BREEDING FOR DROUGHT TOLERANCE ON GROUNDNUT (*ARACHIS HYPOGAEA* L.)

J.H. Williams, R.C. Nageswara Rao and M.H. Vasudeva Rao

ABSTRACT

Current research involves examining the extent of genotypic variation in response to droughts of different kinds and establishing the physiological basis for this variation. The findings of this research can be used to guide screening processes for specific adaptation to droughts likely to occur in rice-based cropping systems.

Early drought may increase yields. This phenomenon may be exploited in pre-rice systems or where a limited amount of irrigation is available.

Genetic variation to improve yields in water deficient situations exists in the crop. Where inadequate water occurs at any or all stages of growth, increased water use, efficiency and tolerance of the reproductive process to drought stress are mechanisms available to increase yield. However, present screening methods are limited to field-based technologies. ICRISAT is using line source methods but, by expressing water applied as a percentage of pan evaporation, it is possible to utilize a two-treatment (non-stress/stress) comparison since the response between different levels of stress is usually linear. A droughted and irrigated treatment is important because yield potential is highly correlated with drought sensitivity particularly for mid season droughts.

Because yield potential is highly correlated with sensitivity to end of season droughts, and the amount of water available in post-rice systems is fairly reliable at a given site, the mechanisms of escape should be exploited for these circumstances. ICRISAT has available lines that have yields of ± t/ha^{-1} after setting characteristics and early yield achievement.

ICRISAT has shown that gypsum may increase yields in droughts in some genotypes, and this opportunity should be exploited when possible.

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INTRODUCTION

In dealing with the possibilities of breeding for improved yields in drought circumstances, it is important at the outset to establish the basic physical and physiological boundaries that determine the opportunities for, and limitations to, progress. Many people assure that when groundnuts are grown after rice, they exploit residual moisture. But the crop has attributes that suit it to other opportunities within the wide spectrum of rice-based farming environments.

Four main opportunities may be defined for growing groundnuts in rice-based farming systems.

1. After rice, without any additional water from sources such as irrigation, rainfall, or a high water table.
2. After rice, when the soil water is augmented by rain or limited irrigation.
3. Before rice, when soil water devices from initial monsoon showers or from irrigation.
4. After rice, but with a high water table.

In all four situations, drought can be expected to play some role in the determination of yield, and the selection of appropriate genotypes will contribute to improved yield.

Drought occurs when the root system is unable to satisfy the demands of the aerial part of the plant for water. The basic determinants of the supply of water are the dimensions and distribution of the root system, the amount of water in the soil, the release pattern of this water, where it is relative to the roots, and the amount of replenishment likely to occur. The basic determinants of the demand for water are the leaf area and its arrangement, the stomatal resistance/conductance, the energy balance of the canopy, and the vapor pressure deficit.

WATER SUPPLY

The root system is the plant part that is responsible for securing water. Groundnuts may have deeper roots than mung beans and cowpeas, and there is evidence to suggest that this rooting depth provides an advantage (Pandey etl al., 1984). Rooting depth is of considerable importance since this defines the water reservoir available for growth. Rooting depth may also be increased if the only water available is at depth. The maximum depth of groundnut roots recorded vary with site and soil, from more than 2.5 m in Florida sands (Boote et al., 1982) to only 1.2 m in an Alfisol in India (Gregory and Reddy, 1982). We have also been able to show that genotypes differ in the speed at which the roots extend down the soil profile (Fig. 1).

However, root distribution in the profile also varies and has important effects on the patterns of drought development in the crop. Root density in the upper horizons (30 cm) is substantial (up to 800 g m^{-3}) but, below this rooting, densities are considerably less(± 25% of the upper horizon). This distribution pattern seems to be an important contributor to the drought tolerance of this crop. The water in the top horizon is freely available and is utilized rapidly at a rate determined largely by the leaf area index and the evaporation potential. Unless replehished, is soon exhausted. However, the water below this horizon is utilized only at a much slower rate (at 50% or less of the potential evapotranspiration rate ICRISAT and University of Nottingham unpublished data). It is not absolutely clear why this 'deep' water is used at a slower rate; but the consequence is to spread the available water over a longer period than for crops such as sorghum (Azam Ali et al., unpublished data).

The slower use of the available reservoir enables the crop to withstand long periods without rainfall. The slow uptake of the soil water from depth may also maximize water use efficiency in droughted crops since the water use efficiency of groundnut seems to be maximized at -1.0 to -1.2 Mpa. (D. Harris, unpublished data). The slow release of water and the resulting lower plant water potentials also have a large impact on the canopy development, since leaf expansion is very sensitive to water balance.

The absolute amount of water available for the crop to use is of considerable importance since this (within bounds) determines the total dry matter that can be achieved and, therefore, the yield that is achievable. There is mounting evidence however, that there are differences in the water use efficiency of groundnut genotypes. We have at ICRISAT shown a 30% difference in the amount of dry matter accumulated for a given amount of water transpired (Fig. 2).

WATER DEMAND

The crop's demand for water is determined primarily by leaf area and atmospheric conditions. Azam Ali (1984 and unpublished data) found that 90% of the variation in the water used by groundnut crops at a given site was accounted for by variation in the leaf area. However, the leaf area development is also very sensitive to the balance of water supply and demand so that, in the face of restricted water availability during canopy development, the canopy develops only very slowly. It thereby ensures that the crop is less likely to experience devastating water deficits. This attribute, combined with very rapid recovery from drought stress, contributes to the crops merits in drought conditions, particularly in mid-season droughts.

The other factors that account for the variations in demand for water are physical environmental factors. Although these are important in the equation, they have only little scope for manipulation. The vapor pressure deficit (VPD) influences the relative gas exchange rates (H_2O and CO_2), with more photosynthesis per unit water transpired being possible where the deficit is low, and less where the VPD is large.

FRUIT INITIATION

As with many crops the initiation of fruit is sensitive to drought. However, because of their indeterminate growth habit, groundnuts have a remarkable resilience to drought. The indeterminate nature of the reproductive establishment process, the large variation in pattern of initiation of pods (Williams et al., 1975) and the substantial ability to improved reproductive growth in response to a later improvement in environment (Williams, 1979) provides the crop scientist with much scope to match genotype with drought patterns dictated by the cropping system and environment. When early drought stress occurs and is released, large differences in the fruit initation of genotypes have been observed, as shown in Figure 3. During the period of early drought, TMV-2 initiated more pods than the other lines. However when the stress was released TMV-2 initiated least new pods while Robut 33-1 initiated most. Clearly these variations, in response to drought, provide opportunities to select genotypes for probable stress patterns in target environments. Where the crop is being grown solely on residual moisture, early and rapid pod initiation is needed to escape the drought. However, where the drought is likely to be released by irrigation or rain, it may be more advantageous to select lines with the ability to establish a large fruit load after the drought.

In groundnuts the reproductive process is perhaps more sensitive to drought than many people recognize. The gynophores (pegs) have to grow down and penetrate the soil surface and, since the soil surface is the first horizon to became dry, the pegs may have trouble penetrating it. This may be the major drought stress problem associated with growing groundnuts where a high water table exists. Even for those pods initiated from nodes below the soil surface, and for those pegs that penetrate before it becomes too hard, the fact that the soil surface does become dry first may create problems particularly relating to calcium availability.

If the fruit are supplied with inadequate amounts of calcium, pegs may fail to develop into pods and/or, within the pods, the embryos may die. Calcium taken up by the roots is not available for fruit initiation and growth; this element is normally absorbed directly from the soil. This process is limited if the soil in the pod zone is dry. At ICRISAT we have examined this effect and found some genotypes for which application of gypsum to increase the pod zone calcium content increases yield in drought while others do not respond (Fig. 4).

DROUGHT RESISTANCE AND YIELD POTENTIAL

In our investigations of the drought responses of groundnut cultivars we have found that yield potential is negatively correlated with drought sensitivity in certain drought patterns. We have investigated these effects by subjecting 22 genotypes of similar maturity to 96 different irrigation treatments which varied the duration, timing, and intensity of drought.

When drought occurs early (vegetative early flowering) the yield potential of the genotypes was poorly correlated with the effect of water deficit on the yield achieved (the sensitivity to drought). When drought occurs late in the crop's life, the relationships between yield potential and drought sensitivity may account for up to 95% of the sensitivity to drought (Fig. 5A). However, early drought may even increase yield, as indicated by the positive sensitivity (Fig. 5B) in some genotypes.

This same phenomenon can be expressed differently by applying a stability analysis (Finlay and Wilkinson, 1963) to these cultivars over the 96 drought environments (Fig. 6). The line EC 76446 with a positive intercept (300 kg ha^{-1}) had above-average yields in the driest environments but a below-average response to increasing mean yield ($b = 0.67$). Other lines had lower intercepts but responded more readily to the improvement in irrigation environments. The most responsive genotype had an average intercept ($a = 0.03$) but an above-average slope ($b = 1.23$).

DROUGHT ESCAPE

We have described some of the factors that influence yields achieved by groundnuts in drought. However, the breeder has at his disposal another strategy that could result in higher yields - escaping the drought. The options for escaping drought depend very largely on when it is likely to occur.

The most common droughts are at the end of the season, when the available moisture is depleted before the crop is mature. Other patterns will occur within the pre-rice and partially-irrigated crops.

However, 'escaping' a deteriorating (residual) moisture supply justifies emphasis. If the crop is being grown on residual moisture, the sooner it initiates reproductive growth and has 'established' pods the better, because the drying of the soil surface represents such a formidable challenge to the crop. The earlier the reproductive initiation the less likely this factor is to limit pod initiation and sink development.

Since the crop has effective mechanisms to 'spread' the available water over a long period of time, it is probable that the most important 'factor' to assure productive use of the water is to establish the fruit 'sink' rapidly. Considerable variation exists for this (Fig. 7). However, set against the benefits possible from early flowering and pod setting, one has to recognize the need to exploit the soil moisture resource to the full to maximize yield. The total growth period needs to coincide approximately with the time of soil water exhaustion. The processes that subsequently adjust this fruit load to the photosynthetic source are then important to ensure that the pods produced are of salable quality.

Work at ICRISAT has concentrated on breeding for earliness since this provides this 'escape' mechanism. We have now selected lines that in our environment are achieving 'maturity' at about 75 days after sowing while the average fastigiata types take ± 100 days to achieve their peak yield (Fig. 8).

BREEDING FOR HIGHER YIELDS IN DROUGHTS

We have listed some of the resources and options that the breeder has at his disposal when working to deminish the effects of drought. The remaining problem left to describe is how he should identify the material likely to fit into his projected cropping system.

Although we are able to show that there is genetic variation in rooting depth, water extraction, and water use efficiency, we have as yet no methods for screening the large numbers that a breeder has to work with. The methods that we have used to date are slight modifications of the traditional approach to breeding - that of selection for yield.

We have used the line-source irrigation system (Hanks et al., 1976) and the rain-free postmonsoon season to create droughts at different times. By managing the occurrence of deficit irrigation we are able to simmulate the patterns of drought in our target environments.

However, it is not essential to use the line source system, particularly as it is a relatively expensive technique. Since most of the pod yield responses to drought (change in grain yield) are linear between the nonstressed situation and the most droughted situation it is necessary only, to establish the nonstressed yield of a line by providing irrigation to half of the plots and allowing drought to take its natural course in the nonirrigated plots. This approach is particularly suited to selecting lines for growing in residual moisture, after rice.

Detecting earliness is also a task for which we do not have any short cuts. Currently this is being done by serial harvesting to identify when yields are first maximized. However, the escape mechanism is likely to be so important in the post-rice crops that selection for yield of mature kernels in these conditions should also identify the earlier lines.

Although these methods are perhaps unsophisticated, they are able to identify material that has an advantage in specific conditions and have the major merit in being usable by many breeders in national research programs.

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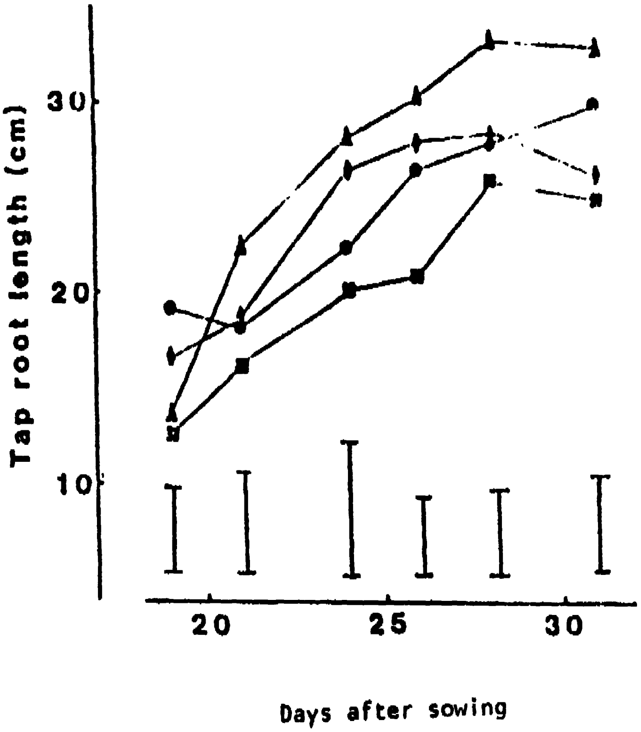


Fig. 1 : Early root extension for four genotypes grown at ICRISAT.

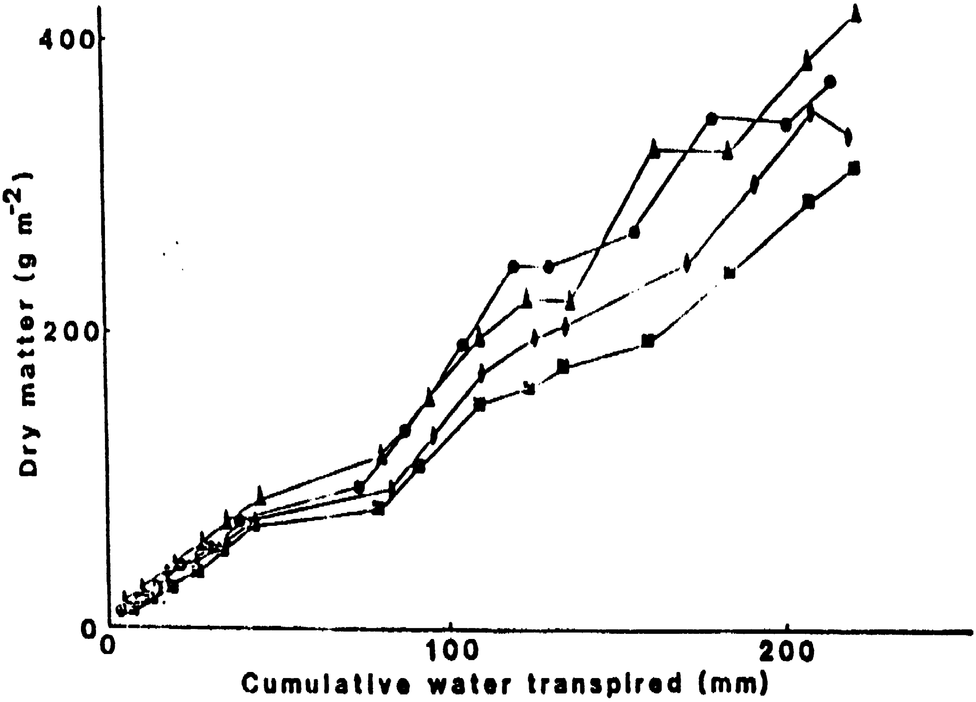
(▲ Robut 33-1; ● TMV2; ♦ NCAc 17090;

■ EC 76446(292).

Fig. 2 : The accumulation of dry matter and the associated water use by four genotypes of groundnut. Slopes of regression of dry matter on water transpired are significantly different at P 0.05.

(▲ Robut 33-1; ● TMV2;

♦ NCAc 17090; ■ EC 76446(292)



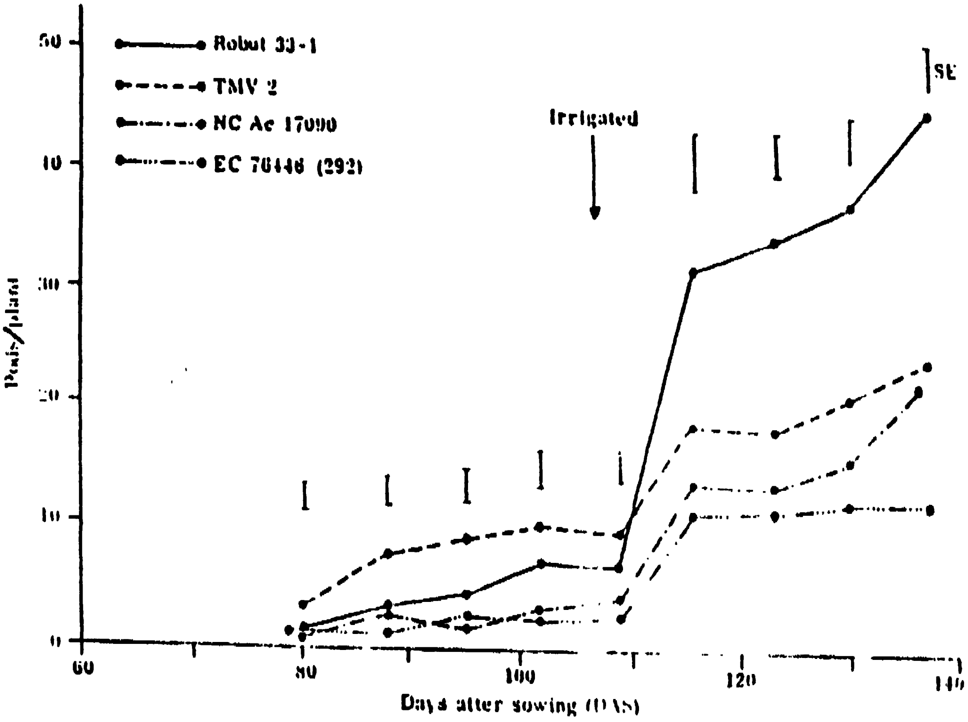


Fig. 3 : Pods developed with time by four groundnut cultivars during drought stress (80-108 DAS) and after irrigation. ICRISAT Center, postrainy season 1982/83.

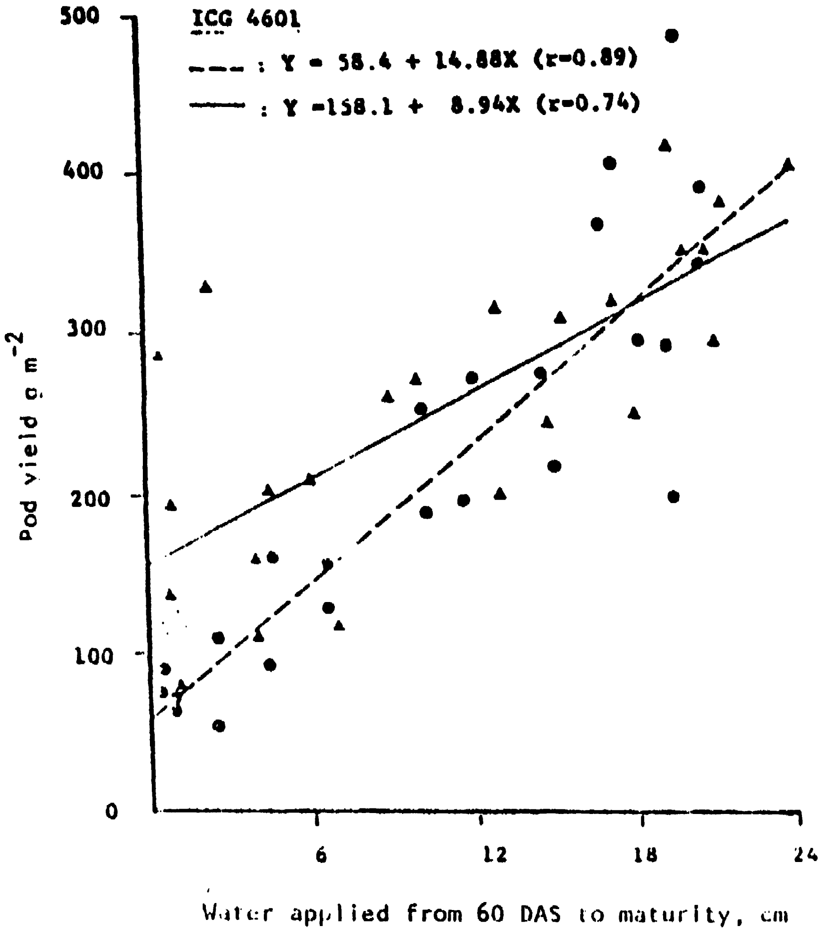


Fig. 4 : The interaction of drought over grain filling with gypsum applied at flowering.

(● 0 kg ha^{-1}; ▲ 500 kg ha^{-1} for the genotype ICG 4601).

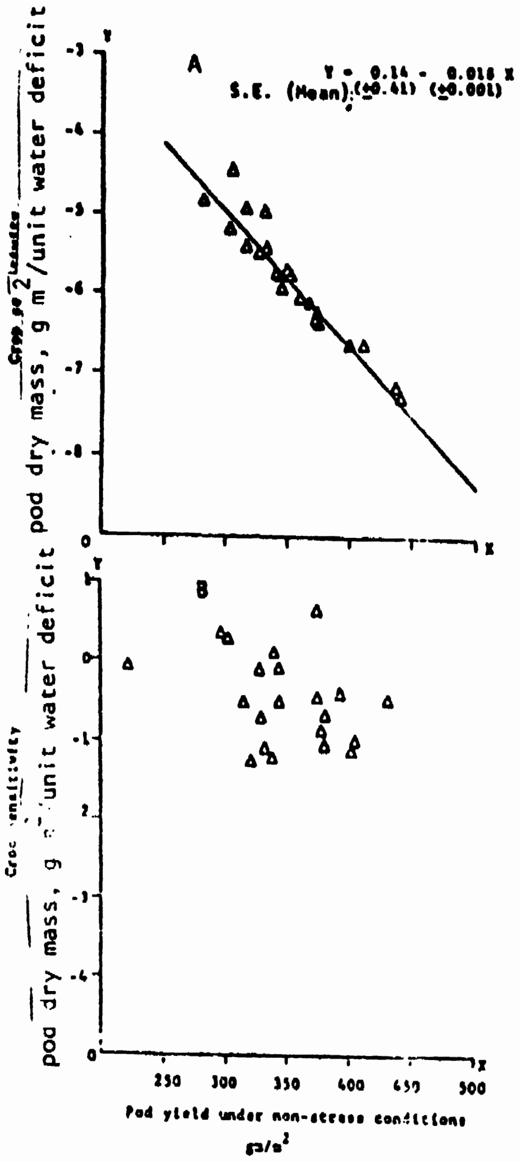


Fig. 5 : The relationship between yield potential and sensitivity to long-duration end season drought (A) and early drought (B) from 22 genotypes.

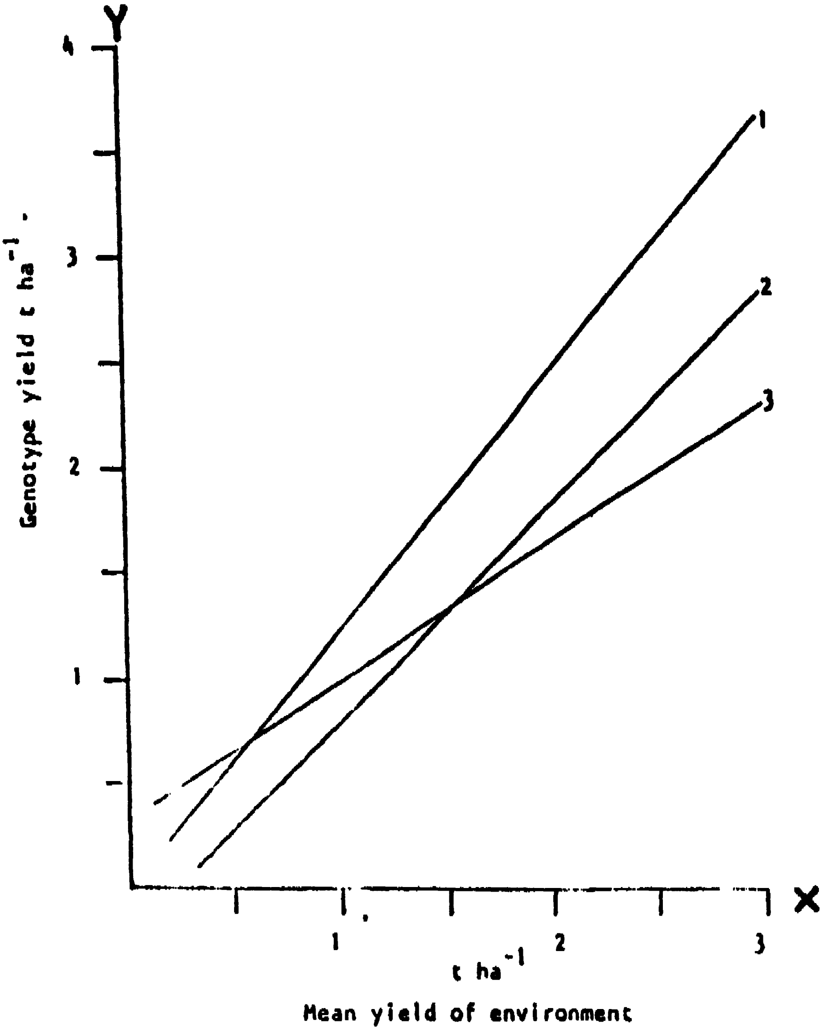


Fig. 6 : Stability analysis for three genotypes selected from 22 grown in 96 drought stress environments.

1. ICGS 36 $Y = 0.03 + 1.23 \times t\ ha^{-1}$
2. KRAP. St 16 $Y = -0.234 + 1.03 \times t\ ha^{-1}$
3. EC 76446 $Y = 0.324 + 0.67 \times t\ ha^{-1}$

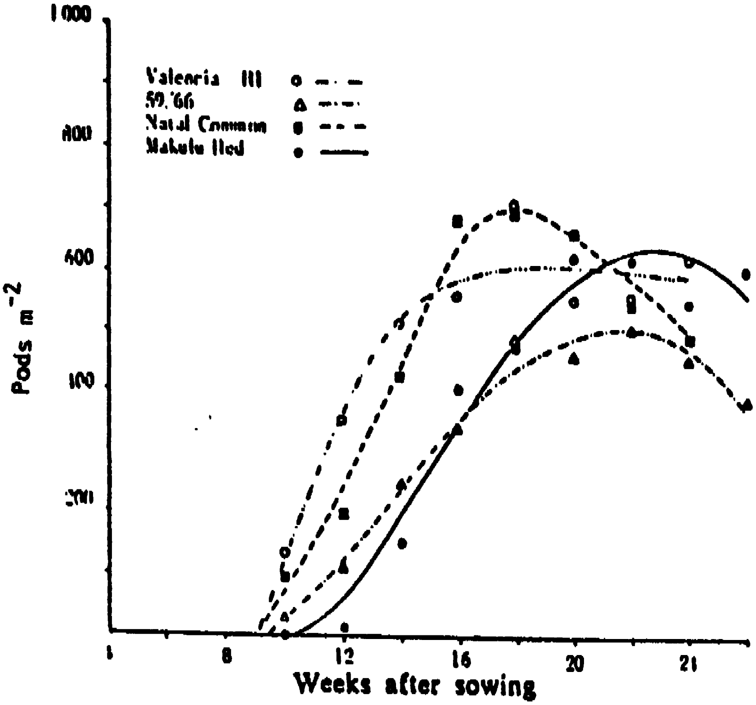


Fig. 7 : Changes with time in the pod number of four groundnut cultivars grown at Salisbury Research Station.

(Williams et al., 1975.)

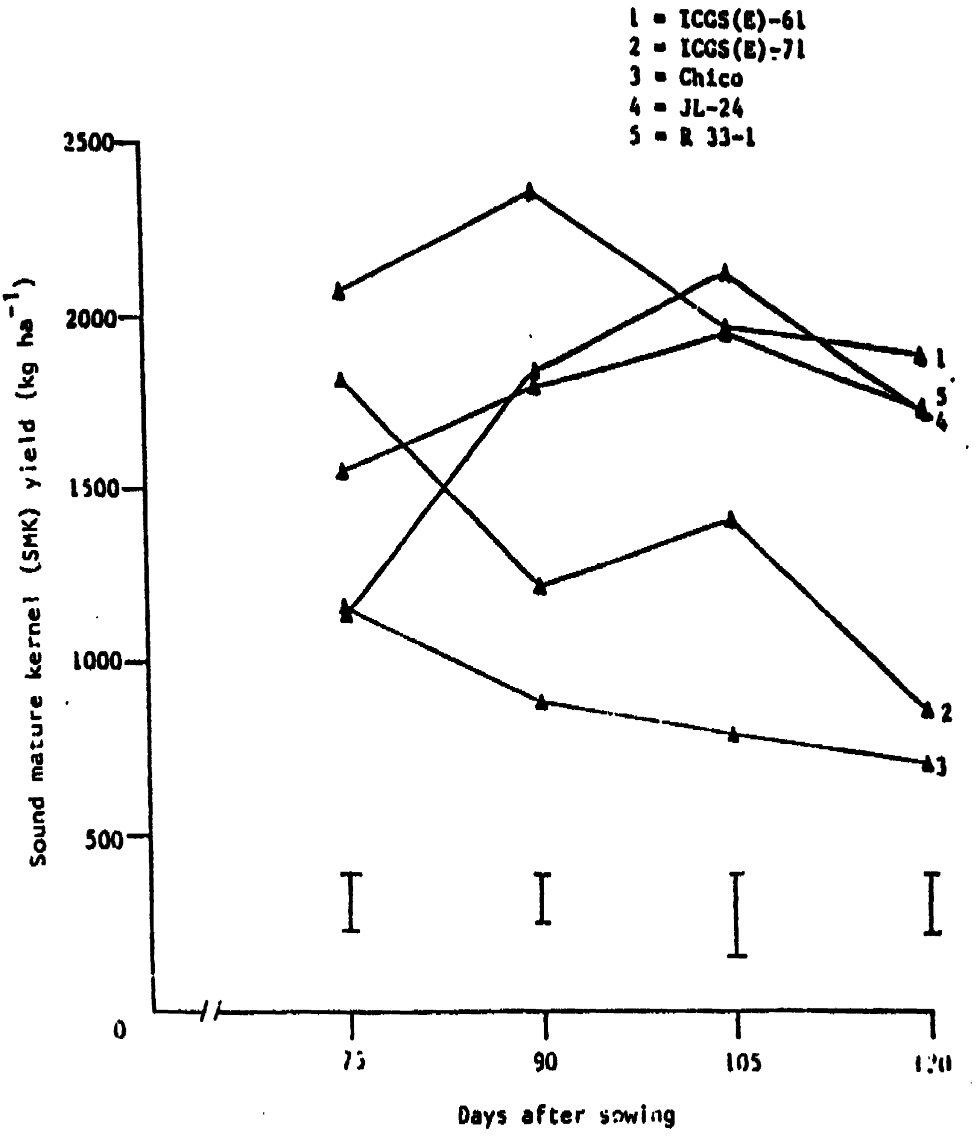


Fig. 8 : Performance of two breeding and three check lines in staggered harvesting at ICRISAT Center, rainy season 1984, under high-input conditions.