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The effect of intercropping with cowpea on genotype × environment interaction in sorghum

M.A. de Queiroz[1], R.W. Willey[2] and N.W. Galwey
Department of Applied Biology, University of Cambridge, Pembroke Street, Cambridge, CB2 3DX, England; [1] Present address: School of Development Studies, University of East Anglia, Norwich, Norfolk, NR4 7TJ, England; [2] Present address: CPATSA/EMBRAPA, Caixa Postal 23, 56300 Petrolina (PE), Brazil

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Summary

Eight sorghum genotypes were grown at Hyderabad, India, in sole crop and in association with cowpea in six environments which differed in soil, season and sowing date. There were genotype × environment (G × E) interactions for sorghum yield and related variables, but the interaction was generally much smaller than the main effects. For each variable, the logarithm of the intercrop : sole crop ratio was generally less sensitive to the environment, but there was a significant G × E interaction for the logarithm of land equivalent ratio, indicating that the precise pattern of G × E effects differed between cropping systems. There was little evidence of G × E effects on cowpea, indicating that the effects of a sorghum genotype on the associated legume will be relatively simple to assess. The total LER was above 1 in most cases, indicating that intercropping gives a yield advantage over a wide range of environments and sorghum genotypes.

Introduction

The grain yield of sorghum genotypes in intercropping with cowpea, and their effect on the grain yield of cowpea, are largely determined by morphological and developmental characteristics of the sorghum genotype used, which can be assessed in sole crop (Galwey, de Queiroz & Willey, 1986). However the pattern of these relationships was found to vary between seasons at Hyderabad, India (de Queiroz, 1984). In 1981, a year of above-average rainfall, the total land equivalent ratio (LER) was mainly determined by the sorghum LER and hence was positively correlated with sorghum canopy development. In 1982, a drought year, total LER was mainly determined by cowpea LER, and hence was negatively correlated with sorghum canopy development, which prevented light from reaching the cowpea. The sorghum genotype × season interaction effects on sorghum grain yield and other variables could largely be accounted for by classifying the genotypes into early, medium and late-maturing groups or into tall and dwarf groups. Whereas interaction effects on grain yield were relatively smaller in intercrop than in sole crop, those on dry fodder yield and heads/plant were not. This suggests that compensation between yield components prevents variation in vegetative growth from influencing yield.

In order to explore the pattern of genotype × environment (G × E) interaction in the sorghum-cowpea intercrop more fully, a range of genotypes, chosen from among those used in the experiments reported previously, was grown in a broader range of environments.

Materials and field methods

Environments. Six widely differing environments were created by combining soil effects, mainly due to variations in moisture-holding capacity, and sowing dates in two seasons. The main features of these environments are presented in Table 1. The late sowing date of environment 3 was expected to result in more damage by insects, especially shoot fly (*Antherigona soccata* Rondani) and stemborer, mainly *Chilo* spp. (Seshu Reddy, 1982).

Genotypes. The sorghum genotypes used were five inbred lines from different stages of yield improvement, S 993, S 1006, S 1021, CS 3541 and SPV 351, two commercial hybrids, CSH 5 and CSH 6 and an Ethiopian land race, E 35-1. The cowpea variety used was C 152 which has a semi-erect growth habit and flowers about 45 days after sowing.

Experimental design. Within each environment a split plot design with two replications was used, in which the sorghum genotypes were allocated to main plots and the intercrop and sole crop to sub-plots. The solecrop cowpea occupied an additional main plot. The main plots were arranged in randomised complete blocks.

In sole cropping the cereal and the legume were sown at seed rates intended to achieve the recommended plant densities (180,000 and 300,000 plants/ha, respectively) whereas in intercropping the sorghum seed rate was 1/3 and the cowpea 2/3 of the corresponding sole crop rates. Thus the treatments formed a replacement series (De Wit, 1960). All plots were sown with 45 cm between rows, and the planting pattern in intercrop was 1 row of sorghum to 2 rows of cowpea. The within-row spacing was 12 cm for the sorghum and 7.5 cm for the cowpea.

The dimensions of the sub-plots were 3.6 m × 9 m for sole crop and 4.5 m × 9 m for intercrop. The central 7 m of the four central rows of the sole-crop plots were harvested giving an area of 10.8 m^2 per plot. In the intercrop plots the two central sorghum rows plus the two central cowpea rows were harvested, and yields per unit area were then adjusted to the correct 1 sorghum:2 cowpea ratio.

Table 1. Some features of the six environments.

Environment	Soil type*	Sowing date	Rainfall (mm)
1	Deep black	18.06.81	1112.0
2	Deep black	11.06.82	671.2
3	Black medium	10.07.82	634.9
4	Deep red	19.06.82	683.4
5	Red medium	21.06.82	619.7
6	Red medium	23.06.81	1081.8

* According to the definitions of Singh and Krantz (1976).

Results and discussion

Environment and genotype effects are highly significant in both cropping systems for both dry fodder and grain yield (Table 2). In spite of lower residual mean squares in intercrop, the F values for intercrop grain yield are lower than those for the sole crop grain yield, indicating that the intercrop was more buffered, as in the experiments reported previously (de Queiroz, 1984). However intercrop and sole crop F values are similar for the dry fodder yield. The G × E interaction is highly significant for grain yield in sole crop but not in intercrop, whereas the interaction for dry fodder is significant only in intercrop.

Environment and genotype effects are highly significant in both systems for all yield components, except heads/plant in sole crop which is significant only at the 5% level (Table 3). The F-values for the G × E interaction are much lower than those for the main effects, but still highly significant in both systems for heads/plant and weight/grain. The MS and F values indicate that the sorghum in intercrop was no more buffered than in sole crop for any single component, confirming that the buffering observed for grain yield is due to compensation between the components.

When the G × E interaction is partitioned into heterogeneity-of-regression and deviation components according to the method of Finlay & Wilkinson (1963) (Tables 2 and 3) the only variables for which the former are significant when tested against the latter are weight/grain in both systems. The regression coefficients of weight/grain for all genotypes in both systems are presented in Table 4, with t tests of the significance of the difference of each slope from 1, and the results from three genotypes showing diverse responses are displayed in Fig. 1. The analyses suggest that the genotype's response to environmental variation in terms of weight/grain was complex. The hybrid CSH 5, of medium height and maturity date, was very unresponsive in sole crop but quite responsive in intercrop, whereas the tall and late E 35-1 was responsive in both systems but especially in sole crop. The genotype SPV 351 produced lighter grains in the environments which caused other genotypes to produce heavier grains, in both systems. These complex relationships can be further studied by analysing the intercrop/sole crop ratios.

A wide range of dry fodder and grain yields was obtained (Tables 5 and 6). The land race E 35-1 was the genotype most productive of fodder but least productive of grain, and its grain yield was not much reduced by intercropping. The hybrid variety CSH 6 showed the converse pattern. The most productive environment was the deep black soil in 1982 (environment 2). The lower yields on this soil in 1981 (environment 1) were probably due to excessive rainfall. The red soils in 1982 (environments 4 and 5) were good environments for most of the genotypes, especially the early-maturing ones which avoided moisture stress. The late genotype E 35-1 suffered most from this and from attack by

Table 2. Analyses of variance of sorghum dry fodder and grain yield.

Variable		Dry fodder yield						Grain yield					
Source of variation	DF	Sole			Inter			Sole			Inter		
		MS	F	P	MS	F	P	MS	F	P	MS	F	P
Environment (E)	5	27132720	7.46	*	11905811	8.70	*	22169600	21.45	***	8440761	20.70	**
Replication within E	6	3633290			1368573			1033504			407816		
Genotype (G)	7	50250640	44.61	***	17665968	44.18	***	19012800	59.93	***	3220829	25.02	***
G× E	35	1666130	1.47	ns	684478	1.71	*	928542	2.92	***	170937	1.33	ns
Heterogeneity	7	2031582	1.29	ns	1044730	1.75	ns	1247120	1.47	ns	173197	1.02	ns
Deviations	28	1574767	1.39	ns	594416	1.49	ns	848897	2.67	**	170372	1.32	ns
Residual	42	1126380			399883			317204			128374		

Table 3. Analyses of variance of sorghum grain yield components.

Variable		Heads/plant						Grains/head						Weight/grain					
Source of variation	DF	Sole crop			Intercrop			Sole crop			Intercrop			Sole crop			Intercrop		
		MS	F	P	MS	F	P	MS	F	P	MS	F	P	MS	F	P	MS	F	P
Environment (E)	5	0.73297	53.935	***	0.1733	108.33	***	1469137	20.49	**	2837567	33.57	***	54.085	59.68	***	73.567	33.00	***
Replication within E	6	0.01359			0.0292			71699			84534			0.906			2.229		
Genotype (G)	7	0.02531	2.235	*	0.6461	22.98	***	1819136	37.83	***	1621948	20.23	***	45.356	20.92	***	32.994	13.50	***
G× E	35	0.05624	4.965	***	0.3036	10.80	***	84824	1.76	*	89346	1.11	ns	11.452	5.28	***	11.033	4.52	***
Heterogeneity	7	0.07653	1.496	ns	0.3022	0.99	ns	90302	1.08	ns	115520	1.40	ns	37.167	7.40	***	33.854	6.35	***
Deviations	28	0.05116	4.517	***	0.3040	10.81	***	83454	1.73	ns	82803	1.03	ns	5.023	2.32	**	5.328	2.18	*
Residual	42	0.01133			0.0281			48081			801185			2.168			2.243		

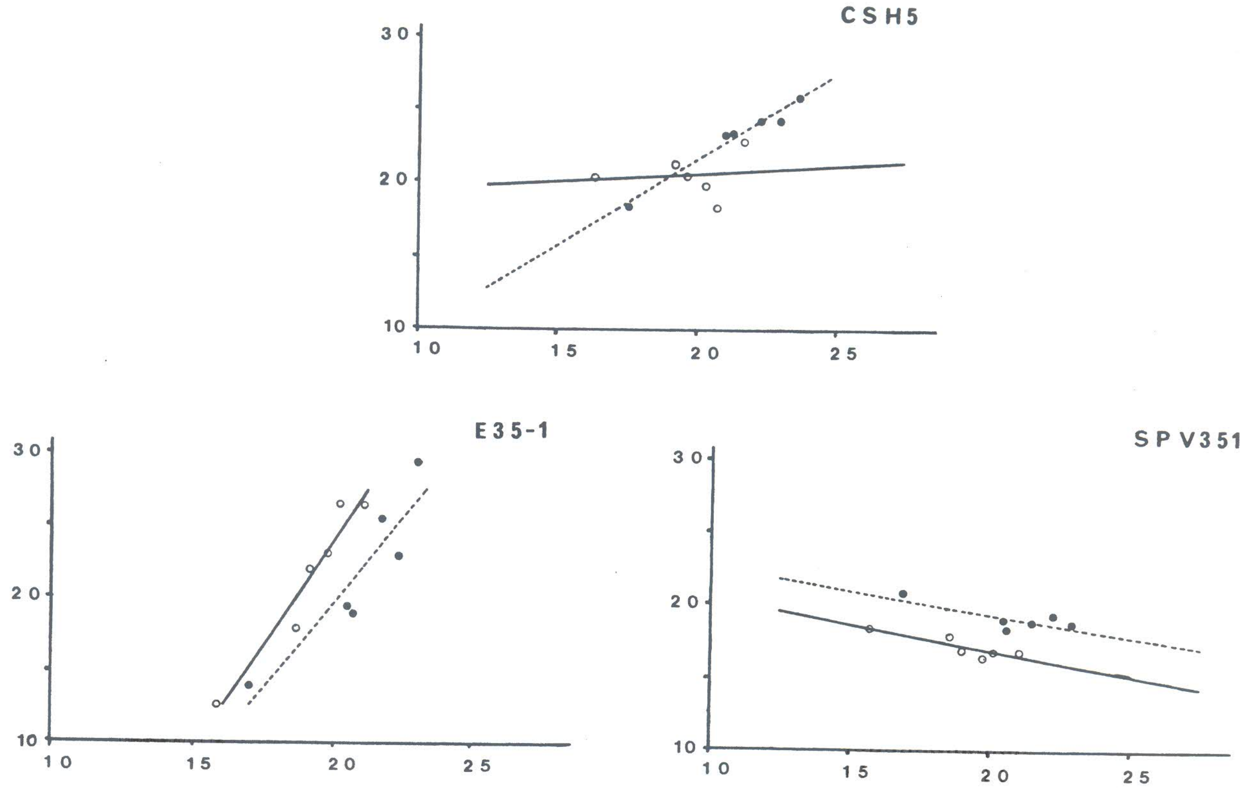

Fig. 1 Regressions of the genotype means for weight/grain (mg) (y axis) on the overall mean for each environment (x axis), in both cropping systems; sole crop value ○, intercrop value ●, sole crop regression line ——, intercrop regression line -----

insects, mainly stembores, but recovered late in the season after the rains had resumed. The least productive environments were the late planting in medium black soil (environment 3) and medium red soil in 1981 (environment 6), mostly because of insect damage. In environment 3 many sorghum plants reacted by producing non-basal tillers, raising the number of heads/plant. High tiller numbers were also found for the late genotype E 35-1 in environments 4 and 5, probably for the same reason.

The analysis of variance of the logarithms of the

Table 4. Regressions of sorghum weight/grain of each genotype on the environment means.

Genotypes	Sole crop			Intercrop		
	b	t†	p	b	t†	p
S 993	0.835	− 0.34	ns	0.881	− 0.29	ns
S 1006	2.021	3.03	*	1.982	2.97	*
S 1021	1.278	0.86	ns	0.970	− 0.09	ns
CSH 5	0.116	− 2.21	ns	1.184	1.81	ns
CSH 6	0.237	− 1.58	ns	0.213	− 2.88	*
CS 3541	1.015	0.07	ns	0.745	− 1.29	ns
E 35-1	2.840	4.94	**	2.327	2.61	*
SPV 351	− 0.341	− 11.87	***	− 0.302	− 9.48	***

† Null hypothesis is $\beta = 1$.

ratios for sorghum grain and dry fodder yield and grain yield components are presented in the Table 7. The F-values for the log (ratios) are lower than the corresponding F-values for the characters either in sole crop or in intercrop (Tables 2 and 3), indicating that responses to environmental variation were broadly similar in the two cropping systems, and hence that the stability of the sorghum genotypes in intercrop can be largely predicted from their stability in sole crop. Even so, there are some highly significant effects, including the G × E interaction for grain yield LER, dry fodder yield LER, heads/plant ratio and weight/grain ratio. The heterogeneity of the regressions in not significant relative to the deviations for any log (ratio), which provides a warning against overinterpreting the regressions for weight/grain in sole and intercrop.

There are significant effects of environment, cropping system and their interaction on several variables in cowpea (Table 8). Though the effect of sorghum genotype on grain yield and pods/plant is highly significant, the sorghum G × E interaction before partitioning is not significant for any variable, which suggests that sorghum genotype effects on cowpea can be assessed in few environments, probably one only. However, when the

Table 5. Mean values of dry fodder and grain yield and yield components of sorghum genotypes in sole crop and intercrop.

Genotype	Dry fodder yield		Grain yield	
	Sole	Inter	Sole	Inter
S 993	9774	4466	2024	1231
S 1006	9566	4168	2202	1348
S 1021	6240	2495	2831	1464
CSH 5	7563	3640	4445	2486
CSH 6	6223	2768	4800	2382
CS 341	7651	3019	3564	1678
E 35-1	12313	6306	1523	1209
SPV 351	8082	3597	4424	2108
Mean	8427	3807	3228	1738
S.E.				
Genotype mean	306	183	163	103
Grand mean	194	119	104	65

Genotype	Heads/plant		Grains/head		Wt/grain	
	Sole	Inter	Sole	Inter	Sole	Inter
S 993	1.031	1.346	545	898	19	20
S 1006	1.035	1.286	567	895	22	24
S 1021	1.142	1.290	864	1107	16	19
CSH 5	1.023	1.215	1341	1753	18	21
CSH 6	1.088	1.345	1260	1623	20	23
CS 3541	1.128	1.364	893	1144	19	20
E 35-1	1.100	1.924	393	793	21	22
SPV 351	1.054	1.192	1392	1519	17	19
Mean	1.075	1.370	907	1216	19	21
S.E.						
Genotype mean	0.031	0.048	63	258	0.4	0.4
Grand mean	0.012	0.017	27	30	0.1	0.2

G × E interaction for cowpea grain yield is partitioned the heterogeneity component is just significant. The regression coefficients are presented in Table 9, with t tests of the significance of the difference of each slope from 1. Though the differences are too small for a conclusive pattern to emerge, the high responsiveness of cowpea to environmental variation when grown in combination with the narrow and short statured sorghum S 1021 and the lesser response in combination with the wide and medium statured CSH 5 are in line with expectation.

The mean values of cowpea grain yield and pods/plant with each sorghum genotype are presented in Table 10, and the mean yields of cowpea fodder and grain in each environment are presented in Table 11. As with the sorghum, the yields varied widely. The landrace E 35-1, which was the most productive of dry fodder, resulted in the lowest cowpea grain yield, whereas the inbred line SPV

Table 6. Mean values of sorghum dry fodder and grain yield and yield components in six environments in sole and intercrop.

Environment	Dry fodder yield		Grain yield	
	Sole	Inter	Sole	Inter
1	7145	3332	2863	1790
2	10190	5261	4502	2785
3	7375	3576	1773	1170
4	9203	3974	4089	1963
5	9323	4015	4134	2023
6	7324	2685	2006	697
S.E.	476	292	254	160

Environment	Heads/plant		Grains/head		Wt/grain	
	Sole	Inter	Sole	Inter	Sole	Inter
1	0.904	1.189	963	1304	19	21
2	0.915	1.047	1217	1756	20	22
3	1.480	2.257	422	754	21	23
4	1.104	1.295	1056	1404	19	21
5	0.979	1.301	1118	1413	20	22
6	1.071	1.131	666	669	16	17
S.E.	0.029	0.043	67	72	0.2	0.4

Table 7. Analyses of variance of log (intercrop/sole crop ratios) for sorghum yields and grain yield components.

Variable		Dry fodder		Grain yield		Heads/ plants		Grains/ head		Weight/ grain	
Source of variation	DF	F	P	F	P	F	P	F	P	F	P
Environment (E)	5	7.43	*	30.30	***	11.50	**	3.45	ns	0.56	ns
Replication within E	6										
Genotype (G)	7	4.04	***	7.78	***	9.35	***	8.07	***	3.41	**
G × E	35	1.89	*	2.15	**	2.12	*	1.09	ns	1.91	*
Heterogeneity	7	1.13	ns	1.31	ns	0.80	ns	1.79	ns	0.19	ns
Deviations	28	1.84	*	2.02	*	2.21	**	0.94	ns	2.35	**
Residual	42										

Table 8. Analyses of variance of cowpea characters in six environments.

Variable		Dry fodder yield		Grain yield		Pods/ plant		Grains/ pod		Weight/ grain	
Source of variation	DF	F	P	F	P	F	P	F	P	F	P
Environment (E)	5	11.63	**	61.08	***	16.62	**	16.96	**	166.95	***
Replication within E	6										
Cowpea treatments	8	2.20	*	11.46	***	2.51	*	1.28	ns	1.59	ns
Sole crop vs intercrop	1	8.36	**	61.71	***	1.73	ns	0.40	ns	5.03	*
Sorghum genotype (G)	7	1.32	ns	4.29	***	2.62	*	1.40	ns	1.10	ns
Cowpea treatment × E	40	1.59	ns	1.38	ns	1.23	ns	0.97	ns	1.16	ns
(Sole crop vs vs intercrop) × E	5	5.19	***	2.78	*	3.35	*	0.37	ns	1.76	ns
G × E	35	1.08	ns	1.18	ns	0.93	ns	1.06	ns	1.09	ns
Heterogeneity	7	1.27	ns	2.47	*	1.43	ns	0.67	ns	1.11	ns
Deviations	28	1.01	ns	0.91	ns	0.90	ns	1.21	ns	1.07	ns
Residual	48										

351 resulted in the highest cowpea grain yield, in spite of producing a fairly high grain yield in intercrop. The most productive environment was the medium red soil in 1981 and the least productive the deep black soil in 1982. The cowpea yields were strongly influenced by *Xanthomonas* sp. bacteria which damaged the foliage far more severely in 1982 (environments 2 to 5) than in 1981 (environments 1 and 6). Within each year damage was more severe on black soils (environments 1, 2 and 3) than red (environments 4, 5 and 6).

The relationships between sorghum and cowpea grain yield is both cropping systems and between sorghum and cowpea LER are displayed graphically in Fig. 2. No clear trend is evident in any of these scatter diagrams: hence it is not possible to say that an environment which is good for sorghum is good (or bad) for cowpea, either in sole or intercrop, nor that an environment which favours intercropping in sorghum favours (or disfavours) it in cowpea. Evidently each environment must be considered on its merits.

The LERs for each genotype in each environment are presented in Table 12. (Because of way in which these values are derived, it is not possible to give standard errors except for the sorghum

Table 9. Regressions of cowpea grain yield in association with each sorghum genotype on the environment means.

Sorghum genotype	b	t†	p
S 993	0.99	− 0.11	ns
S 1006	1.05	0.24	ns
S 1021	1.40	2.90	*
CSH 5	0.75	− 3.56	*
CSH 6	0.97	− 0.41	ns
CS 3541	0.78	− 1.47	ns
E 35-1	0.95	− 0.44	ns
SPV 351	1.11	2.94	*

† Null hypothesis is $\beta = 1$.

Table 10. Mean values of cowpea grain yield and pods/plant in association with each sorghum genotype.

Sorghum genotype	Grain yield (kg/ha)	Pods/plant
S 993	511	2.00
S 1006	531	2.18
S 1021	640	2.23
CSH 5	545	2.16
CSH 6	524	1.96
CS 3541	611	2.38
E 35-1	474	1.82
SPV 351	663	2.50
Mean	562.3	2.15
S.E.		
Genotype mean	35	0.12
Grand mean	15.3	0.08

Table 11. Mean values of cowpea dry fodder and grain yield in six environments in sole and intercrop.

Variable	Dry fodder yield (kg/ha)		Grain yield (kg/ha)	
Environment	Sole	Inter	Sole	Inter
1	581.0	662.5	774.5	534.5
2	686.0	656.5	483.5	326.0
3	466.0	418.5	467.5	379.0
4	1615.5	945.5	1073.5	616.0
5	1442.5	1623.0	860.0	433.5
6	2388.5	1107.5	1430.0	1084.5
Mean	1196.6	902.5	848.2	562.3
S.E.				
Envt. mean	385.7	136.4	105.7	43.1
Grand mean	157.5	55.7	43.1	15.3

LERs.) Sorghum genotypes gave higher LERs in the black soils than in the red, probably because of the higher moisture-holding capacity of the former, but with the exception of some genotypes in environment 6 all the LERs were well above their expected value of 0.33. The Ethiopian land race E 35-1 gave the highest LER except in environment 1, which supports the argument that genotypes selected for sole cropping may not be the best for intercropping. The cowpea LERs on red soil in 1982 tend to be lower than on red soil in 1981 or on black soils. In the former case the high cowpea LERs in are probably due to less competiton by the sorghum (lower sorghum LERs) but the higher LERs on the black soils are achieved without much decrease in the sorghum LERs and are probably due to a lower level of bacterial disease in the intercrop. The cowpea LERs on red soil in 1982, however, were much lower than their expected value of 0.67, probably because in these environments cowpea yield was limited by the bacterial

Table 12. Grain yield LERs for sorghum (S), cowpea (C) and their total (T) for each sorghum genotype in six environments.

Environment	1			2			3		
Sorghum genotype	S	C	T	S	C	T	S	C	T
S 993	0.73	0.59	1.32	0.70	0.57	1.27	1.04	0.88	1.92
S 1006	2.64	0.36	3.00	0.57	0.74	1.31	0.68	0.73	1.41
S 1021	0.68	0.89	1.57	0.56	0.74	1.30	0.73	0.64	1.37
CSH 5	0.58	0.61	1.19	0.66	0.57	1.23	0.69	0.69	1.38
CSH 6	0.51	0.77	1.28	0.62	0.67	1.29	0.52	0.86	1.38
CS 3541	0.38	0.98	1.36	0.55	0.81	1.36	0.55	0.89	1.44
E 35-1	1.12	0.50	1.62	0.78	0.45	1.23	1.20	0.88	2.08
SPV 351	0.51	0.82	1.33	0.63	0.84	1.55	0.63	0.92	1.55
Environment	4			5			6		
Sorghum genotype	S	C	T	S	C	T	S	C	T
S 993	0.51	0.47	0.98	0.50	0.41	0.91	0.28	0.74	1.02
S 1006	0.47	0.62	1.09	0.51	0.51	1.02	0.46	0.77	1.23
S 1021	0.44	0.57	1.01	0.38	0.57	0.95	0.61	0.97	1.58
CSH 5	0.52	0.55	1.07	0.61	0.49	1.10	0.28	0.60	0.88
CSH 6	0.53	0.63	1.16	0.48	0.48	0.96	0.31	0.74	1.05
CS 3541	0.44	0.57	1.01	0.44	0.58	1.02	0.46	0.70	1.16
E 35-1	0.70	0.51	1.21	0.72	0.36	1.08	0.99	0.68	1.67
SPV 351	0.40	0.65	1.05	0.41	0.64	1.05	0.36	0.87	1.23

S.E. factor for sorghum LERs $\overset{\times}{\div}$ 1.21

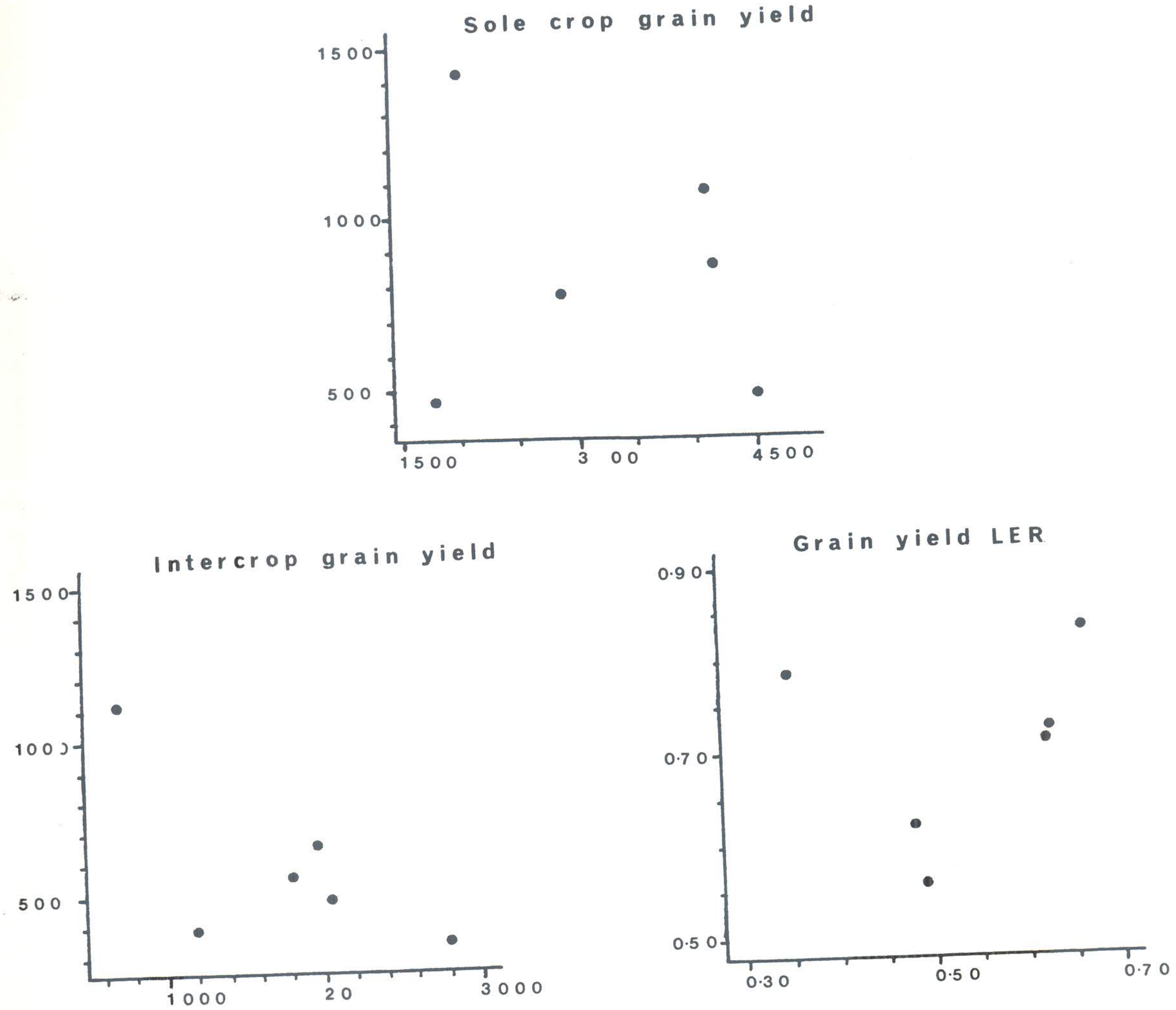

Fig. 2. Relationship between the mean values in each of six environments for sole and intercrop grain yields (kg/ha) and LER measured in cowpea (y axis) and sorghum (x axis).

disease both in sole and in intercrop.

The total LERs were all above 1.0 for the black soil environments but below 1.0 for some sorghum genotypes on the red soils, mostly because of a lower contribution of the sorghum component. These results are not in full agreement with those of Willey (1983) who reported higher LERs from poor environments. However, his environments were created by varying the level of moisture stress keeping the other factors under control, whereas in the present research the environmental variation represents an amalgam of several factors.

Conclusions

Though there are significant G × E interactions for sorghum grain yield and for several related variables, in both sole and intercropping, the main effects are in general much larger than the interaction. This indicates that preliminary evaluation of the performance of sorghum genotypes in either system can be carried out in one or a few environments. The generally lower F values for log (intercrop/sole crop) ratios indicate that the performance in one cropping system is related to the performance in the other. However the significant G × E interaction for sorghum LER indicate that a genotype's detailed response to environmental variation must be assessed in the cropping system in which it is to be grown. Regression of genotype means on environment means was not generally successful in explaining G × E interaction, except, surprisingly, for weight/grain in both systems.

The generally low level of G × E interaction effects on the cowpea indicates that its response to intercropping can be assessed in few environments, and that the limiting factor in the evaluation of sorghum genotypes for intercropping will be the complexity of the sorghum's own response.

The total LERs were generally higher in the black soil environments, but even in the red soils, and even with sorghum genotypes specifically selected for sole cropping such as CSH 5 and CSH 6, total LERs above 1 were sometimes obtained. Clearly, then, the problems of genotype evaluation for intercropping are worth solving.

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