water use could vary with the stage of crop growth during which these droughts occur, and the water-use requirements of the crop at these stages. Using the line-source sprinkler irrigation technique (Hanks et al. 1976), we examined the effects of withholding irrigations at different growth stages on the growth, development, water relations, and yield responses of groundnut cultivar Robut 33-1 grown during the postrainy season. The crop growth phases studied were:

A. emergence to start of flowering,
B. emergence to start of pegging,
C. start of flowering to start of seed growth,
D. start of seed growth to maturity, and
E. continuous stress from emergence to maturity.

Growth phases investigated during 1980/81 and 1981/82 included B to E, while in 1982/83 in place of growth phase D, growth phase A was included to gather additional data on the effects of withholding irrigations during the early growth phases. Although data were collected at three different distances from the line source, for the sake of simplicity in this paper we present data collected at the *12-18* m distance range from the line source, which only represents the fully stressed situation during the periods when line-source irrigations were given.

Seasonal changes in the available soil water at different soil depths in the 0-120 cm soil profile in different treatments during the 1982/83 growing season are presented in Figure 1. The data show that in growth phase A the soil-water extraction was more or less confined to the top 60 cm of soil. In growth phase B, since the drought stress was imposed till the start of pegging, i.e., up to 55 days after emergence (DAE), soil-water extraction in the 0-30 cm soil layer was higher than in growth phase A, and the extraction occurred even in the lower layers. In growth phase C (no irrigations from 30-90 DAE), soil-water extraction occurred at all depths, and at soil depths 60-120 cm the extraction was significantly higher than in the earlier two growth phases. When the drought stress was imposed throughout the growing season, water extraction in the 60-120 cm soil depths was the highest of all the treatments.

The effect of drought stress imposed at different growth phases on the total water use by groundnut during the three years is shown in Table 2. Total water use during the three seasons was different for any given growth phase because of the differences in the rainfall during the preceding rainy season (and hence the initial-profile water content) during the three years and because of the differences in the amount of water applied. However, when water use in any given growth phase is considered as a proportion of the water use in the fully irrigated contr
differences between the three years are less signifi

Peg Penetration into Soil in Relation to Soil-Water Availability

Soil-surface moisture content is considered critical to peg entrance into the soil. Taylor and Ratliff (1969) showed that as the soil dried, its mechanical resistance increased. For fruiting to occur the gynophores must enter the soil. Hence the soil physical condition is of importance since the gynophores are

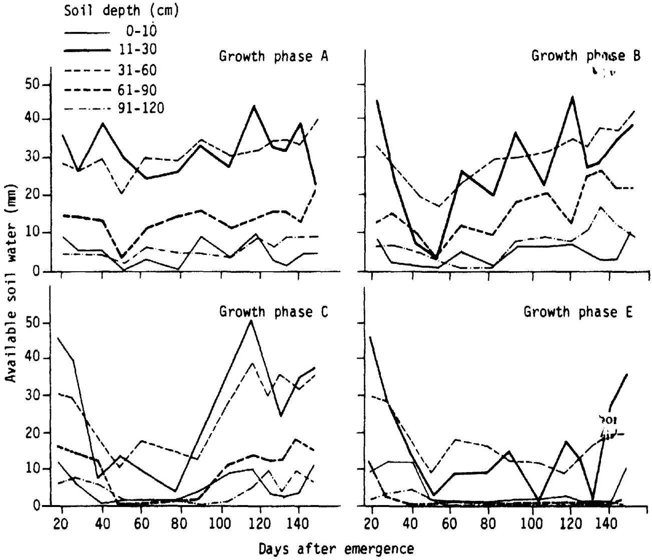

Figure 1. Seasonal changes in available soil water (mm) at different depths (cm) for groundnut subjected to drought stress in different growth phases, ICRISAT Center, 1982/83. (Growth phase A: emergence to start of flowering. B: emergence to start of pegging. C: start of flowering to start of seed growth. E: emergence to maturity.)

le 2. Total water use (mm) of groundnut cv Robut 33-1 when drought stress was imposed at different growth phases ring three growing seasons, ICRISAT Center, 1980-83.

Growth phase	Total water use (mm) 1980/81[1]	 1981/82	 1982/83
A. Emergence to start of flowering	·	—	611
B. Emergence to start of pegging	614	753	494
C. Start of flowering to start of seed growth	483	516	401
D. Start of seed growth to maturity	529	441	
E. Emergence to maturity	176	231	169
Control	807	831	687

1. 77 mm of rain received during the growing season.

ble to exert a pressure equivalent to only 3-4 g cm^{-2} n the soil (Underwood et al. 1971).

We measured the soil-penetration resistance (SPR) n the surface 5-6 cm of soil during the 1982/83 grow[illegible] season from the beginning of pegging to the od development period.

Seasonal variation in the SPR for the different reatments (Fig. 2) shows that in growth phase C, the SPR was higher than in growth phases A and B with he highest SPR value of 9.9 kg cm^{-2} recorded at 86 DAE. In the continuous stress treatment these alues ranged from 8.2-10.3 kg cm^{-2}.

The implications of increased SPR for groundnut re reduced peg penetration into the soil (Cox 1962, Underwood et al. 1971, Boote et al. 1976) and educed peg development into pods (Ono et al. 1974).

Influence of Soil-Water Availability on Crop Growth

Soil-water deficiency is known to inhibit leaf expansion [illegible] stem elongation through lowered relative turgi[illegible] (Slatyer 1955, Allen et al. 1976, Vivekanandan and Gunasena 1976). Leaf area index (LAI) of groundnut in different stress treatments during the 1982/83 growing season is shown in Figure 3. The recovery in leaf-area production when stress was relieved at the start of pegging was remarkable. However, this recovery was much less rapid in the case where stress was imposed during flowering to start of seed growth. The maintenance of leaf area up to the time of maturity was also remarkable for stress imposed in growth phase B as compared to the fully irrigated control. Maximum LAI in the control treatment was 4.4 while in the continuous-stress treatment it was only 1.7. Vivekanandan and Gunasena (1976) also reported reduced LAI with reduced soil-water potential, with maximum LAI of 6.25 at a soil-water potential of -0.033 MPa. A study of the anatomy of groundnut leaves under stress (Ilyina 1959) revealed that leaves formed under stress had smaller cells than others.

Several studies reported reduction in the dry-matter production due to drought stress (Fourrier

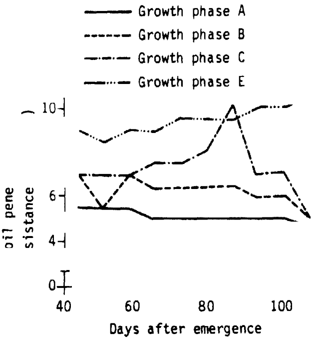

Figure 2. Seasonal changes in mean daily soil-penetration resistance (kg cm^{-2}) in drought-stress treatments imposed at different growth phases, ICRISAT Center, 1982/83.

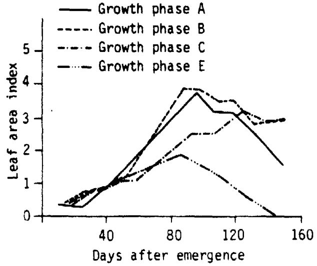

Figure 3. Seasonal changes in the leaf area index of groundnut subjected to drought stress in different growth phases, ICRISAT Center, 1982/83.

and Prevot 1958, Ochs and Wormer 1959, Su et al. 1964, Lenka and Misra 1973, Stansell et al. 1976, Vivekanandan and Gunasena 1976, Pallas et al. 1979). Seasonal variation in the total dry-matter production of groundnut in different stress treatments during the 1982/83 growing season is shown in Figure 4. Although drought stress in growth phase B caused a decrease in dry-matter accumulation compared to growth phase A, there was little difference in the total dry matter at the time of final sampling between the two treatments, thereby emphasizing the rate of recovery from early drought stress in growth phase B. In the treatment covering growth phase C, the crop was irrigated from 90 DAE and the recovery in the accumulation of dry matter did not start until 20 days later. As expected, continuous-stress treatment did not increase dry matter beyond 60 DAE.

Dry-matter partitioning at the time of m expressed as a percentage among various plant pa for stress treatments imposed at different grov phases during the 1982/83 growing season is shown in Table 3. The recovery in dry-matter production for the treatment which was under stress from emergence to pegging (up to 50 DAE) could be gauged from the close correspondence of the different partitioning values between this treatment and the fully-irrigated control treatment. The proportion of dry matter partitioned into pods is the highest for the emergence-to-pegging phase treatment. This could also be judged from the plot of the changes in the pod growth (Fig. 5) which showed a linear growth rate for this treatment. Boote et al. (1982) suggest that an increased ratio of pods to vegetative growth under small periodic water deficits may be a natural and important mechanism of groundnut adaptation to droughty conditions. The extended drought in growth phase C, however, reduced the proportion of dry matter partitioned to the kernel in comparison to the other treatments. Ong (1984) also showed that mild drought stress promoted peg and pod production. Drought stress during pod formation (growth phase C) resulted in a slower rate of pod growth even after the stress was released as Billaz and Ochs (1961) also observed.

Influence of Soil-Water Availability on Plant-Water Status

An understanding of the response of crop foliage to changes in the amount and status of soil water in the root zone is far from complete. Kramer (1963) concluded that too much emphasis was placed on soil-water status and too little on plant-water status. The status of water in the plants represents an integration

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Table 3. Dry-matter partitioning (%) at maturity among the various plant parts when drought stress was imposed at different growth phases, ICRISAT Center, 1982/83.

	Dry-matter distribution (%) for growth phases				
Plant component	A	B	C	E	Control
Leaves	23.5	24.9	20.2	29.8	22.0
Stems	26.6	21.9	18.8	59.0	24.7
Flowers	0.1	0.1	0.1	0.8	0.1
Pegs	5.2	3.4	12.6	0.9	1.5
Pods	27.3	32.1	37.4	6.8	29.8
Kernels	17.3	17.6	15.8	2.7	22.0

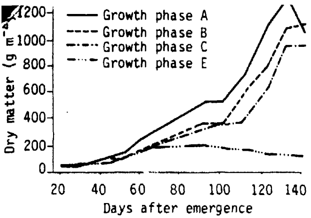

Figure 4. Seasonal changes in dry-matter production ($g\ m^{-2}$) for groundnut subjected to drought stress in different growth phases, ICRISAT Center, 1982/83.

of atmospheric demand, soil-water potential, rooting density, and distribution, as well as other plant characteristics (Kramer 1969). Therefore to obtain a true measure of plant-water deficit, the measurements should be made on the plant. Several plant measurements could be used as indicators of drought stress for groundnut. The most promising ones reported to be useful under field conditions include stomatal resistance (Pallas and Samish 1974, Pallas et al. 1974, Bhagsari et al. 1976), leaf-water potential (Bhagsari et al. 1976, Pallas et al. 1977, Pallas et al. 1979), and canopy temperature (Sanders et al. 1982). Recent advances made in porometry instrumentation now enable measurements of transpiration, which is related to stomatal opening and closing mechanisms under drought stress.

Stomatal Conductance

Under drought stress significant changes in stomatal resistance of groundnut plants have been shown. Bhagsari et al. (1976) showed that when relative water content decreased below 80%, a groundnut crop showed adaptation to drought stress by reducing the stomatal conductance. Diffusive resistance in the stressed plants was 30-35 $s\ cm^{-1}$ while in the watered plants it varied from 0.5-2.5 $s\ cm^{-1}$. Reduced photosynthesis due to drought stress in groundnut was attributed to stomatal closure (Bhagsari et al. 1976).

We made diurnal measurements of stomatal conductance and transpiration using a steady state porometer at weekly intervals from 0900 to 1700 at 2-hour intervals each day throughout the crop-growth period during the 1982/83 growing season. Diurnal variation in the stomatal conductance of groundnut that was subjected to drought stress at different growth phases is shown in Figure 6. These measurements were made at 75 DAE when stress was relieved in growth phases A and B and growth phase C was undergoing stress. Both time of the day and drought stress influenced the observed stomatal conductance values. The recovery from drought stress imposed during growth phase B was reflected well by the typical diurnal response exhibited by the

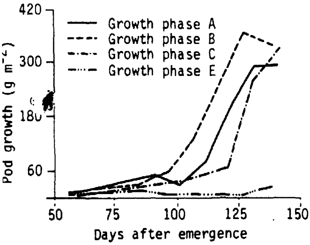

Figure 5. Changes in pod growth ($g\ m^{-2}$) of groundnut subjected to drought stress in different growth phases, ICRISAT Center, 1982/83.

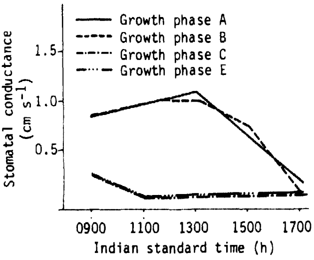

Figure 6. Diurnal variation in stomatal conductance ($cm\ s^{-1}$) of groundnut subjected to drought stress in different growth phases, ICRISAT Center, 1982/83.

groundnut plants to increasing irradiance levels during the day and reduced stomatal conductance in the late afternoon with reduced irradiance levels. Allen et al. (1976) have also shown that even when the stomatal conductance reached 0.1 cm s^{-1}, a cloud cover extending over a 1-hour period could improve it to 0.5 cm s^{-1}. Plants undergoing drought stress in growth phase C and in the continuous drought stress treatment closed their stomata by 1100 in response to reduced soil-water availability.

To show the drought-stress modulated responses of stomatal conductance to photosynthetic photon flux density (PPFD) we used the data collected in the fully-irrigated control treatment and the continuous-stress treatment. In the fully-irrigated control treatment, stomatal conductance increased with increasing PPFD (Fig. 7), a response typical of a crop under adequate water availability. In the continuous drought stress treatment, changing radiation levels had little influence on the stomatal conductance, thereby indicating the dependance of stomatal activity on the soil-water availability.

Seasonal variation in the stomatal conductance of groundnut with drought stress imposed at different growth phases is shown in Figure 8. In growth phase B, which was under drought stress up to about 51 DAE, the conductance was greatly reduced, but recovered steadily after water application, and reached the levels of the fully-irrigated control. In phase C the stomatal conductance reached a [illegible]imum mean value of 0.07 cm s^{-1} from 60-80 DAE. [illegible] 92 DAE when drought stress was relieved, the recovery extended over a longer period. In the continuous-stress treatment the lowest mean value of 0.02 cm s^{-1} was recorded. Measurements made by Allen et al. (1976) also showed that after 17 days of drought the stomatal conductance reached a minimum value of 0.1 cm s^{-1} compared with 0.5 cm s^{-1} in the irrigated plots.

Transpiration

Diurnal variation in groundnut transpiration is shown in Figure 9. The adaptation of groundnut to reduce transpiration under drought stress conditions through stomatal closure is reflected in the pattern of transpiration during the day in growth phase C and the continuous drought stress [illegible]ment.

Seasonal variation in transpiration (Fig. 10) also showed a six-fold reduction in daily mean transpiration during the period when groundnut underwent drought stress. While the fully-irrigated control treatment recorded a daily mean transpiration of 10 μg cm^{-2} s^{-1}, it was 1.8 μg cm^{-2} s^{-1} in groundnut undergoing drought stress in growth phase C.

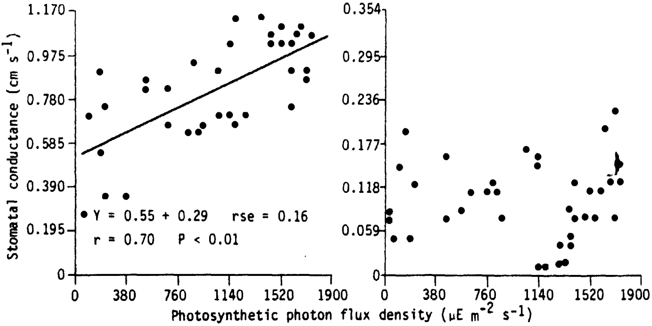

Figure 7. Stomatal conductance (cm s^{-1}) of groundnut as a function of photosynthetic photon flux density in fully-irrigated (left), and continuous-stress treatments, ICRISAT Center, 1982/83.

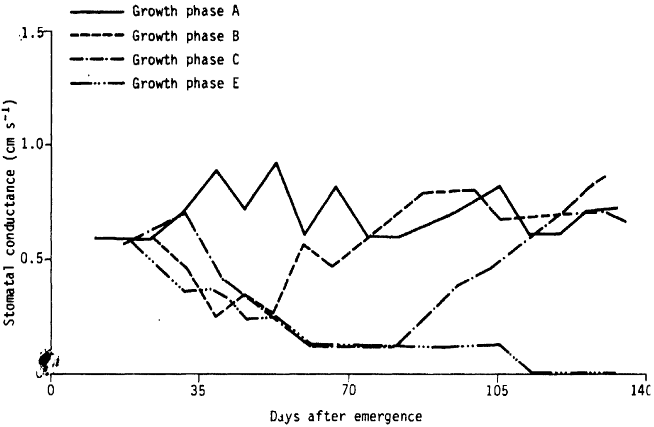

Figure 8. Seasonal changes in average daily stomatal conductance (cm s^{-1}) of groundnut subjected to drought stress in different growth phases, ICRISAT Center, 1982/83.

Canopy Temperature

Diurnal variation in canopy temperature of groundnut measured at 75 DAE in different drought stress treatments is shown in Figure 11. As with stomatal conductance and transpiration, canopy temperature was influenced by time of the day and the stage at which drought stress was imposed. Canopy temperature of groundnut undergoing stress in growth phase C peaked to 35°C at 1300, while in the continuous-stress treatment the canopy reached a maximum temperature of 33°C by 1100 and maintained the same until 1300. In growth phases A and B the canopy temperatures were low because the drought stress was relieved in these treatments long before 75 DAE. Sanders et al. (1982) also observed that canopy temperatures increased with drought. Afternoon canopy temperatures under irrigated conditions in their study were 28.5°C, while they were 35°C in the other treatments where three combinations of drought and soil temperatures were imposed.

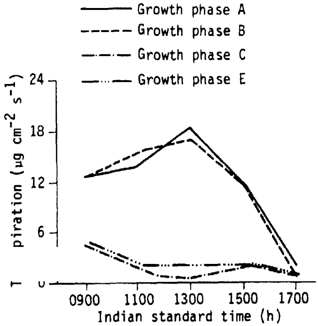

Figure 9. Diurnal variation in transpiration ($\mu g\ cm^{-2}\ s^{-1}$) of groundnut subjected to drought stress in different growth phases, ICRISAT Center, 1982/83.

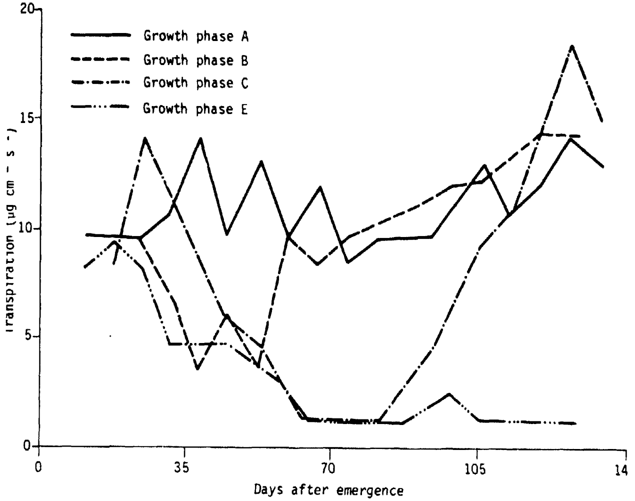

Figure 10. Seasonal changes in mean daily transpiration ($\mu g\ cm^{-2}\ s^{-1}$) of groundnut subjected to drought stress in different growth phases, ICRISAT Center, 1982/83.

Seasonal variation in the canopy-air temperature differential (CATD) are shown in Figure 12. In growth phase B the CATD reached a low value of -2.9°C to 1.9°C during the period of stress, but when stress was released the CATD values reflect the transpirational cooling achieved through adequate water availability. In growth phase C, the CATD values ranged from -3.7°C to 2.0°C during the period of drought stress from 30-90 DAE. The severity of drought stress in the continuous-stress treatment is evident from the more or less positive CATD for most of the growing season.

Leaf-Water Potential

The water potential of plant tissue has become a standard means of expressing plant-water status. Studies conducted so far on measurements of leaf-water potential of groundnuts indicate that reduced

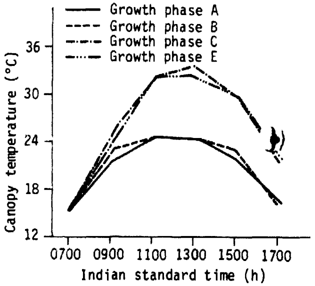

Figure 11. Diurnal variation in canopy temperature (°C) of groundnut subjected to drought stress in different growth phases, ICRISAT Center, 1982/83.

transpiration due to drought stress could lead to leaf- water potentials of -3.0 to -4.5 MPa (Bhagsari et al. 1976, Pallas et al. 1977, 1979), while in the frequently irrigated plants water potentials stayed at around -1.2 or -1.3 MPa (Allen et al. 1976, Pallas et al. 1977, 1979). Patel et al. (1983) showed that leaf-water potentials decreased from -1.0 to -3.8 MPa with a decrease in soil-water potential from -0.05 to -2.0 MPa. Sarma (1984) recorded large differences in leaf-water potentials of groundnut grown under different ET levels. In the treatment that received no supplemental water from emergence to maturity where the seasonal evapotranspiration was only 47 mm, the leaf-water potential reached -6.3 MPa.

Gautreau (1977) used leaf-water potential measurements to evaluate the drought tolerance of 21 groundnut cultivars in Senegal. Early cultivars which avoid the end of wet-season drought by a short life cycle had intermediate leaf-water potential; those with the lowest potentials had the highest yield. Bennett et al. (1981) reported that in field tests, zero-turgor potential occurred at leaf-water potential of -1.6 MPa and concluded that water relations of groundnuts were similar to other crops with no unique drought-resistance mechanism. Stansell et al. (1976) however, noted that clouds can cause significant changes in plant-water status of groundnut in a short time. Therefore they cautioned that care should be taken to sample different treatments under comparable radiation.

Influence of Soil-Water Availability on Pod Yield

It is difficult to find uniform conclusions from studies conducted so far on the influence of soil-water availability on yield at different growth phases. Since groundnut is often grown under contrasting

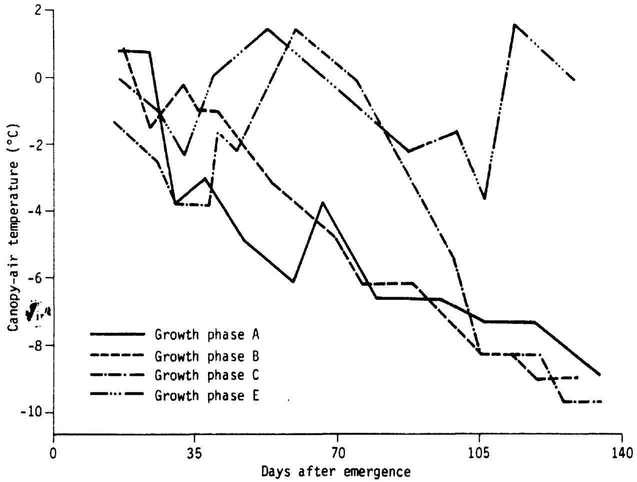

Figure 12. Seasonal changes in mean daily canopy-air temperature differential of groundnut subjected to drought stress in different growth phases, ICRISAT Center, 1982/83.

moisture regimes in a range of environments, measured yield responses are different. While some earlier studies showed a marked trend for higher yields at high moisture levels (Goldberg et al. 1967, Matlock et al. 1961, Su and Lu 1963), the more recent investigations (Nageswara Rao et al. 1985) confirmed that irrigations can be withheld during much of the vegetative period without any apparent effect on pod yield. As shown earlier, drought stress imposed from emergence to start of peg initiation had not affected the total dry matter produced and the rate of pod growth. Various plant-water stress measurements also showed impressive recovery from the stress in this treatment.

Pod yields for different drought-stress treatments during the three growing seasons at ICRISAT Center (Table 4) show that in comparison to the fully irrigated control, stress from emergence to pegging gave 18, 12, and 34% increased yields. As Nageswara Rao et al. (1985) surmised, this effect provides a significant managerial option in that stress at this stage can be allowed to maximize use of irrigation resources. Water savings that accrue from withholding irrigations during this stage could be substantial and could contribute to increased water-use efficiency. It was proposed that in farming systems where irrigation could be used to initiate a crop of groundnut with a long-season cultivar in advance of rains, it may be possible to exploit the benefits of stress before the rains arrive.

When stress was imposed during growth phase C, the reduction in pod yields was 30% during the first season, 18% during the second, and 25% during the third season. Lower soil-moisture content in the top soil might have contributed to considerable mechanical resistance to peg penetration (Cox 1962, Underwood et al. 1971, Boote et al. 1976).

Reductions in pod yield due to stress were l growth phase D. The indeterminate nature crop as well as the subterranean fruiting habit should be considered here. Since fruit initiation continues after the start of kernel growth, soil-water deficits during pod filling stage reduce both the initiation and development of pods (Matlock et al. 1961, Boote et al. 1976, Pallas et al. 1979, Underwood et al. 1971, Ono et al. 1974). High soil temperatures (Ono et al. 1974) might have affected the peg development into pods, and growth of pods in the soil might have been affected by inadequate moisture in the root zone (Allen et al. 1976, Boote et al. 1976).

Developing Strategies for Improved Groundnut Production: Implications of Research on Water Relations

Several speakers in this symposium hav[illegible]eady emphasized the need to develop strategies that will make more efficient use of the limited water available for groundnut production in the SAT. Research on water relations that treats the soil, the plant, and the atmosphere as a continuum emphasizes that drought stresses affect crop growth and development because of low water availability (or in other words, low probability of receiving rainfall) during certain sensitive stages of the crop-growth cycle. Historical rainfall data should permit determination of probabilities of drought stress periods for groundnut from a mean sowing date, which could be calculated from the beginning of rains. As an extension of this approach, information on soil water-holding capacity and patterns of change in evapotranspiration with crop growth could be used in a simple

Table 4. Pod yields (kg ha^{-1}) of groundnut cv Robut 33-1 when drought stress was imposed at different growth phase[illegible]ring three growing seasons, ICRISAT Center, 1980-83.

	Pod yields (kg ha^{-1})		
Growth phase	1980/81[1]	1981/82	1982/83
A. Emergence to start of flowering	—	—	2701
B. Emergence to start of pegging	5480	5300	4396
C. Start of flowering to start of seed growth	3257	3870	2438
D. Start of seed growth to maturity	1450	3610	—
E. Emergence to maturity	590	75	503
Control	4615	4720	3258

1. 77 mm of rain received during the growing season.

moisture model with climatic data as input to compute soil-moisture budget on a daily basis, and to calculate frequencies of stress periods of various lengths.

Knowledge of probable stress periods at a given location could then be used to:

- Select appropriate varieties with a growing cycle that would match the probable stress periods with the dependable-rainfall periods.
- Adjust the sowing date to take advantage of the dependable-rainfall periods. The choice of sowing date adjustments in the SAT may be limited, especially in regions with low rainfall. In view of the capacity of groundnut to withstand stress during the early stages, maximum advantage should be taken of the first rains. This may necessitate the completion of primary tillage after the harvest of the previous crop in order to make use of the first rains for sowing.
- Maximize the water-use efficiency (WUE) under irrigated conditions by establishing the groundnut crop with irrigation ahead of the probable date of beginning of rains. This would take advantage of the lower water needs during the early growth phase, followed by more judicious water use during the later stages when the water requirements are maximum.

Available information on groundnut rooting patterns and water-extraction rates suggests that if other conditions are equal, soils that hold more water in the top 60 cm confer a comparative advantage. Where groundnut is grown under irrigated conditions this would mean more frequent but shallow irrigations. Under these conditions varieties that have a greater proportion of their root system in the top 60 cm may exhibit higher water-use efficiency. Also, research on agronomic practices that enable plants to use more of the water available in the soil for transpiration than evaporation should lead to improvements in WUE.

P[illegible] measurements of drought stress such as stomatal conductance, transpiration, and canopy temperatures should be useful to assess the relative susceptibility of different varieties to drought stress in a given growth phase. The data collected in the studies described in this paper and elsewhere suggest adaptation of groundnut to drought stress. A range of adaptation mechanisms or crop acclimation to stress has been suggested by Turner (1979). Incorporation of such drought-resistant characters into groundnut may depend upon field evaluation of these techniques over a large number of varieties. However these techniques can only be limited t evaluation of advanced breeding lines in view of th time it takes to make these measurements. Hence a Turner (1982) suggests, there is a need to develo suitable visual techniques such as leaf rolling, wilting, or tip burning for screening large populations.

References

Ali, A. M., Mohan, J. C., and **Shantha, R.** 1974. Response of groundnut to different moisture regimes and farm yard manure. Madras Agricultural Journal 61:472-476.

Allen, L.H., Jr., Boote, K. J., and **Hammond, L. C.** 1976. Peanut stomatal diffusion resistance affected by soil water and solar radiation. Proceedings, Soil and Crop Science Society of Florida 35:42-46.

Angus, J. F., Hasegawa, S., Hsiao, T. C., Liboon, S. P., and **Zandstra, H. G.** 1983. The water balance of post-monsoonal dryland crops. Journal of Agricultural Science (UK) 101:699-710.

Avasarmal, B. C., Bharambe, P. R., and **Shinde, J. S.** 1982. Soil moisture extraction pattern of different crops grown on vertisol under rainfed condition. Journal of Maharashtra Agricultural Universities 7:125-129.

Babu, N. R., Reddy, S. R., Reddi, G. H. S., and **Reddy, D. S.** 1984. Effects of fertilizers, irrigation and plant density on groundnut. Fertilizer Research 5:273-279.

Bennett, J. M., Boote, K. J., and **Hammond, L. C.** 1981. Alterations in the components of peanut leaf-water potential during desiccation. Journal of Experimental Botany 32:1035-1043.

Bhagsari, A.S., Brown, R. H., and **Schepers J. S.** 1976. Effect of moisture stress on photosynthesis and some related physiological characteristics in peanut. Crop Science 16:712-715.

Bhan, S. 1973. Water relations of groundnut in relation to variety, spacing and soil fertility under arid conditions. Indian Journal of Agricultural Sciences 43:759-765.

Bhan, S., and **Misra, D. K.** 1970. Water utilization by groundnut (*Arachis hypogaea* L.) as influenced due to variety, plant population and soil fertility level under arid zone conditions. Indian Journal of Agronomy 15:258-263.

Bhargava, P. N., Pradhan, A., and **Das, M. N.** 1974. Influence of rainfall on crop production. JNKVV Research Journal 8:22-29.

Billaz, R., and **Ochs, R.** 1961. [Stages of susceptibility of groundnuts to drought.] Stades de sensibilité de l'arachide à la sécheresse. (In Fr.) Oléagineux 16:605-611.

Boote, K. J., Varnell, R. J., and Duncan, W. G. 1976. Relationships of size, osmotic concentration and sugar concentration of peanut pods to soil water. Proceedings, Soil and Crop Science Society of Florida 35:47-50.

Boote, K. J., Stansell, J. R., Schubert, A. M., and Stone, J. F. 1982. Irrigation, water use, and water relations. Pages 164-205 *in* Peanut science and technology (Pattee, H. E., and Young, C. T., eds.). Yoakum, Texas, USA: American Peanut Research and Education Society.

Charoy, J. 1974. [Water dynamics in a tropical ferruginous soil of dune origin at Tarna and application to millet, groundnut and bare soil.] Dynamique de l'eau dans les sols ferrugineux tropicaux d'origine dunaire de tarna et application au mil, à l'arachide et au sol nu. (In Fr. Summaries in En. Es.) Agronomie Tropicale 29:821-830.

Cheema, S.S., Kundra, H.C., and **Kaul, J.S.** 1974. Response of groundnuts to various soil moisture regimes and methods of P application. Journal of Research, Punjab Agricultural University 11:380-385.

Choy, E. W. C., Stone, J. F., and **Garton, J. E.** 1977. Row spacing and direction effects on water uptake characteristics of peanuts. Soil Science Society of America Journal 41:428-432.

Cox, F. R. 1962. The effect of plant population, various fertilisers, and soil moisture on the grade and yield of peanuts. Ph.D thesis, North Carolina State University, Raleigh, North Carolina, USA.

Davidson, J. M., Garton, J. E., Matlock, R. S., Schwab, D., Stone, J. F., and **Tripp, L. D.** 1973. Irrigation and water use. Pages 361-382 *in* Peanuts culture and uses. Stillwater, Oklahoma, USA: American Peanut Research and Education Association.

Davidson, J. I., Jr., Blackenship, P. D., Sanders, T. H., Cole, R. J., Hill, R. A., Henning, R. J., and **Guerke, W. R.** 1983. Effect of row spacing, row orientation, and gypsum on the production and quality of nonirrigated Florunner peanuts. Proceedings of American Peanut Research and Education Society 15:46-57.

Fourrier, P., and **Prevot, P.** 1958. [Influence on groundnuts of rainfall, chemical manuring and steeping the seeds.] Influence sur l'arachide de la pluviosité de la fumure minérale et du trempage des graines (In Fr. Summary in En.) Oléagineux 13:805-809.

Gautreau, J. 1977. [Levels of intervariety leaf potentials and adaptation of the groundnut to drought in Senegal.] Niveaux de potentiels foliaires intervariétaux de l'arachide à la sécheresse au Sénégal. (In Fr. summaries in En, Es.) Oléagineux 32:323-332.

Goldberg, S.D., Gornat, B., and **Sadan, D.** 1967. Relation between water consumption of peanuts and class A pan evaporation during the growing season. Soil Science 104:289-296.

Hammond, L.C., Boote, K.J., Varnell, R.J., and [illegible]son, W. K. 1978. Water use and yield of peanuts on a [illegible] drained sandy soil. Proceedings of American Peanu[illegible] Research and Education Association 10:73.

Hammond, L. C., and **Boote, K. J.** 1981. Water-use efficiency of peanuts. Proceedings of American Peanut Research and Education Society 13:109.

Henning, R. J., Allison, A. H., and **Tripp, L. D.** 1982. Cultural practices. Pages 123-138 *in* Peanut science and technology (Pattee, H.E., and Young, C. T. eds.). Yoakum, Texas, USA: American Peanut Research and Education Society.

Hanks, R. J., Keller, J., Rasmussen, V. P., and **Wilson, G. D.** 1976. Line source sprinkler for continuous variable irrigation crop-production studies. Soil Science Society of America Journal 40:426-429.

Ilyina, A. I. 1959. [Study of the periods of high susceptibility of groundnuts to different soil moisture conditions.] Etude des périodes de haute sensibilité de l'arachide aux différences d'humidité du sol (In Fr.) Oléagineux 14:89-92.

Kadam, D.M., Rao, G.R., and **Varade, S. B.** 19[illegible]n the prediction of reference crop evapotranspiration and consumptive use of different crops. Annals of Arid Zone 17:99-111.

Kassam, A. H., Kowal, J. M., and **Harkness, C.** 1975. Water use and growth of groundnut at Samaru, northern Nigeria. Tropical Agriculture (Guilford) 52:105-112.

Keese, C. W., Denton, J. S., Hiler, E. A., and **Newman, J. S.** 1975. Pages 42-47 *in* Irrigation practices in peanut production in Texas. College Station, Texas, USA: Texas A&M University.

Kramer, P. J. 1963. Water stress and plant growth. Agronomy Journal 55:31-36.

Kramer, P. J. 1969. Plant and soil water relationships: a modern synthesis. New York, USA: McGraw-Hill.

Lenka, D., and **Misra, P.K.** 1973. Response of groundnut (*Arachis hypogaea* L.) to irrigation. Indian Journal of Agronomy 18:492- 497.

Mantell, A., and **Goldin, E.** 1964. Influence of irrigation frequency and intensity on the yield and quality of [illegible]nuts. Israel Journal of Agricultural Research 14:203-2.[illegible]

Matlock, R.S., Garton, J.E., and **Stone, J.F.** 1961. Peanut irrigation studies in Oklahoma, 1956-1959. Oklahoma Agricultural Experimental Station Bulletin no. B-580. Stillwater, Oklahoma: Oklahoma State University.

McCauley, G.N., Stone, J.F., and **Choy, E.W.C.** 1978. Evapotranspiration reduction by field geometry effects in peanuts and grain sorghum. Agricultural Meteorology 19:295-304.

Metelerkamp, H.R.R. 1975. Irrigation scheduling by means of a class "A" pan evaporation. Rhodesian Agricultural Journal Technical Bulletin no. 16. Salisbury, Rhodesia: The Government Printer.

Nageswara Rao, R.C., Sardar Singh, Sivakumar, M.V.K., Srivastava, K.L., and Williams, J.H. 1985. Effect of water deficit at different growth phases of peanut. I. Yield responses. Agronomy Journal 77:782-786.

Narasimham, R.L., Rao, I.V.S., and Rao, M.S. 1977. Effect of moisture stress on response of groundnut to phosphate fertilisation. Indian Journal of Agricultural Sciences 47:573-576.

Ochs, R., and Wormer, T.M. 1959. [Influence of the supply of water on the growth of groundnuts.] Influence de l'alimentation en eau sur la croissance de l'arachide (In Fr.) Oléagineux 14:281-291.

Ong, C.K. 1984. The influence of temperature and water deficits on the partitioning of dry matter in groundnut (*Arachis hypogaea* L.). Journal of Experimental Botany 35:746-755.

O[illegible] Y., Nakayama, K., and Kubota, M. 1974. Effects of soil temperature and soil moisture in the podding zone on the pod development of groundnut plants. Proceedings of the Crop Science Society of Japan 43:247-251.

Pallas, J.E., Jr., and Samish, Y.B. 1974. Photosynthetic response of peanut. Crop Science 14:478-482.

Pallas, J.E., Jr., Samish, Y.B., and Willmer, C.M. 1974. Endogenous rhythmic activity of photosynthesis, transpiration, dark respiration, and carbon dioxide compensation point of peanut leaves. Plant Physiology 53:907-911.

Pallas, J.E., Jr., Stansell, J.R., and Bruce, R.R. 1977. Peanut seed germination as related to soil water regime during pod development. Agronomy Journal 69:381-383.

Pallas, J.E., Jr., Stansell, J.R., and Koske, T.J. 1979. Effects of drought on Florunner peanuts. Agronomy Journal 71: 853-858.

Panabokke, C.R. 1959. Water consumption patterns of crops in the dry zone environment of Ceylon. Tropical Agriculturalist 115:187-194.

P[illegible] C.L., Padalia, M.R., and Babaria, N.B. 1983. Growth and plant water relations in groundnut grown under different soil moisture stresses. Indian Journal of Agricultural Sciences 53: 340-345.

Pattee, H. E., and Young, C. T. 1982. A look to the future. Pages 754-764 *in* Peanut science and technology (Pattee, H. E., and Young, C. T., eds.). Yoakum, Texas, USA: American Peanut Research and Education Society.

Reddy, G.H.S., and Reddy, M.N. 1977. Efficient use of irrigation water for wheat and groundnut. Mysore Journal of Agricultural Sciences 11:22-27.

Reddy, K.A., Venkatachari, A., and Rao, P.S.P. 1980. Evapotranspiration and water use efficiency of different crops. Indian Journal of Agronomy 25:176-180.

Reddy, N.M., Havanagi, G.V., and Hegde, B.R. 1978. Effect of soil moisture level and geometry of planting on the yield and water use of groundnut. Mysore Journal of Agricultural Sciences 12:50-55.

Robertson, W.K., Hammond, L.C., Johnson, J.T., and Boote, K.J. 1980. Effects of plant-water stress on root distribution of corn, soybeans, and peanuts in sandy soil. Agronomy Journal 72: 548-550.

Samples, L. E. 1981. Peanut irrigation in Georgia. Circular 685. Tifton, Georgia, USA: University of Georgia.

Sanders, T. H., Blankenship, P. D., Cole, R. J., and Hill, R. A. 1982. Effects of drought and soil temperature on peanut canopy, stem and pod temperatures. Proceedings of American Peanut Research and Education Society.

Sarma, P. S. 1984. Soil-plant-water relations, growth and yield of groundnut under moisture stress. Ph.D. thesis, Andhra Pradesh Agricultural University, Hyderabad, Andhra Pradesh, India.

Shalhevet, J., Mantell, A., Bielorai, H., and Shimshi, D. 1976. Irrigation of field and orchard crops under semi-arid conditions. IIIC Publication no. 1. Bet Dagan, Israel: International Irrigation Information Center. 110 pp.

Sindagi, S.S., and Reddy, B.S.G. 1972. Effect of sowing date and rainfall distribution on the yield of groundnut crops. *In* Proceedings of drought seminar, Bangalore, India: University of Agricultural Sciences.

Slatyer, R.O. 1955. Studies on water relations of crop plants grown under natural rainfall in North Australia. Australian Journal of Agricultural Research 6:365-377.

Stansell, J.R., Shepherd, J.L., Pallas, J.E., Jr., Bruce, R.R., Minton, N.A., Bell, D.K., and Morgan, L.W. 1976. Peanut responses to soil variables in the southeast. Peanut Science 3: 44-48.

Su, K.C., and Lu, P. C. 1963. The effect of time of irrigation and amount of water irrigated on peanut yield. Journal of the Agricultural Association of China 41:43-51.

Su, K. C., Chen, T. R., Hsu, S. C., and Tseng, M. T. 1964. Studies on the processing of water absorption and economized irrigation of peanuts. Journal of the Agricultural Association of China 45:31-40.

Taylor, H.M., and Ratliff, L.M. 1969. Root elongation of cotton and peanuts as a function of soil strength and water content. Soil Science 108:113-119.

Turner, N. C. 1979. Drought resistance and adaptation to water deficits in crop plants. Pages 343-372 *in* Stress physiology in crop plants (Mussell, H., and Staples, R. C., eds.). New York, USA: John Wiley.

Turner, N. C. 1982. Factors influencing sorghum yields, environmental stresses. Pages 191-203 *in* Sorghum in the eighties: proceedings of the International Symposium on Sorghum, 2-7 Nov 1981, ICRISAT Center, India. Vol. 1. Patancheru, A. P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Underwood, C. V., Taylor, H. M., and Hoveland, C. S. 1971. Soil physical factors affecting peanut pod development. Agronomy Journal 63:953-954.

Vivekanandan, A. S., and Gunasena, H. P. M. 1976. Lysimetric studies on the effect of soil moisture tension on the growth and yield of maize (*Zea mays* L.) and groundnut (*Arachis hypogaea* L.) Beitrage zur Tropischen Landwirtschaft und Veterinaermedizin 14: 269-378.