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Response of Groundnut to Drought Stress in Different Growth Phases

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ABSTRACT

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The response of ground nut (*Arachis hypogaea* L.) cultivar Robut 33-1 to drought stress imposed at different growth phases was studied during the 1982–83 post-rainy season on a medium deep Alfisol at the ICRISAT Center, Patancheru, India. Irrigation amount was varied to three levels for the growth phases: (1) emergence to flowering, (2) emergence to pegging, (3) start of flowering to start of seed growth, and (4) emergence to maturity. Soil water extraction in treatments 1 and 2 was mostly from the surface 60 cm of soil, whereas in treatment 3 extraction from the 60–120 cm soil layer was significantly higher. Total water use varied with the growth phase and also with the intensity of drought stress within a growth phase. Stress imposed in treatment 2 resulted in increases in pod number and dry matter. Significantly higher pod and kernel yields were obtained in treatment 2. Quality of kernels was also superior in treatment 2, as shown by the improved seed weight, oil and protein contents, and the percentage of seed to pod weight. In treatment 3, low yields and a lower percentage of sound mature kernels were observed. Drought stress imposed from flowering to start of seed growth was shown to be important for both yield and quality.

INTRODUCTION

In the semi-arid tropics, groundnut (*Arachis hypogaea* L.) yields are low and variable. Erratic rainfall is one of the major factors responsible for yield fluctuations (Kanwar et al., 1983). Water deficits affect groundnut growth, depending on the stage of crop growth and the degree or intensity of drought stress. In order to develop management strategies for increased and stable groundnut yields in these areas, it is necessary to study the effect of drought stress at different growth phases on both yield and seed quality.

Early vegetative growth has not been shown to be sensitive to drought stress,

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since the water absorbed during the first month after sowing was found to be small (Su et al., 1964). Nageswara Rao et al. (1985) showed that decreased irrigation during the early phase was even beneficial. In a review of the studies on water relations of groundnut, Sivakumar and Sarma (1986) cited several studies which showed the flowering and pod development phases to be sensitive to drought stress.

The total water use of groundnut is controlled by climatic, agronomic and varietal factors. Hence the total water use reported in the literature varies from 250 mm under rainfed conditions (Angus et al., 1983) to 830 mm under fully irrigated conditions (Nageswara Rao et al., 1985). Soil water availability exerts a controlling influence on peak water use as reported by Vivekanandan and Gunasena (1976), who measured peak values of 6.1, 4.8, and 3.8 mm day^{-1} under high, intermediate, and low soil-water potentials, respectively.

Soil water deficiency is known to inhibit leaf expansion, stem elongation and dry-matter production (Vivekanandan and Gunasena, 1976). Because groundnut is grown under widely different moisture regimes in a range of environments, measured yield responses to soil water differ in different studies and it is difficult to draw uniform conclusions from these. While some earlier studies showed a marked trend for higher yields at high moisture levels (Matlock et al., 1961; Goldberg et al., 1967), 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.

The kernel quality of a groundnut crop is known to suffer from moisture stress (Pallas et al., 1977). The most significant consequences are decreased seed weight (Varnell et al., 1976) and germinability (Cox et al., 1976).

The objective of the present study was to investigate the influence of the adequacy or lack of soil water at different growth phases on groundnut growth, water use, and quality and quantity of seed produced.

MATERIALS AND METHODS

The experiment was conducted during the 1982–83 post-rainy season (November–April) on a medium deep Alfisol (Fine, clayey mixed hyperthermic Lithic Rhodustalf) at the International Crops Research Institute for Semi-Arid Tropics (ICRISAT), Patancheru, India (17°32′N, 78°16′E). The treatment were laid out in a split-plot design with four replications. The main-plot treatments were the growth phases of the crop, during which irrigation was varied using a line-source sprinkler as described by Hanks et al. (1976). They were:

- treatment 1: Line-source irrigation from emergence to flowering.
- treatment 2: Line-source irrigation from emergence to pegging.
- treatment 3: Line-source irrigation from start of flowering to start of seed growth.

- treatment 4: Line-source irrigation from emergence to maturity.

The irrigation schedule for the growing season in different treatments is shown in Fig. 1. Anticipating that the amount of water applied would be a function of distance from the line source, each main treatment was divided into three subtreatments (A, B and C) based on the distance from the sprinkler line. Subtreatment A was between 0 and 6 m, B between 6 and 12 m, and C between 12 and 18 m from the sprinkler line. The amount of water applied was measured by placing catchcans. Subtreatment 4A received the maximum amount of applied water evenly distributed throughout the season; this subtreatment is considered as the fully irrigated control.

Groundnut cv. Robut 33-1 was sown on 29 October and emergence was completed by 5 November. The plot size was 14 m×18 m. Row spacing was 30 cm with a plant-to-plant spacing of 10 cm within the row. A basal dose of 100 kg ha^{-1} of diammonium phosphate (18% N and 20% P_2O_5) was applied.

Profile water content was measured with a Type I.H. II neutron moisture meter (Didcot Instrument Co. Ltd., Abingdon, Oxon, OX10 8BB Great Britain) at 7–10-days interval throughout the growing season, from 30 to 120 cm soil depth at 15-cm intervals. Soil moisture in the top 30 cm was measured gravimetrically. Plant available water in the soil profile was determined from the field measurements and available moisture-holding capacity in the 120 cm deep profile is 140 mm.

Total water use was computed with the water-balance equation. Deep drainage below 120 cm was considered negligible based on soil moisture measurements following each irrigation, which showed little or no increase in the moisture content of the 105–120-cm soil layer after irrigation.

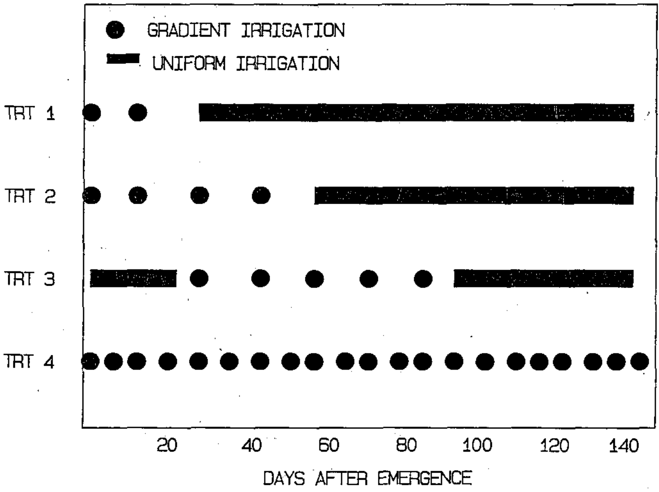

Fig. 1. Schedule of irrigations applied to groundnut in different treatments.

Growth measurements were made by sampling the whole plants at 7–10-days interval in a 0.75 m^2 area in each replicate. Plants were dried to constant weight at 65 °C and then weighed.

Pod and kernel yields were obtained from a net area of 9 m^2. The kernel quality of seed was analyzed for oil, protein, sugars and starch. Oil content was analyzed by the methods given by AOCS (1981). Protein was estimated by the Microkjeldahl method (AOAC, 1975).

RESULTS

Environment during the growing season

Meteorological data for the growing season are presented in Table 1. No rainfall was received during the growing season. Maximum air temperatures and pan evaporation rates increased from planting to maturity.

Available soil water, water use and dry-matter production. To describe the soil water profile and the dry-matter production patterns, subtreatment C of each treatment was chosen since it represents the driest end of the scale during the period when line-source irrigations were given.

In treatment 1, the duration of drought stress was relatively short (Fig. 1) and the crop received uniform irrigations for the remainder of the growing season. Soil water extraction in subtreatment 1C was more or less confined to the top 60 cm of soil (Fig. 2) and maximum dry-matter was in excess of 1000 g m^{-2} (Fig. 3).

In treatment 2, drought stress was imposed up to the start of pegging, i.e. 55 days after emergence. Soil water extraction in the 0–30-cm soil layer in subtreatment 2C was higher than in subtreatment 1C, and some extraction occurred even in the lower layers (Fig. 2). Both applied water and total water use were lower for all subtreatments in treatment 2 than for treatment 1 (Table

TABLE 1

Meteorological parameters during the 1982–83 post-rainy season

Month	Rainfall (mm)	Temperature (°C)		Pan evaporation (mm)	Relative humidity (%)		Wind (km h^{-1})	Sun shine (h)	Solar radiation (MJ m^{-2})
		Max	Min		07:17 h	14:17 h			
Nov	0	28.5	17.3	132.3	90.9	49.1	7.6	8.1	16.95
Dec	0	28.2	13.2	149.2	92.2	40.3	6.4	9.4	16.45
Jan	0	28.8	13.1	169.9	85.8	33.4	6.6	10.0	18.67
Feb	0	32.3	17.0	210.5	75.1	26.6	8.3	10.1	20.87
Mar	0	36.5	19.9	303.9	61.1	22.5	8.2	10.3	22.52

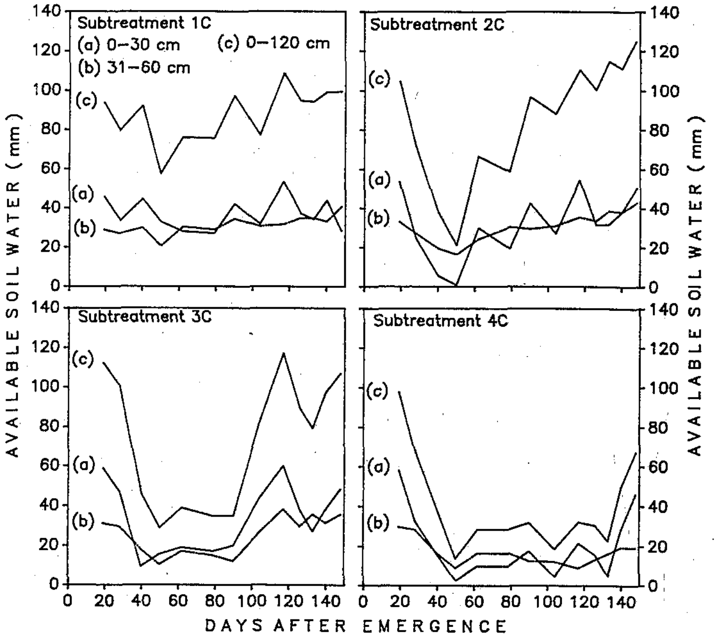

Fig. 2. Seasonal changes in available soil water at different soil depths in subtreatments 1C, 2C, 3C and 4C.

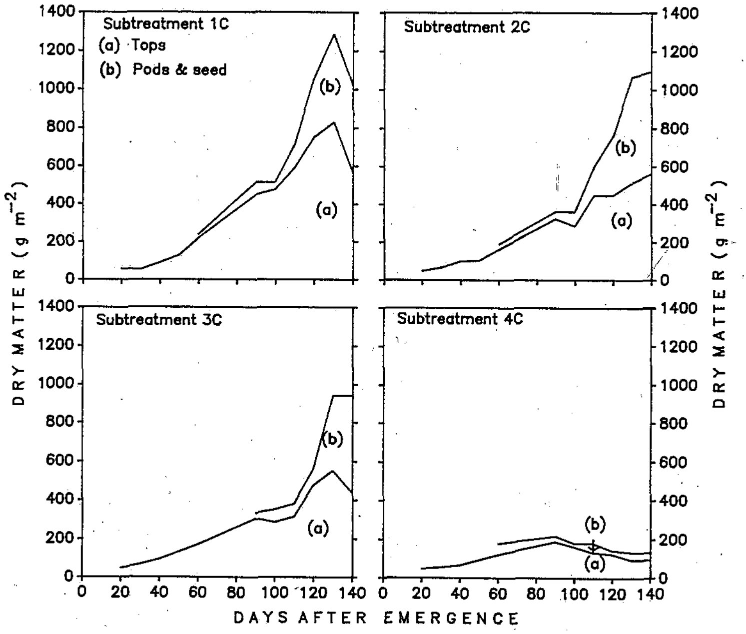

Fig. 3. Seasonal changes in dry-matter production of groundnut in subtreatments 1C, 2C, 3C and 4C.

TABLE 2

Amount of water applied and total water use in different treatments

Main treatment	Subtreatment	Net amount of water applied (mm)	Total water use (mm)
1	A	665	592
	B	657	603
	C	623	635
2	A	630	576
	B	589	579
	C	522	524
3	A	603	595
	B	553	525
	C	477	448
4	A	739	697
	B	409	418
	C	27	169

2). Although drought stress in subtreatment 2C caused a decrease in dry-matter accumulation for the first 80 days compared to subtreatment 1C, differences in the maximum dry-matter production between the two treatments were smaller, thereby emphasizing the rate of recovery from early drought stress in subtreatment 2C.

In subtreatment 3C (no irrigation between days 30 and 90), soil water extraction occurred at all depths (Fig. 2), and at soil depths 60–120 cm extraction was significantly higher than in subtreatments 1C and 2C. The longer stress duration and lower amounts of applied water for subtreatment 3C resulted in water-use levels (Table 2) lower than those for the corresponding subtreatments in 1 and 2. Although the crop received uniform irrigations from 90 DAE (days after emergence), the recovery in the accumulation of dry matter for subtreatment 3C did not start until 20 days later (Fig. 3).

In subtreatment 4C, which received only 27 mm of applied water throughout the growing season, water extraction was maximum in the 60–120 cm soil depths till 80 DAE (Fig. 2), after which available water dropped to such low levels that little or no water extraction occurred. As a consequence, dry matter production in subtreatment 4C showed little increase beyond 60 DAE (Fig. 3).

Pod and kernel yields and water-use efficiency. Final plant population, pod yield, water-use efficiency and harvest index (ratio of pod yield to total dry matter yield) for different treatments are shown in Table 3. Maximum pod yields were obtained in subtreatment 2B where the yields were 46% above control (4A).

TABLE 3

Plant population at harvest, pod yield, water use efficiency and harvest index at different ET levels for different treatments during the 1982–83 post-rainy season

Treatment	Final plant population (×1000 plants per ha)	Pod yield (kg ha^{-1})	Water-use efficiency (kg ha^{-1} cm^{-1})	Harvest index (%)
1A	209	2950	49.8	22.3
1B	207	2820	46.7	19.6
1C	201	2700	42.5	20.0
2A	202	3060	53.2	47.3
2B	202	4740	81.9	36.9
2C	219	4400	83.9	33.7
3A	197	3000	50.4	25.2
3B	107	2680	51.1	22.1
3C	194	2440	54.4	18.9
4A	214	3260	46.7	32.7
4B	203	2260	54.0	29.6
4C	217	500	29.8	10.4
SE(±)	14	536	4.5	2.6

TABLE 4

100 kernel weight, protein content, oil content and shelling percentage for different treatments

Treatment	100 kernel weight (g)	Protein content (%)	Oil content (%)	Shelling percentage
1A	54.9	29.4	43.9	72
1B	49.3	28.8	41.9	72
1C	46.4	29.5	41.5	67
2A	59.5	34.0	43.8	73
2B	58.1	29.7	42.4	74
2C	50.8	29.8	41.5	70
3A	52.6	30.0	43.4	69
3B	45.7	30.1	43.4	68
3C	29.2	28.4	38.1	63
4A	57.7	31.0	41.4	77
4B	55.9	33.7	40.1	73
4C	22.3	30.8	39.3	48
SE(±)	0.17	0.17	0.18	0.57

Pod yields in 4C were 89% lower than those in subtreatment 2B. In comparison to 4A, the stress treatments resulted in higher water-use efficiencies. Maximum harvest index was also recorded with treatment 2.

Seed quality. Seed weight was maximum in subtreatments 2A and 2B (Table 4). Seed weight in subtreatment 3C was close to subtreatment 4C although 3C received more water (Table 2). Subtreatment 2A showed the highest protein and oil contents. Shelling percentage (ratio between seed and pod weights) was maximum in the irrigated control (4A) and was low for all subtreatments of treatment 3.

DISCUSSION

Water extraction patterns varied with the growth phase during which drought stress was imposed. When drought stress was imposed during the early phases of crop growth, i.e. up to flowering and up to pegging stages, plant water needs were small and water extraction was confined to the top layers of the soil. In treatment 3, where drought stress was imposed from flowering to start of seed growth, water depletion in the surface 60 cm was maximum and the available soil water level in these layers fell below 30 mm, particularly in subtreatment 3C up to 110 days when pod formation occurred and seed filling commenced. In view of the fact that maximum water extraction occurred from the top 30 cm of soil (Mantell and Goldin, 1964), inadequate available soil water in this layer could have caused considerable drought stress in treatment 3. In subtreatment 4C, soil water in all soil layers was below 20 mm from 30 DAE, reflecting the severe drought conditions under which groundnut was grown in this subtreatment.

Total water use varied with the drought-stress treatment and also with the intensity of drought stress within a growth phase.

Early drought stress stimulated growth as shown by the increased rates of dry-matter production (Fig. 2). Comparison of dry-matter distribution patterns for tops, pod and seed components for subtreatments 3C (Fig. 3) and 4C (Fig. 3) with subtreatment 2C (Fig. 3) clearly shows that water stress during early stages could be easily compensated by a flush of growth in the late stages. Mid-season drought stress (treatment 3) brings about a large reduction in dry-matter production, although the total amount of water applied compares well with the other treatments.

Significantly superior pod and kernel yields were obtained in subtreatments 2B and 2C. A plot (Fig. 4) of the relative kernel yield ($\mathrm{KY}_i/\mathrm{KY}_{\max}$) and relative ET ($\mathrm{ET}_i/\mathrm{ET}_{\max}$) clearly shows the yield advantage for these two subtreatments. KY_i and ET_i represent respectively the kernel yield and evapotranspiration, in a given subtreatment (i), and $\mathrm{KY}_{\max}$ and $\mathrm{ET}_{\max}$ represent respectively the maximum kernel yield and the maximum ET recorded in the experiment. Favourable partitioning of total biomass into the reproductive structures (Fig. 2) contributed to the observed yield advantages in treatment 2. The fully irrigated control (4A), where the relative ET was 1.0, shows a relative kernel yield much below that of subtreatment 2A. This confirms the earlier conclusions of Na-

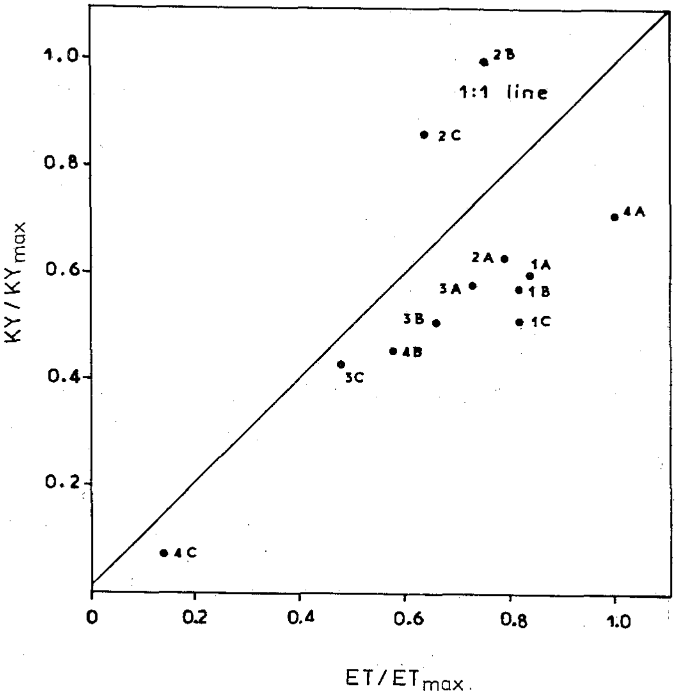

Fig. 4. Relative kernel yield (KY/KY_{max}) in relation to relative evapotranspiration (ET/ET_{max}) for different treatments.

geswara Rao et al. (1985) that maximum yields of groundnut can be achieved with decreased irrigations during the early phase. Excessive irrigations promote vegetative growth at the expense of reproductive growth. Yield reduction in subtreatment 3C relative to subtreatments 3A and 3B was not unexpected, since the period of pod formation and pod addition is when groundnut was reported to be most sensitive to water deficit (Sandhu et al., 1972).

Data on seed quality indicate that moisture stress imposed from emergence to peg initiation (treatment 2) proved beneficial since it resulted in increased seed weight, oil and protein contents, and higher shelling percentage (proportion of seed to pod weight). Higher protein and oil contents are associated with better seed quality. The bold seeds obtained in this treatment, as indicated by the highest test weight, i.e. the weight of 100 kernels, resulted in higher pod and kernel yields.

The poor shelling percentages in treatment 3 could be attributed to delayed fruit-set following the moisture stress. Lowest kernel weight and shelling percentage obtained in subtreatment 4C show a response typical of groundnuts which suffered from drought throughout the growing season.

CONCLUSIONS

Data presented in this study show that maximum yields of groundnut and improved quality of seeds could be ensured with limited supplemental irrigations, taking into consideration the growth phases sensitive to drought stress. Drought stress from emergence to peg initiation conferred an advantage in growth since the dry-matter production in this treatment increased over the fully irrigated control subtreatment. Groundnut showed a remarkable tolerance to drought stress from emergence to peg initiation, and benefits from this drought stress when additional irrigations are given in the later growth phases. Drought stress imposed from start of flowering to start of seed growth proved this to be a sensitive phase as it reduced seed yield and quality.

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