Drought Effects on Growth and *Aspergillus* Infestation of Groundnut Cultivars in West Africa[1]

D.C. Greenberg[2], J.H. Williams[3], F. Waliyar[4], and B.J. Ndunguru[5]

Abstract

*Groundnut (*Arachis hypogaea *L.) genotypes from SADCC/ICRISAT Groundnut Project (Malawi), ICRISAT Center (India), and West Africa were evaluated for growth rates, partitioning to reproductive components, and susceptibility to* Aspergillus *spp in five stress environments. Poor partitioning observed in genotypes from the SADCC region may be indicative of greater susceptibility to stress during the reproductive stage than lines with proven drought resistance. Most SADCC lines were also found to be more susceptible to seed infection by* Aspergillus flavus *and* A. niger *than the established West African cultivars.*

Sumário

Efeito da Seca no Crescimento e na Infecção com *Aspergillus* de Cultivares de Amendoim na África Ocidental. *Genótipos de amendoim (*Arachis hypogaea *L.) do Projecto de Amendoim da SADCC/ICRISAT (Maláwi), ICRISAT-Centro (India) e da África Ocidental, foram avaliados em cinco ambientes de stress no respeitante às suas taxas de crescimento, partição para os componentes reprodutivos e pela susceptibilidade ao* Aspergillus *sp. A pobre partição dos genótipos provenientes da região da SADCC, pode ser indicador duma maior susceptibilidade ao stress, durante o estádio reprodutivo, em relação a linhas de comprovada resistência à seca. Foi ainda determinado que a maioria das linhas da SADCC são mais susceptíveis à infecção da semente com* Aspergillus flavus *e* A. niger, *do que os cultivares da África Ocidental já estabelecidos.*

Introduction

Drought is a common problem facing dryland farmers of the semi-arid tropics. Droughts are complex situations and crops may experience various combinations of drought stress, heat stress, and nutrient stress and may become more susceptible to damage by diseases or pests. Drought is commonly associated with low atmospheric humidity, which can in its own right reduce the proportion of flowers that

1. Paper was presented by Dr B.J. Ndunguru.
2. Principal Groundnut Breeder, ICRISAT Sahelian Center, B.P. 12404, Niamey, Niger (via Paris).
3. Principal Physiologist at the above address.
4. Principal Groundnut Pathologist at the above address.
5. Principal Groundnut Agronomist and Team Leader at the above address.

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form pods in groundnuts (*Arachis hypogaea* L.) (Lee et al. 1972). The development of genotypes that are more productive under drought-stress conditions is an important objective of the ICRISAT groundnut improvement programs.

Research on the effects of drought may be facilitated by the use of many useful statistical and process-based models to analyze yields achieved by crops. Firstly, breeders commonly use the stability analysis methods proposed by Finlay and Wilkinson (1963) and modified by Eberhart and Russell (1966) to assist in selection of genotypes with stability of yield over a range of environments. These methods have gained widespread acceptance and are used in this paper without detailed discussion of the methodology.

Secondly, for indeterminate crops, Duncan et al. (1978) proposed that yield differences could be analyzed against the model:

$$Y = C \times d \times p$$

where Y is the yield, C is the mean crop growth rate, d is the duration of reproductive growth, and p is the mean fraction of crop growth partitioned towards the reproductive sink. This approach has the advantage of separating the determination of yield into distinct independent processes and allowing an understanding of the various attributes of genotypes. To date, there have been many analyses of the yields of various crops exploiting the Duncan et al. 1978 model. These analyses have been restricted to few treatments because of the perceived need to undertake growth analysis to determine the C and p components of the model and have not been applicable for the selection of genotypes. However, J.H. Williams and V.M. Ramraj (ICRISAT Center, India, personal communication, 1989) have shown that final vegetative and reproductive yield data combined with limited phenological observations (times from sowing to flowering and harvest) can provide good estimates of the C and p determinants of yield without the need for destructive growth analysis. This approach, when applied to a large numbers of chickpea (*Cicer arietinum* L.) lines, has been effective in determining the scope for genetic improvement (J.H. Williams and N.P. Saxena, ICRISAT Center, India, personal communication, 1989).

The most commonly perceived effect of droughts is loss of yield. But, in the case of groundnuts, drought over the period that the crop is approaching maturity (end-season drought) results in increased infection of the pods by *Aspergillus* spp with attendant deterioration in quality (Zambettakis et al. 1981; Mehan et al. 1988).

The SADCC/ICRISAT Groundnut Project in Malawi has not so far been able to screen groundnut material for drought responses in a systematic way, but this has been done for some SADCC lines provided to the West African Groundnut Improvement Program and which have performed well in western Africa. This paper compares the drought responses of these lines to those of the western Africa released cultivars, for the stability of their C, p, and yields in five quantified water-supply environments. It also reports on the relative susceptibility of these lines to *Aspergillus* spp in a situation where a terminal drought stress was imposed at about 50% pod-fill.

Materials and Methods

The results presented in this paper come from two trials grown at the ICRISAT Sahelian Center, Niamey, Niger, in 1989. These trials used 36 groundnut lines of which 4 were from the SADCC/ICRISAT Groundnut Project, 5 from the Niger national program, 2 from national programs in India, and 25 from ICRISAT Center. The first trial was sown on 2 February in the dry season. This trial was a split-plot design with three irrigation treatments replicated three times as the main plots. The quantity of irrigation given was calculated by estimating the potential evapotranspiration (PET) according to the Penman (1948) equation, and multiplying this figure by five. In the three irrigation treatments, the calculated quantity was applied once every 5, 10, or 15 days, giving these treatments 100%, 50%, and 33% of the PET. All treatments were given sufficient irrigation to establish the crop and the different treatments were imposed 3 weeks after sowing. Each main plot was surrounded by 1.5 m of border on all sides and contained two replicates of subplots of 36 groundnut lines arranged in a 6×6 simple lattice design. The subplots comprised three rows, each 1.5 m long, with 0.5 m between rows. For each groundnut genotype, all the three irrigation treatments were harvested when the control treatment was mature to avoid the stress treatments receiving more water than expected by remaining in the field longer.

The second trial was sown on 31 Jul 1989, about a month after the rains had set in, and used 35 of the same 36 groundnut lines as the first trial. This trial was divided in two halves with one half being irrigated through to maturity after the rains ceased (5 Oct

1989) and the other half being subjected to end-season drought. Each half of the trial contained the 36 groundnut genotypes, arranged as a 6 × 6 lattice with four replicates with five-row plots 3-m long with rows 0.5 m apart (7.5 m^2 plot area). The trial was harvested between 25 October and 11 November.

Both trials were regularly observed to determine the date at which 50% of the plants in each plot had commenced flowering. At harvest, the dry mass of haulms, pods, and seeds were measured. The times between sowing, flowering, and maturity were converted to thermal time (°C day) using daily temperature data (recorded at the ICRISAT Sahelian Center meteorological station) in the equation below (Mohamed et al. 1988), which assumes a base temperature for development of 10°C.

$$TT\ (°C\ day) = [(Max + Min)/2] - 10$$

The thermal times for the crops to mature in the two experiments were very similar for most genotypes (the largest difference for any genotype was 15%) but the means of the two experiments differed by only 9%, with the second trial maturing earlier.

Crop growth rate (C) and pod growth rate (PGR) were calculated as the linear rate of increase in t ha^{-1} (°C day)$^{-1}$ over the relevant crop growth periods for each genotype. To determine C, the growth period was measured from sowing to harvest, and to determine the PGR the growth was measured from 50% flowering to harvest. The partition coefficient (p) was calculated as PGR/C, according to the method of Duncan et al. (1978).

For the second experiment, the seeds were examined for infection by *Aspergillus* spp. This was done by plating on filter paper 75 surface-sterilized seeds of each genotype in two replicates of the trial. High humidity was maintained by adding distilled water to the plates to keep the filter paper moist. After 6 days of incubation, the number of seeds colonized by *A. flavus* and *A. niger* were recorded.

Results

The yields and estimated values of C and p for the genotypes in each of the environments showed that in all the five water-supply environments there was considerable diversity, and the environments highlighted different attributes of the genotypes. Because of the differences that existed in time-to-maturity between genotypes, we have grouped the genotypes as early maturing and medium/late maturing for comparison.

Yields

Yields of pod, seed, and haulm in all these environments are shown in Table 1. Significant differences in yield were found between genotypes. Pod yields were the highest in the rainy season control treatment, whereas haulm yields were the highest in the the dry-season control treatment.

Crop growth rate

Growth rates varied threefold between the best and the poorest environment, and among genotypes, but the variation among genotypes within the environments was generally smaller. However, the performances of individual genotypes across environments were usually consistent (as indicated by the high r^2 values in the Finlay and Wilkinson stability analysis) (Table 2).

Early lines. The C of ICGV-SM 83033 (ICGMS 33) was above average (Fig. 1) in all the five environments, while that of ICGV-SM 85045 (ICGMS 68) was below average in all environments, particularly so in the control environment of Experiment 1. The western African released (and drought tolerant) cv 55–437 was average for C in the best environment but tended to be better than average in the treatments that resulted in low C. However, 796, another western African released line, was below average for growth rate. ICGV 86047, which was bred in India, was consistently better than average across each environment.

Medium and late lines. ICGV-SM 83708 (ICGMS 42) and the western Africa cv 28–206 had similar C across the environments (Fig. 2), which was almost double the average of the control treatment but only slightly better than the average of the driest treatment. The other lines, i.e., ICGV-SM 83005 (ICGMS 5), ICGV-SM 85038 (ICGMS 63), and ICGV 87123 were very close to average across the environments, but it should be noted that there was considerable instability reflected in the lower r^2 of their regressions on the mean yields under different environments (Table 2).

Partitioning

In the second experiment, partitioning coefficients were, generally speaking, high (around 0.90) for both

Table 1. Performance of selected genotypes in drought simulation trials, ICRISAT Sahelian Center, Sadoré, Niger, 1989[1].

Genotype	Irrigation treatment [2]										Mean days to harvest
	1	2	3	4	5	1	2	3	4	5	
	Haulm yield (t ha^{-1})					Pod yield (t ha^{-1})					
ICGV 86047	3.11	1.99	1.56	0.92	0.80	1.41	0.58	0.35	1.22	1.07	100
796	2.18	1.36	1.24	0.84	0.57	1.72	0.61	0.38	1.15	0.84	101
55–437	2.00	1.77	1.50	0.73	0.60	1.44	0.61	0.26	0.99	0.86	101
ICGV-SM 83033 (ICGMS 33)	4.19	2.94	1.91	1.26	0.95	0.78	0.33	0.18	1.30	0.99	103
ICGV-SM 85045 (ICGMS 68)	3.13	2.52	1.98	1.10	0.81	1.46	0.51	0.32	1.25	0.88	103
ICGV 87123	2.61	2.16	1.93	1.18	0.69	1.80	0.58	0.29	1.34	0.82	108
ICGV-SM 83005 (ICGMS 5)	3.69	2.72	2.16	1.29	0.64	1.21	0.49	0.13	0.86	0.57	108
ICGV-SM 85038 (ICGMS 63)	3.95	2.85	2.66	0.47	0.55	1.19	0.26	0.09	0.67	0.47	110
28–206	6.20	4.06	3.12	1.22	1.24	1.23	0.39	0.16	1.15	0.66	118
ICGV-SM 83708 (ICGMS 42)	5.57	3.60	2.90	0.78	1.08	1.42	0.34	0.17	0.87	0.88	119
SE	±0.26	±0.26	±0.26	±0.12	±0.11	±0.10	±0.10	±0.10	±0.11	±0.10	± 0.4
Mean (35 cvs)	3.58	2.42	1.79	1.06	0.85	1.24	0.52	0.23	1.10	0.84	108
CV (%)	18	18	18	21	26	28	28	28	19	23	1

1. 6 × 6 lattice with 4–6 replicates, plot size 2.25 m^2 (prerainy season) and 7.5 m^2 (rainy season).
2. Treatment 1 = Irrigated every 5 days; prerainy season.
   Treatment 2 = Irrigated every 10 days; prerainy season.
   Treatment 3 = Irrigated every 15 days; prerainy season.
   Treatment 4 = Irrigated through to maturity; rainy season.
   Treatment 5 = No irrigation at the end of the season; rainy season.
3. Numbers in parentheses are Arcsin transformed values.

Continued.

Table 1. Performance of selected genotypes in drought simulation trials, ICRISAT Sahelian Center, Sadoré, Niger, 1989[1]. *Continued.*

	Irrigation treatment[2]								
	1	2	3	4	5	4	5	4	5
Genotype	Seed yield (t ha^{-1})					*A. flavus* infestation (%)		*A. niger* infestation (%)	
ICGV 86047	0.62	0.21	0.10	0.78	0.78	8(16)3	4(12)	33(35)	26(31)
796	0.58	0.26	0.16	0.72	0.62	4(12)	1(5)	28(30)	10(18)
55–437	0.77	0.26	0.08	0.69	0.58	2(8)	1(5)	41(40)	10(18)
ICGV-SM 83033 (ICGMS 33)	0.19	0.09	0.04	0.84	0.54	21(27)	2(6)	37(36)	23(28)
ICGV-SM 85045 (ICGMS 68)	0.50	0.15	0.08	0.84	0.57	41(40)	9(17)	66(56)	31(33)
ICGV 87123	0.86	0.21	0.13	0.85	0.53	11(20)	3(9)	65(54)	17(25)
ICGV-SM 83005 (ICGMS 5)	0.30	0.10	0.02	0.54	0.37	19(26)	3(7)	63(53)	25(30)
ICGV-SM 85038 (ICGMS 63)	0.45	0.01	0.00	0.41	0.27	5(12)	32(34)	92(74)	48(44)
28–206	0.32	0.09	0.00	0.73	0.43	12(20)	3(10)	45(42)	34(35)
ICGV-SM 83708 (ICGMS 42)	0.53	0.08	0.03	0.55	0.54	57(49)	83(69)	83(66)	81(67)
SE	±0.05	±0.05	±0.05	±0.08	±0.07	(±5)	(±5)	±11(±7)	±11(±7)
Mean (35 cvs)	0.40	0.15	0.06	0.66	0.51	14(19)	9(14)	51(46)	46(33)
CV (%)	40	40	40	24	28	(40)	(40)	(36)	(36)

1. 6 × 6 lattice with 4–6 replicates, plot size 2.25 m^2 (prerainy season) and 7.5 m^2 (rainy season).
2. Treatment 1 = Irrigated every 5 days; prerainy season.
   Treatment 2 = Irrigated every 10 days; prerainy season.
   Treatment 3 = Irrigated every 15 days; prerainy season.
   Treatment 4 = Irrigated through to maturity; rainy season.
   Treatment 5 = No irrigation at the end of the season; rainy season.
3. Numbers in parentheses are Arcsin transformed values.

Table 2. Regression parameters for the relationship of genotype crop growth rate (C) and partition on mean crop growth rate and partitioning, ICRISAT Sahelian Center, Sadoré, Niger, 1989.

	C regression parameters			Partition regression parameters			
Genotype	a	b1	r^2	a	b1	b2	r^2
ICGV-SM 85045 (ICGMS 68)	0.165	0.798	99	0.035	1.018		97
55–437	0.246	0.921	98	−0.462	3.831	−2.375	99
ICGV 86047	0.095	1.011	94	0.171	0.950		99
796	0.011	0.913	94	0.038	0.263	−1.329	99
ICGV-SM 83033 (ICGMS33)	0.237	0.954	94	0.237	0.599	1.499	99
ICGV-SM 83005 (ICGMS 5)	−0.115	1.055	89	−0.103	1.059		98
ICGV-SM 83708 (ICGMS 42)	−0.395	1.418	80	−0.225	1.248		99
ICGV-SM 85038 (ICGMS 63)	−0.314	1.119	66	−0.256	1.269		97
ICGV 87123	0.095	1.011	94	0.087	1.021		98
28–206	−0.353	1.490	88	−0.242	1.208		96

the water treatments; however, in the first experiment, the mean partitioning showed that there was a steady decline as the treatments became less favorable (Figs. 3 and 4). Partitioning of genotypes across these treatments demonstrated considerable variation, and the responses differed from those observed for C in that some very strongly curvilinear patterns were observed, while the C were usually linearly related to the treatment means. The partition coefficients above 1.0 (Fig. 3) indicate that either the assimilate already formed in the leaves is being translocated to the pods, or that the leaves are being shed before maturity.

Early genotypes. The partitioning response of ICGV-SM 85045 (ICGMS 68) was average and that of ICGV-SM 83033 (ICGMS 33) well below average (Fig. 3), except in the rainy-season experiments when the variability among genotypes was much smaller. In contrast to this, the Sahelian lines (55–437 and 796) were substantially better than average over all the three environments of Experiment 1. ICGV 86047 from ICRISAT Center was consistently better than average over all the environments.

Medium and late genotypes. In all the environments, the ICGMS selections were below average in their partitioning (Fig. 4). The same applies to the western African line 28–206. However, ICGV 87123 from ICRISAT Center was found to be consistently above average across all the environments.

Infection by *Aspergillus flavus* and *Aspergillus niger*

Seed colonization was high in all the genotypes in both irrigated and end-season droughted treatments (Table 1). ICGV-SM 83708 (ICGMS 42) was the most infected by *A. flavus* (49% in the irrigated treatment and 69% in the other treatment). The least infected line was the western African cv 55–437, which is known for its resistance to *A. flavus* (Zambettakis et al. 1981). All the lines tested were susceptible to *A. niger* but the lines from SADCC were infected approximately twice as severely as the western African lines were.

Discussion

Before we consider the C and p of varieties, we should consider the factors that influence these parameters in the test environments created by different irrigation treatments. Where water is in short supply, crop growth rate is the outcome of (a) the crops' ability to take up water and (b) the ratio of water used to carbon assimilated (Passioura 1977). The differences between genotypes and environments reflect the ability of genotypes to initiate enough fruit to utilize the carbon assimilates available. Duncan et al. (1978) showed that groundnut yields in Florida, USA, were associated with changes in p. In our experiments, we

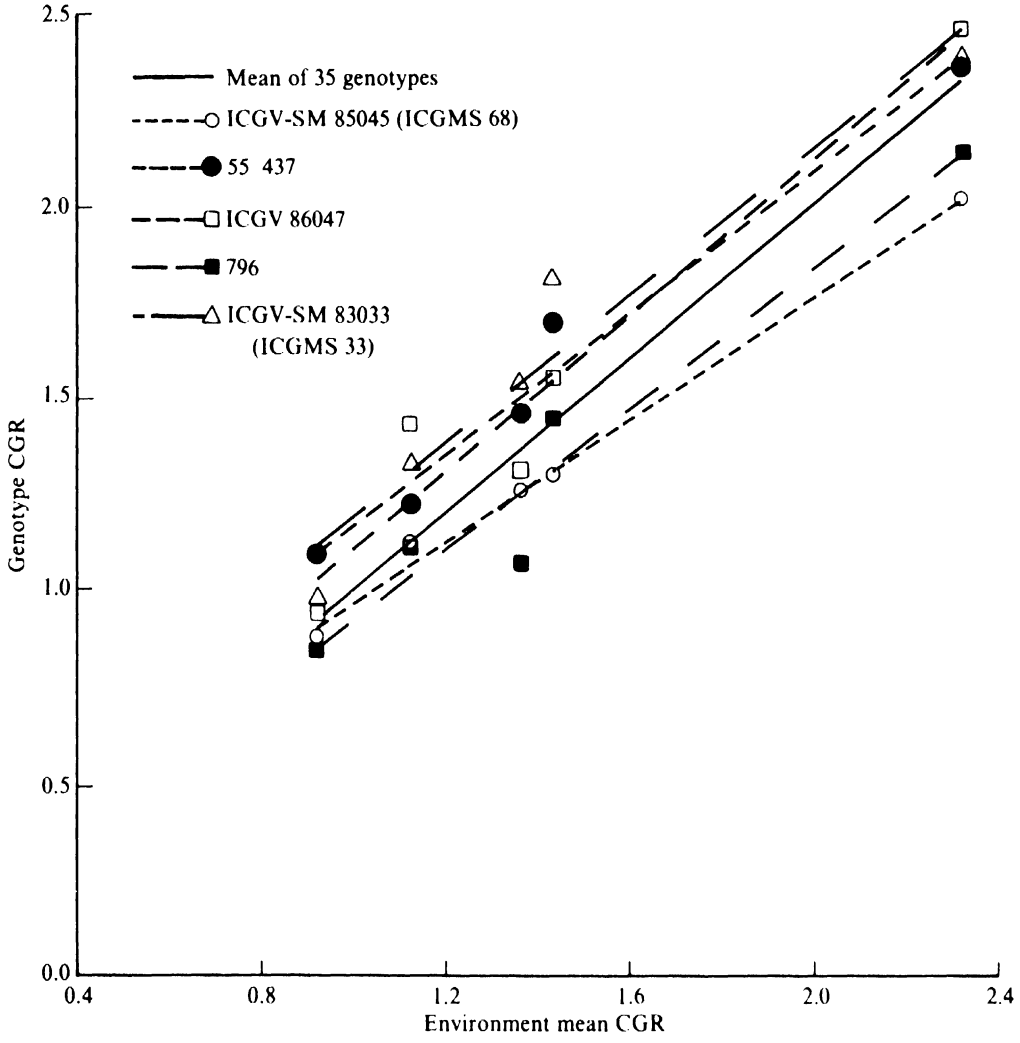

Figure 1. Crop growth rate (CGR) of selected groundnut genotypes over five drought environments, ICRISAT Sahelian Center, Sadoré, Niger, 1989.

exposed the crops to high temperature, low humidity, and inadequate water supply, either throughout the crops' life or only towards the end. Even in the fully irrigated summer crop, the plants were subjected to low humidity and high temperatures. Despite the high crop-growth rates in this environment, the failure in producing enough pods to utilize the available water resulted in lower yields than in the rainy season when the C was lower but p was higher. Temperatures above 33°C have been shown to reduce flower development (Fortanier 1957; de Beer 1963). The tolerance of reproductive processes to high temperatures is certainly a desirable attribute in drought-prone areas, considering the association of drought with higher plant and atmospheric temperatures. The high partitioning observed in both the end-season drought and the control of Experiment 2 is to be expected because of the priority that established pods have for assimilates in the event of assimilate shortage (Williams et al. 1976). In the rainy season control treatment, the

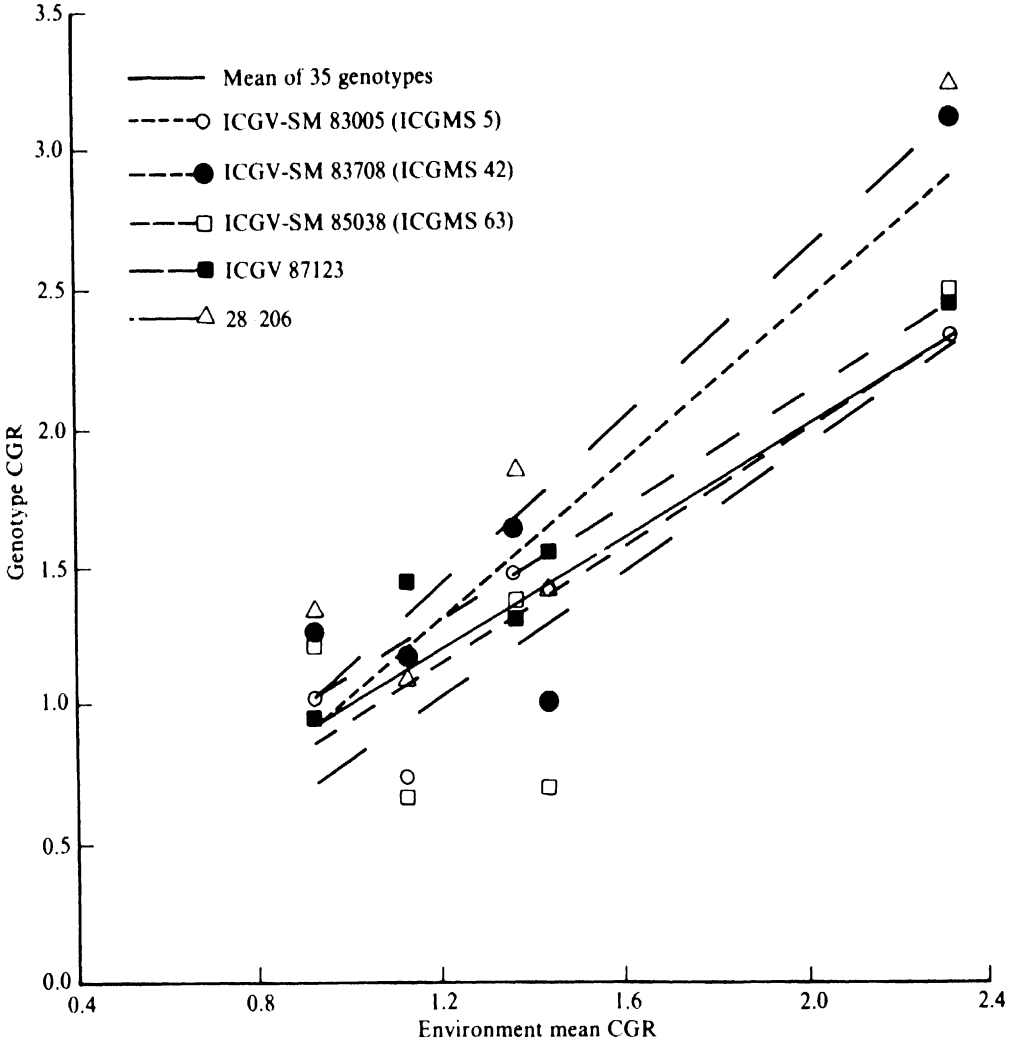

Figure 2. Crop growth rate (CGR) of selected groundnut genotypes over five drought environments, ICRISAT Sahelian Center, Sadoré, Niger, 1989.

high partitioning of the genotypes discussed is consistent with their ability to yield well in nonstressed environments (Duncan et al. 1978).

The varieties compared in this paper provide some interesting insights into the processes that lead to high yields and adaptation to the areas where they originate. Generally, all those genotypes with known drought tolerance (55–437, ICGV 87123, and 796) had C that was close to or slightly above the average in all the environments. Also, they were substantially better in partitioning in Experiment 1, where temperature and drought stress occurred during the reproductive initiation stage. In contrast, cv 28–206, which was released for the more humid zones of western Africa, was lower than average in partitioning and had above-average growth rate. This, we believe, is because the longer vegetative phase and the lower partitioning allowed more root growth, which led to

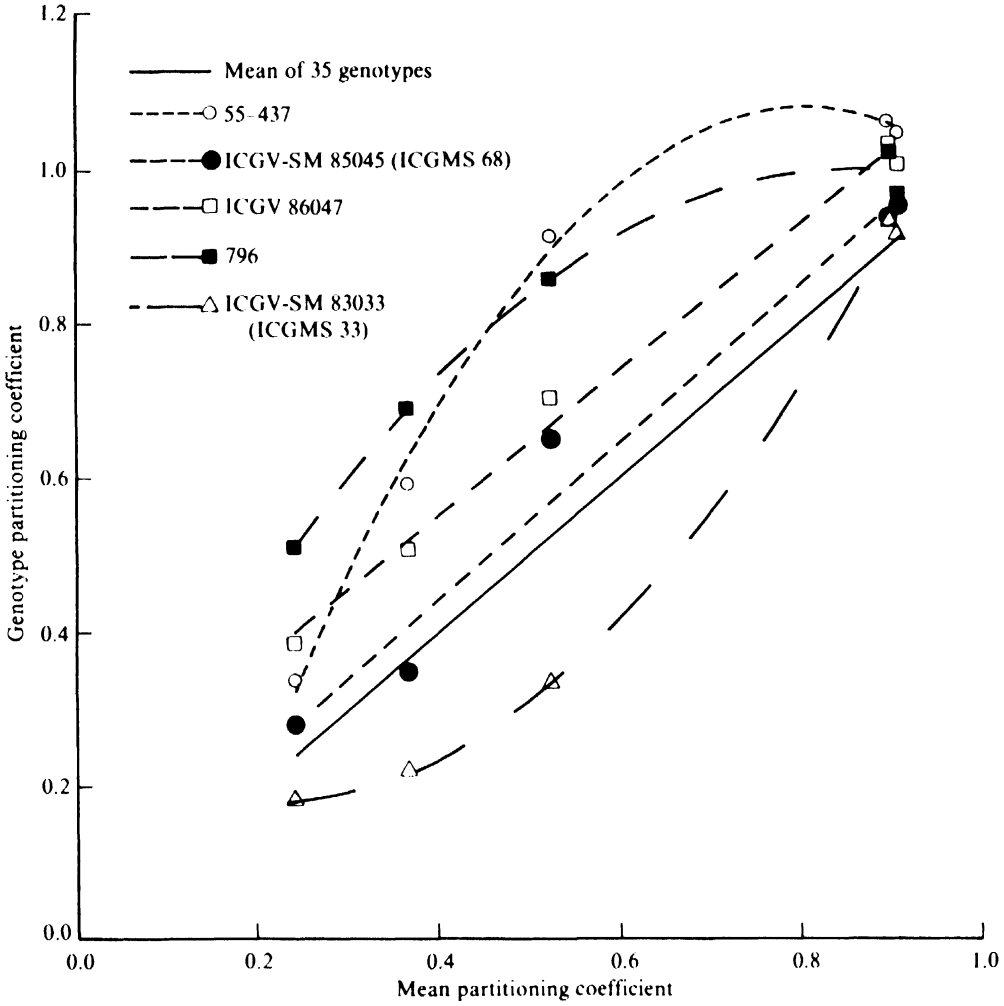

Figure 3. Partitioning of selected groundnut genotypes over five drought environments, ICRISAT Sahelian Center, Sadoré, Niger, 1989.

increased water uptake, resulting in the higher growth rate.

The generally poor partitioning of the SADCC/ICRISAT Groundnut Project (Malawi) lines in the early droughts must be a cause for concern since it indicates that this material is much more vulnerable to these stresses. One could argue that since the SADCC/ICRISAT Groundnut Project lines are proving to be successful in the region, the stresses encountered in western Africa are not common in southern Africa. However, droughts are a serious problem in many areas in the SADCC region. Since, from the evidence of western Africa genotypes, it is possible to have these stress-resistant attributes in lines with good partitioning in nonstressed conditions, we feel that a deliberate effort to introduce stability for partitioning under stress conditions into the breeding and evaluation program would be beneficial. The method that we have employed here is relatively simple and does not require sophisticated equipment.

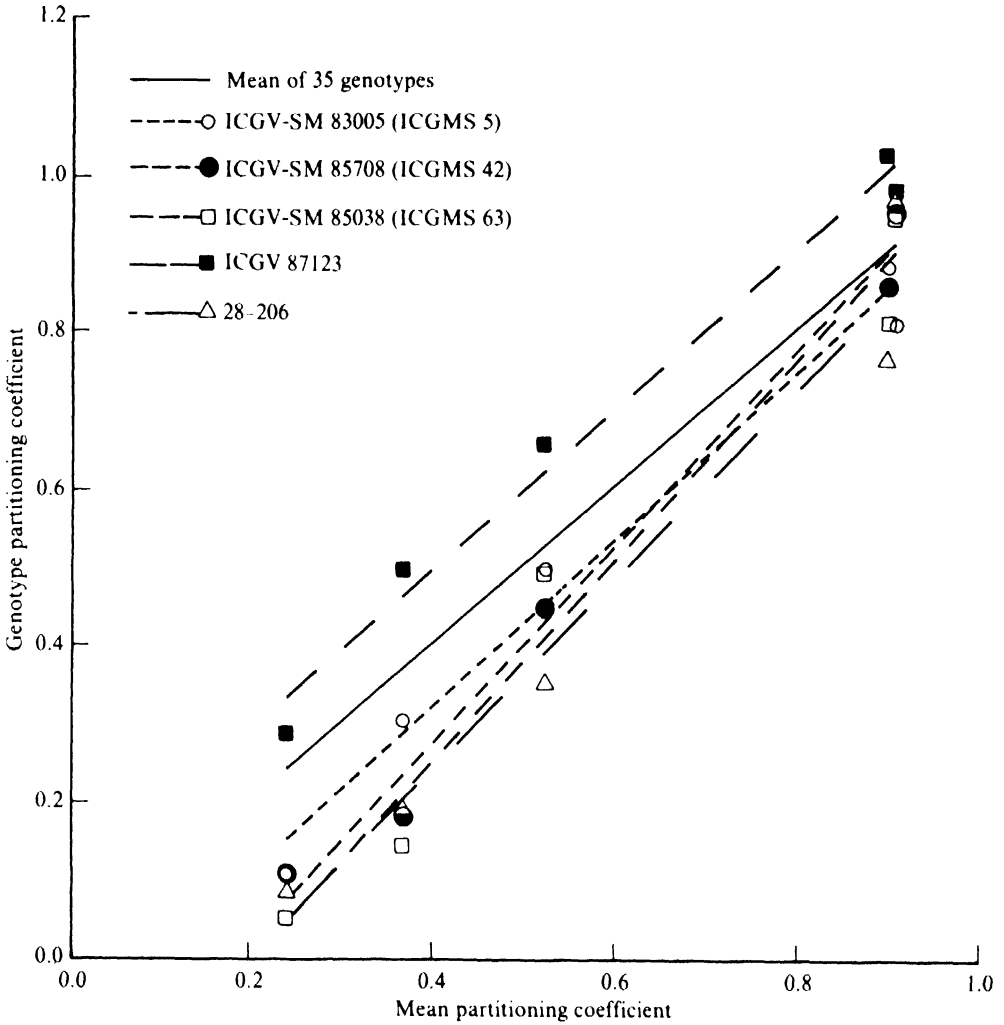

Figure 4. Partitioning of selected groundnut genotypes over five drought environments, ICRISAT Sahelian Center, Sadoré, Niger, 1989.

We feel that analyses, such as we have undertaken, could be a valuable addition to the SADCC/ICRISAT Groundnut Project (Malawi) crop improvement process.

The observed levels of resistance to *A. flavus* show that within the ICGMS lines there is considerable variability in this resistance. Clearly, with increased emphasis on screening, resistant materials could be developed within the SADCC/ICRISAT Groundnut Project. However, while the levels of resistance demonstrated by the western African lines are generally higher than those in the SADCC/ICRISAT Groundnut Project lines, it is possible that these lines are more resistant to the local strains of fungi. Therefore, these results should be confirmed in the region before further action is taken. The same consideration would seem to apply to *A. niger*, which affects seed quality of groundnut, reduces germination, and causes crown rot or seedling disease.

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Discussion

Freire: Do you think that drought screening during the dry/cool season can be used with a good degree of reliability?

Ndunguru: We attempted to screen for drought at ICRISAT Sahelian Center during the cold season without much success. Hence, all our screening for drought is carried out either during the hot season or during the rainy season by sowing date.

Hildebrand: Why did cold-season screening for drought resistance in Niger fail?

Ndunguru: Temperatures were decreasing and these low temperatures may have resulted in evapotranspiration rates that were too low to allow imposition of sufficiently severe drought treatments.

Schmidt: I am impressed by the varietal differences in drought tolerance. The question is, whether there is a complication by differences in vegetative growth or leaf area leading to differences in moisture consumption. This may result in differences between varieties with regard to optimal spacing. Would the differences in drought resistance still exist with each variety sown at its optimal spacing?

Ndunguru: The experiments have been conducted during one season only and the question of optimal spacing has not yet been included.

Mande: How did you determine the quantity of water to be applied in the irrigated treatments and when did you start irrigating?

Ndunguru: The quantity of irrigation given was calculated by estimating the potential evapotranspiration (PET) according to the Penman equation and multiplying this figure by 5. In all the treatments, irrigation started 3 weeks after emergence.