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Cultivar Mixtures: a Means of Exploiting Morpho-Developmental Differences among Cultivated Groundnuts*

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yields would be maximized by using heterogeneous populations that contain several genotypes whose demands for environmental factors differ in space or time, thus encouraging a complementary and fuller exploitation of available environmental resources (Trenbath, 1976; Willey, 1979).

Modest yield advantages of up to 13% have been observed in mixed stands of soybean (*Glycine max* (L.) Merr.; Brim and Schutz, 1968; Fehr and Rodriguez, 1974), barley (*Hordeum vulgare* L.; Clay and Allard, 1969), and oat (*Avena sativa* L.; Frey and Maldonado, 1967; Shorter and Frey, 1979).

Synergistic interactions for fruit yield of groundnuts (*Arachis hypogaea* L.) have been obtained by sowing mixtures of a bunch or intermediate-bunch variety with a prostrate type in alternating hills or rows (Beg et al., 1975). These combinations of genotypes, when sown in blends, however, failed to outyield their components grown as sole crops. Yet, the vast variation for growth patterns among groundnut cultivars may provide opportunities for favorable interactions among genotypes in mixed stands. Groundnut cultivars have growth durations that vary from 80 to 140 days; they vary in branching habit from the erect sequential pattern of the *A.h. fastigiata* subspecies to the alternate, and sometimes prostrate, branching habit of the *A.h. hypogaea* subspecies (Gibbons et al., 1972), and they vary for root length and numbers (Ketring et al., 1982).

Our objectives were to determine (1) whether by sowing groundnut cultivars in mixed stands, synergistic interactions among cultivars could be exploited to increase yield of pods, kernels, or haulms relative to those of the sole crops, and (2) whether certain combinations of growth patterns produce a greater frequency of overcompensatory reactions than do others.

MATERIALS AND METHODS

The names and growth habits of the eight groundnut cultivars used in the 1983–1984 dry season, and the eight used in the 1984 rainy season, are shown in Table 1. In the rainy season, each strain was paired with every other strain to create 28 two-cultivar combinations. In the dry season, 16 two-cultivar combinations were formed by pairing each cultivar with one other cultivar of the same and three of different growth-habit classes.

The experiments in both seasons were sown in split-plot designs, with plant density serving as main plots and the 28 or 16 cultivar combinations as subplots. Three plant densities of 13, 20, and 40 seeds m^{-2} were created in the dry season by spacing rows 75, 50, and 25 cm apart, respectively, and 10 cm between seeds within all rows. In the rainy season, sowing rates of 20 and 40 seeds m^{-2} were created by spacing seeds at 14-cm intervals in rows 35 cm apart and at 10-cm intervals in rows 25 cm apart, respectively.

In the rainy season, each cultivar combination was sown in a 12-row plot. The first three rows of each plot were sown with the two cultivars alternating

TABLE 1

Groundnut genotypes comprising varietal mixtures in the 1983-1984 dry season and the 1984 rainy season, their growth-habit classifications, abbreviations, and the days to harvest

Growth habit	Cultivar	Abbrev.	Harvest DAS[1]
1983-1984 dry season			
Spanish	Chico	C	106
	TMV-2	T	119
Valencia	Gangapuri	G	122
	EC 100827	E	119
Virginia bunch	Robut 33-1	R	125
	S 7-2-13	S	131
Virginia runner	M-13	M	149
	Kadiri 71-1	K	—
1984 rainy season			
Spanish	Chico	C	90
	TMV-2	T	108
Valencia	Gangapuri	G	93
	NCAc 17090	N	121
Virginia bunch	ICGS-4	I	129
	S 7-2-13	S	137
Virginia runner	M-13	M	145
	Kadiri 71-1	K	142

[1] Days after sowing

within and between rows to create the mixed intercrop. The sole crops of each cultivar were formed by sowing one cultivar in rows 4–6 and the other in rows 7–9. Alternating rows of solid stands of the two cultivars were sown in rows 10–12 to give the row intercrop: i.e., row 10 and 12 were sown with the first cultivar and row 11 with the second cultivar. In the dry season, plots consisted of nine rows, three rows each of the two genotypes as sole crops in rows 1–3 and 4–6, and alternating rows of the cultivars were sown in rows 7–9. Rows were 4 m long in the dry, and 4.5 m in the rainy season. Treatments were replicated three times in the dry and eight times in the wet season. One week after seedling emergence, missing hills were resown. This raised the average plant stand to 87% of expected in the rainy season. In the dry season, however, even resowing did not improve stands of Kadiri 71-1 adequately, thus forcing us to discard the four combinations in which it occurred.

Both experiments were conducted on an Alfisol soil at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India. The dry and rainy-season experiments were sown on 9 December 1983 and 20 June 1984, respectively. Furrow irrigation was used throughout the entire dry season, whereas in the rainy season, sprinkler irrigation was provided to initiate germination, at emergence, and from 15 August to maturity.

In the rainy season, applications of an insecticide, monocrotophos (Dimethylphosphate of 3-hydroxy-N-methyl-bis-crotonamide), were made 49 and 62 days after sowing (DAS) to control the leafminer *Apoaerema medicella*. The fungicide Chlorothalonil (Tetrachloroisophthalonitrile) was applied 39, 46, and 66 DAS to control rust (*Puccinia arachidis*) and early (*Cercospora arachidiicola* Hori.) and late [*Phaeoisariopsis personata* (Berk. Curt.) V. Arx.] leaf spots. These diseases appeared late in the season and caused significant defoliation by 120 DAS.

Plants of a given cultivar were harvested when mature as determined by shelling out pods from border plants. Cultivars were harvested by hand at the times shown in Table 1. Only rows bordered by the same treatment were harvested; i.e., rows 2, 5, 8, 10 and 11 in the rainy season and rows 2, 5, 7, and 8 in the dry season. Pods were cleaned and dried at 35°C, after which pod and seed weights were recorded. In the rainy season, haulms were cut at ground level and were dried at 65°C, and dry weight was taken.

Yield response of a cultivar in a mixture (either mixed or alternate-row intercrop) relative to its yield in pure stand was expressed as a Land Equivalent Ratio (LER; Mead and Willey, 1980), herein called Component LER (CLER). A CLER is the ratio of a cultivar's yield in a mixture to its yield as a pure stand in a similar area of land. With each cultivar occuring in seven mixtures, the pure-stand yields of each cultivar could be averaged over seven subplots within each main plot; this average was used as the denominator of the CLER. The two CLER values from each plot were summed to produce the Mixture LER (MLER). An MLER greater than 1.0 would indicate occurrence of synergistic interactions among cultivars in the mixture, whereas an MLER less than 1.0 would indicate undercompensatory reactions between the components. Because MLER values are based on ratios, and ratios may have errors that are not normally distributed, we analyzed the distribution of MLER residuals. Skewness of the MLER residuals was detected for the mixed intercrops, which had skewness coefficients of 0.74 for haulms and 0.46 for pods with standard deviations, computed as $\sqrt{6/N}$ (Snedecor and Cochran, 1980), of 0.12. The significance of MLER deviations needs to be interpreted with caution for the mixed intercrops.

RESULTS

Yield of pods, kernels, and haulms of the eight groundnut cultivars differed greatly between sole crop and mixed stands. The component LER values (CLER) generally ranged from 0.24 to 0.80 for yields of each trait from either mixed or alternate-row intercrops of the wet season, averaged over plant densities. The CLER values of NCAc 17090 and S 7-2-13 were predominantly larger than 0.5, whereas those of Chico and ICGS-4 were most often less than 0.5.

Interaction between cultivars in a mixture most frequently resulted in equal compensation [Mixture LER (MLER) of 1.0], although instances of both over-compensation (MLER > 1.0) and under-compensation (MLER < 1.0) occurred (Fig. 1). The MLER values ranged from 0.81 to 1.23 for pod yield, from 0.82 to 1.29 for kernel yield, and from 0.89 to 1.18 for haulm yield, averaged over densities in the wet season. Mixtures evaluated in the dry season had MLER values for pod yields ranging from 0.90 to 1.10 (Table 2).

Relative to the row intercropping, mixed intercropping produced the largest positive MLER values. In mixed intercrops, the mean MLER values were 1.04, 1.08, and 1.03 for yields of pods, kernels, and haulms, respectively, whereas

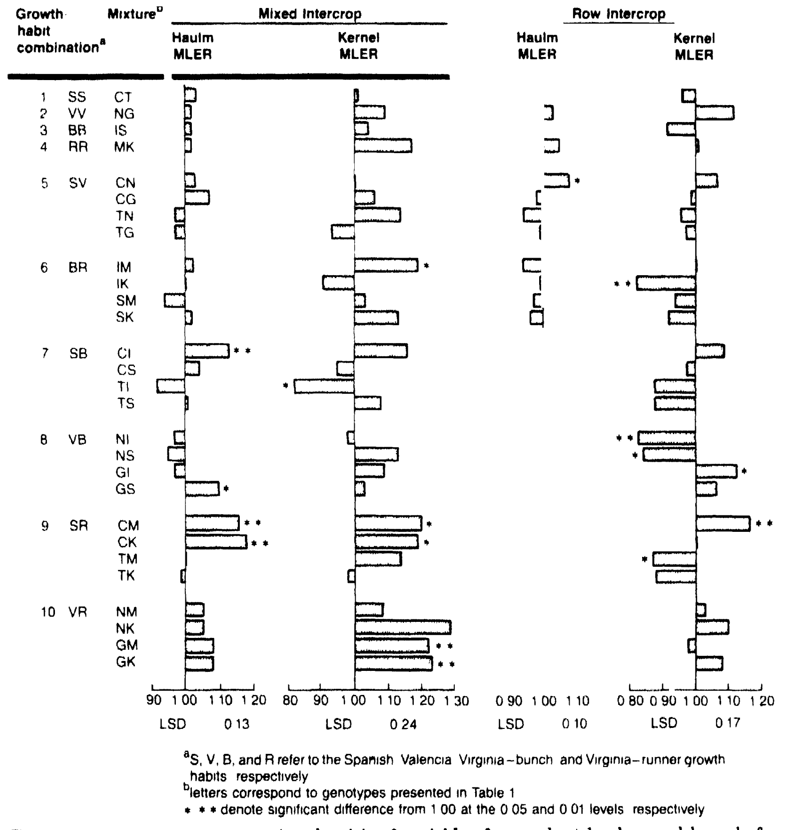

Fig. 1. Mixture-LERs across sowing densities for yields of groundnut haulms and kernels from mixtures sown as mixed or row intercrops in the rainy season, in order of increasingly diverse growth-habit combinations.

TABLE 2

Mixture-LERs of pod yields from row intercrops of 12 mixtures of groundnut cultivars representing nine growth-habit combinations at three plant densities, and averaged over densities, in the dry season

Growth habit comb. [a]	Mixture[b]	Mixture-LERs			
		Sowing rates (seeds m^2)			
		13	20	40	avg.
SS	CT	0.99	1.03	0.99	1.00
VV	GE	0.95	1.07	0.96	0.99
BB	RS	0.90	0.93	1.04	0.96
SV	ET	1.02	0.98	0.85	0.95
	TG	1.07	1.06	0.97	1.03
BR	RM	0.90	0.95	0.84	0.90
SB	CR	0.96	1.03	1.00	0.99
	CS	1.03	0.98	1.11	1.04
VB	GR	1.27	0.90	1.14	1.10
	GS	0.89	1.03	1.21*	1.04
SR	TM	0.85	1.13	0.98	0.99
VR	ME	1.06	0.86	1.30**	1.07

[a] Letters S, V, B, and R refer to the Spanish, Valencia, Virginia bunch, and Virginia-runner growth habits, respectively.
[b] Letters correspond to genotypes presented in Table 1.
*,** indicate significant difference from 1.00 at the 0.05 or 0.01 levels, respectively.

they were 1.00, 0.98, and 1.00, respectively, in the row intercrops, averaged over mixtures and densities. The greater frequency of MLER values above 1.0 for the mixed intercrops may be due to greater contact between plants of different cultivars. In contrast, nearly all instances of under-compensation occurred when mixtures were sown as row intercrops (Fig. 1), suggesting that competition among plants of the same cultivar contributed to reducing MLER values. However, since residuals of MLER values were positively skewed for mixed intercrops and normally distributed for row intercrops, there was some bias toward higher MLER values in mixed — as compared to row — intercrops.

Mixtures of cultivars from different subspecies which have diversity for maturity and growth habit exhibited much greater frequency of both over- and under-compensatory interactions than did those among strains from the same subspecies. Kernel yield over-compensation was greater among intersubspecific mixtures (growth-habit combinations 7–10) than among the intrasubspecific mixtures (combinations 1–6) when sown as mixed intercrops (Fig. 1). In the row intercrops, also, the intersubspecific mixtures had MLER values that deviated from 1.0 most often, but for undercompensatory reactions.

Among the different intersubspecific mixtures, the type of compensation depended on the growth habit of the Virginia strain. Mixtures with Virginia bunch strains (Growth habit combinations 7 and 8) exhibited instances of undercompensation, whereas mixtures with runner strains (Combinations 9 and 10) showed over-compensation, particularly for kernel yield when grown as mixed intercrops. This difference cannot be attributed to growth habit alone because the runner strains were also later-maturing. However, the importance of growth habit is supported by Beg et al. (1975), who found favorable interactions for fruit yield of mixtures between a prostrate Virginia cultivar and cultivars of more erect habit, but not between those of intermediate and bunch habit.

Nearly all synergistic interactions for yield of pods and kernels occurred when a cultivar of Virginia runner growth habit was a component of the mixture. Runner cultivars, however, were present in only half of the instances of overcompensation for haulm yield, suggesting that the positive influence of mixing runner and bunch growth habits is more specific for reproductive than for vegetative growth. Genotypic variability for general mixing ability for yield of both grain and straw has been observed among 1:1 mixtures of *Avena sativa* lines by Shorter and Frey (1979).

Over-compensation was not limited to mixtures of diverse growth patterns, however. For example, the mixture with two Virginia runner cultivars showed over-compensation for pod yield in the mixed intercrop with both components outyielding their sole-crop means. Also, mixtures with a particular combination of growth habits exhibited diverse reactions. For example, within the Spanish/Virginia-runner combinations, nearly all mixtures containing Chico were overcompensating, whereas those with TMV-2 were neutral or undercompensating.

DISCUSSION

Mixtures of genotypes with different maturities are expected to have less competition between their component genotypes, as growth requirements of each component will likely peak at different times (Andrews and Kassam, 1976). This does not seem to be a general phenomenon in our study. Early genotypes showed no general positive response when their companions were late, suggesting that early-season exploitation of resources by early and late genotypes is similar. Late genotypes showed positive response when paired with only the less productive of the early genotypes. For example, the two latest cultivars of the rainy season experiment had pod-yield CLER values of 0.67 to 0.91 when paired with Chico, but when paired with the equally early but more productive Gangapuri, their CLER values fell to 0.49–0.63.

The specificity of compensatory interactions to both combination of plant cultivars and test environment would make it difficult to screen for and utilize over-compensating combinations of groundnut genotypes.

Over-compensation for pod yields by mixtures sometimes depended on the plant density. For example, Chico in mixtures with Virginia genotypes exhibited over-compensation only at one population level (Table 3). Seemingly, over-compensation resulted when the population was sufficiently large for the responsive Virginia genotype to benefit from intercropping (mixtures CM and CI), but not so large that yields of Chico were reduced (mixtures CK and CS). The 28 rainy-season mixtures showed significant interaction with plant density for pod and kernel MLER values from row intercrops, and similar but non-significant interaction from the mixed intercrops. Therefore, tests for over-compensation for fruit yield of groundnut mixtures would need to be conducted at a specific and practical plant density, as was found by Fehr and Rodriguez (1974) for soybean blends.

The consistency of MLERs across seasons cannot be determined from our study because only five mixtures were common to both seasons, and four of them showed neutral compensation in both seasons. The fifth mixture (GS) showed over-compensation for pod yields in both seasons, but only in a single density of the row intercrop.

Another deterrent to recommending groundnut mixtures to farmers is that mixtures with over-compensation failed to exceed the yield of the best sole crop. Pod yields of mixtures reached only 88 and 95% of the sole-crop yield of the most productive genotype at the low and high plant densities, respectively, in the rainy season (Table 4). At the highest density in the dry season, both genotypes of the overcompensating mixture, ME, showed positive pod yield

TABLE 3

Pod yield mixture-LERs from mixtures of Chico with one of four Virginia varieties and the component-LERs of the component genotypes, grown as row intercrops at two plant densities in the rainy season

Mixture[a]	Sowing rate/m^2	MLER	CLER	
			Chico	Virginia variety
CK	20	1.23**	0.51	0.73**
	40	0.93	0.27**	0.66**
CM	20	1.06	0.47	0.60*
	40	1.29**	0.47	0.82**
CS	20	1.17**	0.42	0.76**
	40	0.96	0.27**	0.70**
CI	20	0.99	0.50	0.49
	40	1.19*	0.50	0.69**

[a] Letters correspond to genotypes presented in Table 1.
*,** denote significant difference from 1.00 for MLERs and 0.50 for CLERs at the 0.05 and 0.01 levels, respectively.

TABLE 4

Yields (kg ha^{-1}) of groundnut pods (above diagonal) and haulms (below diagonal) of 28 mixed intercrops and 8 cultivars sown as sole crops, at high (1st line[†]) and low (2nd line) plant densities

	Mixed intercrops								Sole crop
	C	T	N	G	I	S	M	K	
C		2920[†]	3510	2900	3240	1740	2170	1570	2400
		2040	2690	2170	2050	1580	1520	1540	1620
T	3320		3770	2840	2510	2370	2540	2190	3260
	2570		2910	2140	2090	1890	1820	1880	2420
N	4110	4210		3650	3510	2660	3260	3000	3960
	3250	3720		2960	3020	2520	2400	3000	3450
G	3640	3890	4550		2900	2390	2500	2520	3170
	2760	3170	3940		2790	1860	2070	1820	2380
I	2270	2950	3980	3120		1640	2290	1560	2790
	1710	2370	3180	2710		2070	1770	1590	2690
S	3160	3760	3860	4020	2900		1470	1670	1700
	2900	3050	3530	3590	2950		1480	1550	1600
M	2940	3180	4190	3560	2400	2900		1450	1090
	2250	3070	3520	3220	2350	2880		1350	1030
K	2790	3170	3680	3690	2300	3220	2620		1250
	2470	2700	3660	2830	2180	2850	2490		1300
Sole crop	1900	3750	4950	4130	1880	3410	2590	2790	
	1470	3320	4070	3310	1870	3180	2340	2520	

[a] Letters correspond to genotypes presented in Table 1.
[†] SE of $\bar{x}$ differences 280 kg ha^{-1} (pod), 286 kg ha^{-1} (haulm), for mixture yields within the same plant density

responses in the mixed sowing (CLERs of 0.66 for M and 0.62 for E); yet the mixture's yield was only 93% of the most productive genotype. Since nearly all mixtures with overcompensation for pod yield contained one or both of the low-yielding Virgina-runner strains, their lack of yield superiority is not surprising. This lack of yield advantage indicates the inability of our 'successful' mixtures to exploit the available growth resources more fully than the best adapted cultivar in pure stand.

For mixtures of groundnut strains to benefit farmers, mixtures must either yield higher than the most productive sole crop or be more stable over environments. Frey and Maldonado (1977) found mixtures of oat cultivars to have yield advantage over homogeneous cultivars, particularly in the stress rather than non-stress environments. Our failure to find mixtures with absolute yield advantages while attempting to optimize the production environment suggests that future experimentation with groundnut mixtures in the tropics should focus on stability rather than maximization of yield.

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