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INTERCROPPING SHORT AND LONG DURATION GROUNDNUT (*ARACHIS HYPOGAEA*) GENOTYPES TO INCREASE PRODUCTIVITY IN ENVIRONMENTS PRONE TO END-OF-SEASON DROUGHTS

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SUMMARY

Three short duration and one long duration groundnut genotypes, grown either 'sole' or as intercrops (in 1:1 ratios of the short duration with the long duration genotypes), were compared in four trials. The intercrop treatments resulted in Land Equivalent Ratios (LERs) of up to 1.25 for pod yield and total biomass despite moderate or severe water deficits at the end of the season. Specific combinations of genotypes were necessary to maximize the LER. The results indicate there is scope for achieving greater productivity in environments with a variable season length by growing late and early genotypes together in an intercrop system.

R. C. Nageswara Rao, K. D. R. Wadia y J. H. Williams: *Cultivo intercalado de genotipos de cacahuete (*Arachis hypogaea*) de corta y larga duración para aumentar la productividad en los entornos propensos a las sequías de fin de temporada.*

RESUMEN

Tres genotipos de cacahuete de corta duración y uno de larga duración, cultivados como monocultivo o como cultivo intercalado (en la proporción de 1:1 del genotipo de corta duración con los de larga duración), fueron comparados en cuatro ensayos. Los tratamientos de cultivo intercalado dieron como resultado coeficientes de tierra de cultivo equivalente (LER) de hasta 1,25 para rendimiento de vaina y biomasa total, a pesar de una falta de agua moderada o severa al final de la campaña. Hicieron falta determinadas combinaciones de genotipos para maximizar el LER. Los resultados indican que hay amplitud para lograr una mayor productividad en los entornos de temporadas de duración variable cultivando juntos genotipos tempranos y tardíos en un sistema de cultivo intercalado.

INTRODUCTION

The yield of groundnuts (*Arachis hypogaea* L.) in well watered crops depends on the crop growth rate (CGR), the partitioning of the assimilate to the fruit, and the duration of the crop. Providing that optimum radiation is intercepted and water is available there are only small genotypic differences in CGR. Thus, for genotypes with similar partitioning the yield potential increases with crop duration (Duncan *et al.*, 1978). However, in the seasonally-dry tropics, where 67% of the global production of groundnuts occurs, the time during which

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water is available for crop growth varies from season to season, imposing a variable limit to the duration of crop growth. When a long rainy season occurs the greater yield potential of the long duration genotypes can be achieved, but the resources of time and water are not fully utilized by the short duration genotypes. In years when the season ends early, the yield potential of the long season genotypes is not achieved but the earlier maturing genotypes yield more by escaping the end-of-season drought. It is clear that the farmer faces a dilemma - early maturing genotypes are more likely to mature and achieve their full yield potential, but because of their shorter duration this is less than the yield potential of late maturing types.

Research at ICRISAT has shown that sensitivity to drought during pod filling is closely associated with the yield potential of a genotype in well watered environments. Thus there seems to be little scope for selecting genotypes with both high yield potential (complete partitioning to pods) and 'resistance' to this pattern of drought (Nageswara Rao *et al.*, 1988). Other management practices are therefore needed to maximize yields in these variable environments.

Intercropping is popular in rainfed agriculture because intercrops may maximize the utilization of resources (Rao and Willey, 1980; Reddy and Willey, 1981). In general, the advantage of an intercrop depends on one crop exploiting a resource that the other is not exploiting fully. Thus advantages may derive from either absolute, temporal, or spacial differences in resource demand. Intercropping most commonly attempts to maximize the differences in resource requirements of two crop species.

Groundnut cultivars vary significantly in growth duration, canopy structure, shoot and root growth (Ketring *et al.*, 1982), and in their response to adverse situations (Gibbons *et al.*, 1972). This diversity offers the possibility of using groundnut genotypes with variable phenology and duration to maximize use of available environmental resources in much the same way as intercrops of different species. Synergistic interactions have been demonstrated for mixtures of Spanish and Virginia groundnut types with a prostrate habit (Beg *et al.*, 1975). Rattunde *et al.* (1988) have shown the same effect using alternating rows of genotypes with differing maturities.

Growing early and late maturing genotypes separately could spread the risk of end-of-season drought, but growing alternate rows of these types may provide the resource-based benefits of intercropping. Removal of the early genotype may increase the water resource for the longer duration genotype in drought years. In years with long rainy seasons the longer duration genotypes may also be able to exploit some of the light previously being intercepted by the early genotype. Williams (1979) found positive yield responses to the removal of adjacent rows until very shortly before harvest in well watered conditions.

This study examines the scope for improving groundnut production in environments characterized by variable season length by using the intercropping strategy in conditions of simulated drought and of limited and erratic rainfall.

MATERIALS AND METHODS

One trial was conducted at ICRISAT (17° 32′ N, 78° 16′ E) and three at the Dry Farming Research Station at Anantapur (14° 41′ N, 77° 37′ E). Plots consisted of 8 rows for the sole crop, or 16 rows of alternating early and late genotypes for the 'intercrop' treatments. The rows were 30 cm apart and seeds were sown at 10 cm intervals within the rows. Seeds were treated with Captan and Thiram (each at 3 g kg^{-1} of seed) to prevent seedling diseases. The crop was further protected against pests and diseases throughout the season using appropriate chemicals. A basal fertilizer application of 100 kg ha^{-1} of diammonium phosphate (18:46:0 N:P_2O_5:K) was incorporated when the fields were cultivated.

Plants were harvested by hand from each plot separately and the pods removed. At ICRISAT the vegetative parts were oven-dried at 80°C for 24 h and weights recorded; at Anantapur the vegetative parts were weighed fresh and sub-samples oven-dried to determine the moisture content of the shoots. Pods were air-dried in the shade for 7 to 10 days then weighed. Final seed moisture content in pod samples from all plots varied between 8 and 9%. The total dry matter (TDM) was adjusted for the high energy content in the pods according to the method of Duncan *et al.* (1978), i.e. vegetative weight + (pod weight × 1.65). The yield response of the intercrop treatment relative to that of the sole crop of each component genotype was computed using the Land Equivalent Ratio (LER) as defined by Mead and Willey (1980).

Experiment 1

This experiment was conducted at the ICRISAT Centre, during the 1985–86 post-rainy season, on an Alfisol (a hyperthermic Rhodustalf) with a water-holding capacity of 100 mm in the 120 cm soil profile. The field was prepared as broad beds 1.2 m wide with 0.3 m wide furrows between them. The seeds were hand sown on 7 December 1985 in rows at right angles to the edge of the bed with 30 cm between rows and 10 cm between seeds within rows. Each cropping treatment plot was 12 m long and eight beds wide: each bed formed a plot for the drought treatments (Fig. 1). Cropping system treatments were arranged in a randomized block design, replicated three times.

One long duration genotype, Kadiri 71-1 (subsp. *hypogaea* var. *hypogaea*), and three short duration genotypes (subsp. *fastigiata* var. *hirsuta*) were either grown as sole crops, or intercropped with long and short duration genotypes in alternate rows.

The mean air temperature and evaporation rate steadily increased as the season progressed (Table 1). All treatments received uniform sprinkler irrigation applications of about 50 mm at 10-day intervals until the end of February and at weekly intervals from March onwards as evaporative demands increased. The uniform irrigation continued until 92 days after sowing (DAS), when the drought treatments commenced. The intermittent rains in January and February

Table 1. *Summary of weather data during the 1985–86 post-rainy season, ICRISAT Centre*

	Temperature (°C)		RH at 14.00 h (%)	Wind (km h^{-1})	Rainfall (mm)	Evaporation (mm)
	Max.	Min.				
December	28.6	13.3	34.6	7.2	8.1	152.4
January	27.0	13.4	38.5	8.5	53.0	151.5
February	30.3	17.4	37.0	11.3	43.6	184.3
March	35.1	20.1	25.0	10.3	0.0	291.8
April (1–24)	38.4	23.5	23.9	9.7	9.6	249.3

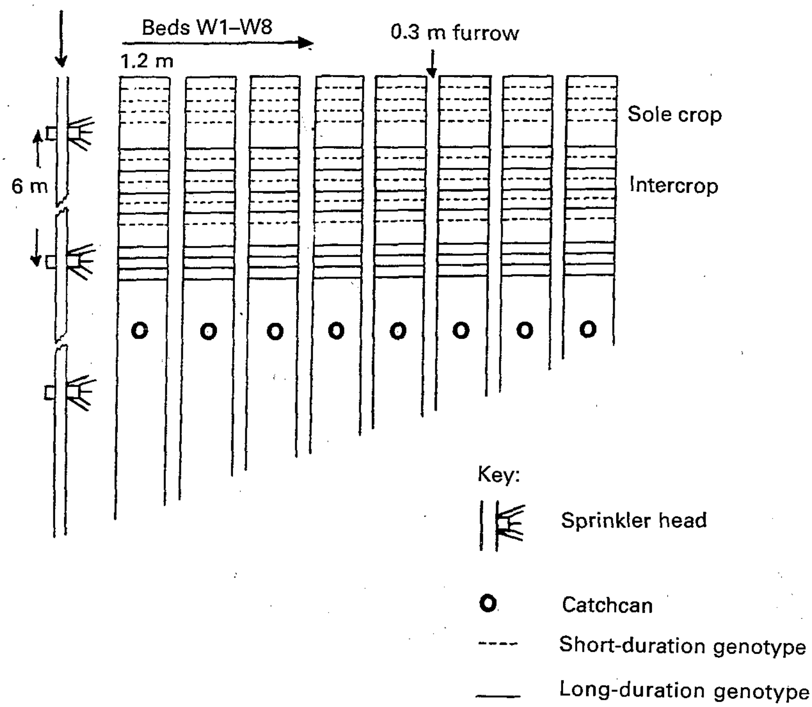

Fig. 1. The line-source sprinkler irrigation system and field arrangement of genotypes, sprinklers and catchcans used to establish a gradient of water deficiency across the experiment unit.

did not affect the experiment since the drought treatments were not imposed until March. Short duration genotypes in both the sole and intercrop treatments were harvested 122 DAS and the long duration genotype at 139 DAS.

Eight levels of drought were created by varying the amount of water applied using the line-source sprinkler technique (Hanks *et al.*, 1976) which produced a linear gradient in irrigation across the eight beds depending upon distance from the sprinkler line (Fig. 1). The amount of water applied at each line-source irrigation was measured by placing catch-cans on each of the eight beds at three locations within each replicate, then taking the average of the three locations and summing over the period of drought (Table 2). Water deficits relative to potential evaporation were calculated using the formula:

Table 2. *Total water applied to long and short duration genotypes and intercrops in the different drought level treatments (W1–W8) during the period of drought at ICRISAT in 1985–86 (Experiment 1)*

	Distance from the sprinkler line (m)	Water applied (cm) to long duration genotypes and intercrops (90–139 DAS)	Water applied (cm) to short duration genotypes (90–122 DAS)
W1	2.25	41.7	22.6
W2	3.75	36.4	19.4
W3	5.25	32.8	16.9
W4	6.75	29.9	14.7
W5	8.25	24.5	11.4
W6	9.75	19.5	7.9
W7	11.25	15.0	4.4
W8	12.75	11.5	1.5

$$\% \text{ Water deficit} = (X_1 - X_2)/X_1 \times 100$$

where X_1 is the cumulative pan evaporation during the treatment period and X_2 the cumulative amount of water applied over the treatment period.

Because of the systematic nature of line source irrigation, each level of irrigation was statistically analysed both as a separate experiment and as a response to irrigation amount using regression techniques.

Experiments 2, 3 and 4

These experiments were sown at Anantapur on 24 July 1985 (Experiment 2), 31 August 1985 (Experiment 3), and 10 August 1986 (Experiment 4) under rainfed conditions on shallow Alfisols with a water holding capacity of 50 mm in the 50 cm soil profile (Huda and Virmani, 1987). Early and late maturing genotypes were harvested as detailed in Table 3.

In both years the mean maximum temperatures were around 32°C; the mean minimum temperature was 22°C in 1985 and 24°C in 1986. In 1985 wind velocity was about 25 km h^{-1} in the first half of the season and reduced steadily to 3 or 4 km h^{-1} by the end of the season; in 1986 the wind speeds were 3–6 km h^{-1} more. In 1985 the total rainfall during the season was 269.6 mm, and Experiments 2 and 3 experienced different patterns of drought: Experiment 2 experienced a severe mid-season drought and a moderate end-of-season drought, while Experiment 3 experienced predominantly an end-of-season drought (Table 3). In 1986 the total rainfall during the growing season was 282.7 mm and water deficits occurred mainly during the last month of crop growth. The daily meteorological data for the 1985 and 1986 rainy seasons were analysed using a simple soil water budget model (Popov, 1984) to characterize the water deficit experienced by the crop on a weekly basis during crop growth.

Because of shortages of seed some short duration genotypes used in Experiment 1 could not be used in all experiments and genotypes with comparable

Table 3. *Crop duration and water deficit over the last four weeks of growth for the rainfed experiments at Anantapur (Experiments 2, 3 and 4)*

	Harvest (DAS)		Water deficit (%) over last four weeks of growth				
	early genotypes	late genotypes	1st	2nd	3rd	4th	Mean
Experiment 2, 1985	111	122	0	67	88	12	42
Experiment 3, 1985	102	115	100	100	100	78	95
Experiment 4, 1986	88	110	36	0	96	100	58

attributes (M. J. V. Rao, personal communication) were substituted (see Table 5).

RESULTS

Experiment 1

Yields were linearly related to the water deficit across the eight irrigation levels. However, to simplify data presentation the yield data are presented for three levels of water stress: the fully irrigated treatment (W1), the 55% water deficit treatment (W5) and the 80% deficit treatment (W8) in Table 4.

In fully irrigated conditions, both pod and haulm yields of the long season Kadiri 71-1 were higher than those of the early genotypes; however, the rela-

Table 4. *Pod and total dry matter yields (t ha^{-1}) achieved by sole crops of short and long duration genotypes and their intercrops in different drought level treatments (W1, W5, W8), Experiment 1*

		Early genotypes		Kadiri 71-1		Total for the intercrop	SE (mean)
		Sole	Intercrop	Sole	Intercrop		
			Pod yield				
W1	ICGV 86056	2.5	1.1	3.0	1.6	2.7	± 0.19
	ICGV 86061	2.0	1.1		1.6	2.7	
	JL 24	2.0	1.1		1.4	2.5	
W5	ICGV 86056	2.3	1.2	1.6	1.0	2.2	± 0.15
	ICGV 86061	2.4	1.2		1.1	2.3	
	JL 24	2.0	1.2		0.9	2.1	
W8	ICGV 86056	1.6	0.9	0.5	0.4	1.3	± 0.08
	ICGV 86061	1.7	0.8		0.3	1.1	
	JL 24	1.2	0.7		0.4	1.1	
			Dry matter yield				
W1	ICGV 86056	6.7	3.0	13.9	6.8	9.8	± 0.71
	ICGV 86061	5.2	2.9		7.4	10.3	
	JL 24	6.7	3.5		6.8	10.3	
W5	ICGV 86056	5.8	3.1	6.4	3.9	7.0	± 0.39
	ICGV 86061	5.8	2.9		4.1	7.0	
	JL 24	6.0	3.3		3.6	6.9	
W8	ICGV 86056	3.6	2.0	3.6	2.1	4.1	± 0.22
	ICGV 86061	3.8	1.8		1.6	3.4	
	JL 24	3.4	2.0		1.9	3.9	

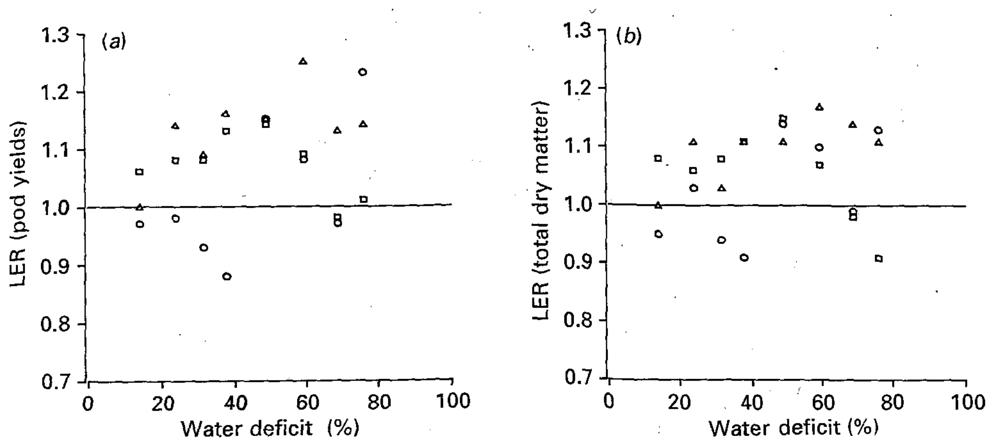

Fig. 2. Land equivalent ratios (LERs) for (a) pod yields and (b) total dry matter for three short- and long-duration groundnut intercrop treatments at different water deficits (Experiment 1); o, ICGV 86056 + Kadiri 71-1; □, ICGV 86061 + Kadiri 71-1; △, JL 24 + Kadiri 71-1.

tively poor harvest index (21%) of Kadiri 71-1 was clearly demonstrated. The intercrops provided a fairly wide range of TDMs depending on the early genotype involved.

At intermediate stress levels, TDM was greater in all the intercrop systems than in the sole crops. However, although pod yields of the early genotypes in the intercrop were greater than those of the sole crop this was offset by the lower pod yield of the long season type, and in absolute terms the pod yields of the intercrop were similar to those of the early maturing genotypes.

In severe water deficits, the TDM of Kadiri 71-1 grown as a sole crop was only slightly greater than that of the earlier maturing genotypes. However, pod yields were severely affected relative to the short duration lines, and much of the growth that did occur was in the haulms. The intercrops had a small advantage in TDM but smaller pod yields than the sole crops of the early genotypes.

The LERs for TDM and pod yield across the full spectrum of water treatments (Fig. 2) show that individual genotypes responded differently to the drought. ICGV 86056 responded more erratically than the other intercrop treatments and only demonstrated benefits from intercropping in the drier half of the spectrum; ICGV 86061 produced peak LERs through the middle range of water deficits; with JL 24, the LER increased progressively as the water deficit increased.

Experiments 2, 3 and 4

Experiment 2 experienced mostly a mid-season drought (a 90% deficit for three weeks) and showed little advantage from the intercropping strategy as the intercropping treatments produced lower pod yields but similar TDM relative to those of sole crops of the short duration genotypes (Table 5): LERs were slightly less than 1 for pod yields but slightly more than 1 for TDM.

Experiments 3 and 4 experienced end-of-season droughts and yields were

Table 5. *Pod and total dry matter yields (t ha^{-1}) of sole crops of short and long duration genotypes and their intercrops under rainfed conditions at Anantapur in 1985 and 1986*

Experiment		Early genotype Sole	Early genotype Intercrop	Kadiri 71-1 Sole	Kadiri 71-1 Intercrop	Total for the intercrop	SE (mean)	LER
				Pod yield				
2	ICGV 86056	1.5	0.7	0.6	0.3	1.0	± 0.04	0.96
	ICGV 86061	1.6	0.7		0.4	1.1		1.01
	TMV 2	1.4	0.6		0.3	0.9		0.93
3	ICGV 86056	0.8	0.2	0.3	0.5	0.7	± 0.06	1.25
	ICGV 86014	0.6	0.2		0.4	0.6		1.23
	JL 24	0.7	0.2		0.4	0.6		1.19
4	ICGV 86056	1.2	0.7	0.9	0.5	1.2	± 0.06	1.14
	ICGV 86061	1.4	0.6		0.5	1.1		1.01
	TMV 2	1.0	0.6		0.6	1.2		1.18
				Total dry matter				
2	ICGV 86056	4.4	2.1	4.0	2.3	4.4	± 0.05	1.05
	ICGV 86061	4.8	2.2		2.6	4.8		1.08
	TMV 2	4.4	1.9		2.4	4.3		1.02
3	ICGV 86056	2.1	1.2	2.3	1.3	2.5	± 0.12	1.15
	ICGV 86014	1.8	1.3		1.0	2.3		1.10
	JL 24	1.9	1.3		1.0	2.3		1.09
4	ICGV 86056	3.4	1.9	3.3	1.7	3.6	± 0.16	1.06
	ICGV 86061	3.8	1.8		1.7	3.5		0.99
	TMV 2	3.3	2.0		1.8	3.8		1.14

very much lower than those observed in Experiment 1, reflecting the small amount of water available to the crops. As with Experiment 1, the benefits of early maturity in this situation were well demonstrated by the sole crops. However, the LERs for pods of most intercrops were between 1.1 and 1.2 except ICGV 86061 which showed no advantage in Experiment 4. The LERs for TDM also showed a small but consistent advantage of about 10% in these experiments.

DISCUSSION

The data from Experiment 1, where end-of-season drought of varying severity was simulated, clearly demonstrate the advantages and disadvantages of genotypes with different durations grown as sole crops under such conditions.

The LERs obtained in Experiments 1, 3 and 4 demonstrate that the option of growing genotypes with different season length requirements as an 'intercrop' is a better solution to variable season length than simply spreading the risk by growing a range of genotypes as sole crops. When the best combination of early and late maturing genotypes were intercropped, pod yields were comparable to those achieved by the sole crop of the early genotype, because of the early genotype's greater contribution, as reported by Rattunde *et al.* (1988), and the benefits of decreased competition with the later maturing component of the intercrop. This result is consistent with the hypothesis of intercropping advantages based on improved resource availability (Willey, 1981), and with the results of a line-source intercropping experiment with two species with differing maturities, millet and groundnut (Natarajan and Willey, 1986).

The experiments also showed a fairly strong interaction between genotypes, indicating the need to determine the best combinations of genotypes, and to improve our understanding of the physiological basis for synergistic interactions that could improve the value of intercropping early and late genotypes in all circumstances.

One obvious avenue for improvement would be to use long season genotypes with a better harvest index than that of Kadiri 71-1, which had a very low harvest index (about 20%) suggesting that a greater proportion of the intercrop advantage for total growth could be in the pod component. Although the intercropping of early and late maturing genotypes resulted in absolute benefits for TDM, the effect was not so apparent for pod yields because of the lower partitioning of Kadiri 71-1. While it is probable that the yield of an intercrop using a long season genotype with greater partitioning to the pods would have been greater than that of a sole crop of the early maturing genotypes, this still needs to be demonstrated.

The fodder production in Experiments 1 and 2 was clearly increased by the combination of genotypes used here. This may be of considerable value to the farmer because the value of fodder in India usually increases dramatically in times of drought (T. S. Walker, personal communication).

In both the simulated and naturally occurring drought conditions we found benefits from the intercrop, although the droughts usually commenced while the early maturing genotypes were still in the ground and depleting the soil water resource, thus leaving less of the limiting water resource for the benefit of the long season genotype. This could be one of the reasons for the generally greater LERs at the middle range of water deficits in Experiment 1. The small amounts of water added by line source irrigation after the early genotype had been harvested would have sustained good water relations for longer in the intercropped than in the completely covered sole crop of Kadiri 71.1. Further research into the factors limiting the exploitation of water by the long season component of the intercrop after the harvest of the early genotype could help optimize the temporal and spatial utilization of this resource.

Some potential problems may be anticipated in an early–late intercrop of groundnuts. For example, the success of this approach depends on the farmer's ability to harvest the early maturing genotype without major disturbance of the long duration crop. Where hand harvesting is practised this should present no problem. The early genotypes may also affect disease incidence. Foliar diseases tend to develop fastest on the early maturing genotypes, thus exposing the long season genotype to greater inoculum loads at an earlier stage of development. Such considerations should influence the selection of genotypes tested for intercropping. Considerable attention also needs to be given to disease control either through the use of chemicals or resistant genotypes.

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