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Stability of Performance of a Pigeonpea/ Sorghum Intercrop System

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Abstract

Results of 89 experiments available on sorghum/pigeonpea intercrops have been pooled, and some basis for understanding the stability of performance is presented. On an average, the intercrop system provides the equivalent of 90% of the sole-sorghum yield and about 52% of the sole-pigeonpea yield. Row arrangements, either 1 sorghum: 1 pigeonpea or 2 sorghum: 1 pigeonpea do not make much difference to sorghum yields or the overall advantage (42%); however, the probability of obtaining more sorghum seems slightly higher in 2:1. Stability is evaluated by the (1) coefficient of variation in yields, (2) relative advantage of the intercrop with changes in fertility and water use, (3) regression of yields, and (4) returns from soles and intercrops against the environmental index based on location mean performance. Coefficient of variation of intercrop yields was less than the yields of sole crops, but this method does not suggest substantially higher stability for intercrops. The relative advantage of intercropping remained more or less similar at different levels of fertility. There was no relationship between relative advantage and the amount of water used. Regression analysis showed that the intercrop system is superior to sole crops at all levels of yields and is more widely adoptable. The failure of intercropping to obtain a specified income level, with either constant prices or randomly varied prices, was less frequent than for sole cropping.

That crop mixtures provide insurance against risks and give stable returns even under aberrant weather has often been said to be the outweighing consideration why small farmers show preference for them over sole crops. The major way intercropping can achieve greater stability is from the compensation of one component when the other fails or grows poorly because of drought, pests, etc.; when the two species are growing separately as soles, there is no possibility of this compensation. Anderson and Williams (1954) quote maize/sorghum as an example where if rains are poor, sorghum is higher yielding, and, in years of high rainfall, maize is higher yielding but still with reasonable yields from sorghum. Fisher (1976) reported substantial compensation when the maize in a maize/bean mixture suffered considerable damage due to both hail and disease. Similar effects are suggested for millet/sorghum and sorghum/pigeonpea — i.e., if early rains fail, the later-maturing crop can compensate; if later rains fail, there is still the yield from the early crop. However, Harwood and Price (1975) have questioned this compensation effect. They reported from their experiments that crop failure often occurred after considerable intercrop competition had already taken place, and they considered sole cropping to be more stable.

Another way intercropping could achieve greater stability is if it gives higher yield advantages under stress — in other words, this would ensure less yield fluctuation than from sole cropping even under unfavorable conditions (Ogunfowara and Norman 1974). Mixtures might also stabilize returns over seasons, as they provide more than one commodity and can act as a buffer against frequent price changes in any one component (although this effect occurs, of course, whether the crops are mixed or grown separately). Prices fluctuate quite often in countries such as India, where more than

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40% of food items come from rainfed agriculture.

Growing two or more crops together on the same land in various spatial arrangements has been a centuries-old practice in India. "Intercropping" is more frequently used to refer to the arrangement where each species in the mixture is in distinct rows. This system of cropping is more prevalent in low- and erratic-rainfall regions where agriculture is more risky (Aiyer 1949). Intercropping with a late-maturing crop is particularly important on lighter soils where double cropping by sequence or relay is a rare possibility to extend cropping more than a single crop. Pigeonpea/sorghum is one of the most widely grown and typical of the intercrop systems where an early-maturing cereal is combined with a late-maturing legume. Of the little intercropping research so far conducted, pigeonpea/sorghum has received relatively more attention than others. This combination is found throughout the country (Aiyer 1949, Kaushik 1951), but sorghum as a food crop is more important in the central and south central (Deccan plateau) semi-arid areas. Subsistence farmers expect a "full" yield of sorghum from intercropping and consider pigeonpea as a "bonus" or "extra" crop (Shelke 1977, Krishnamurthy et al. 1978).

The evidence for higher yields of sorghum/pigeonpea intercropping is fairly well established, but how stable this intercrop is over sole cropping is not known. This paper examines the stability of yields and returns of pigeonpea/sorghum intercrop based on a large amount of experimental data.

Source of Data

Results of experiments on sorghum/pigeonpea, or those containing this combination, from the All India Coordinated Sorghum Improvement Project (AICSIP), All India Coordinated Research Project for Dryland Agriculture (AICRPDA), ICRISAT, All India Coordinated Model Agronomic Experiment Scheme (AICMES), and a few others, were collected and used for the present study (see Appendix I). Of the 89 experiments that could be found, 15 did not have a sole crop of pigeonpea, whereas 12 did not have sole sorghum, thus making only 62 experiments useful for the purpose of calculating land equivalent ratios. Along with yields, information on soil type, sowing and harvest time, fertilizer used, row proportions, populations adopted, weekly rainfall, and evaporation at the experimental site was also gathered.

Stability of Sorghum-Proportional Yields in the Intercrop

The traditional intercropping system consists of a high proportion of sorghum (i.e., one to six rows of sorghum alternating with one or two rows of pigeonpea) in order to ensure the "full" yield of sorghum, which the farmer prefers. This is unfavorable to pigeonpea as it occupies too little area of the ground after sorghum harvest to be able to use late-season resources efficiently; as a result, the overall advantage is not high. Based on AICRPDA results, Krishnamurthy et al (1978) summarized that the productivity is high with the arrangements of 1 sorghum : 1 pigeonpea, 2 : 2 and 2 : 1 — all three being equally good — 2 sorghum : 1 pigeonpea could be recommended because of ease in planting with the local drills. Intercropped pigeonpea is very much reduced in growth, and late in the season may provide relatively little leaf cover even in 2 : 1 (Willey and Natarajan 1978). It has often been suggested that alternate rows provide more uniform distribution of pigeonpea plants and the scope for improved performance is higher. However, since these systems have to meet the specific requirements of the farmer, it is important to examine how far the objective of "full" yield of sorghum is met for different spatial arrangements. It is particularly important in alternate rows, since the sorghum-proportional area is reduced. Results from Shelke's trials (Shelke 1977) and some of the ICRISAT studies indicate that "full" yield of sorghum can be obtained from 2 sorghum : 1 pigeonpea, provided the full population of the sole crop is maintained in intercropping.

The consistency of sorghum-proportional yields in these two arrangements (2S: 1P and 1S : 1P) has been examined from the experiments that have used constant optimum population in sole and intercrop (Table 1). It can be seen that complete yield of sole sorghum could

Table 1. Effect of 1:1 and 2:1 row planting methods in sorghum/pigeonpea intercropping on land equivalent ratios.

	Sorghum[a]			Pigeonpea			Total		
	1S:1PP		2S:1PP	1S:1PP[b]		2S:1PP[c]	1S:1PP		2S:1PP
	0.876		0.899	0.543		0.521	1.40		1.42
SE±	0.012		0.013	0.022		0.021	0.027		0.024
T test	(0.05)	NS			NS			NS	

a. Average of 57 observations.
b. Average of 40 observations.
c. Average of 53 observations.

not always be achieved from intercropping, and the two row arrangements did not differ significantly. The 2:1 arrangement has given a slightly higher proportion of sorghum — i.e., 90%, compared to the 1:1, which gave 88% of the sole crop. The frequency distribution of sorghum land equivalents (Fig. 1) also shows that the probability of obtaining high proportional yields is somewhat higher in the 2:1 than in the 1:1. For example, the proportion of observations which gives a sorghum land equivalent of 0.9 or more is 50% in the 2:1 compared to 35% in the 1:1. The pigeonpea yields in the intercrop were 52–54% of the sole crop. Alternate rows showed only a slight advantage to pigeonpea, and there was no significant difference between the two arrangements. The overall advantage worked out to just over 40%.

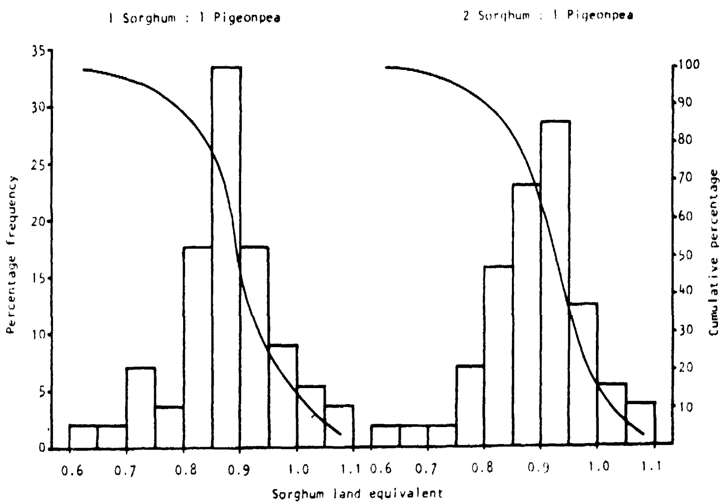

Figure 1. Distribution of sorghum relative yields in two row arrangements of sorghum/pigeonpea intercropping with sorghum population the same as in sole crop (57 observations).

Stability of Intercrop Advantage

The behavior of the relative intercrop advantage expressed as a land equivalent ratio is due to the stress of two major resources, fertility and water.

Not many experiments have studied the effect of different levels of N in intercropping. The data collected was from different experiments conducted at different levels of fertility. Figure 2 shows the relative advantage for different levels of applied N, averaged over a number of experiments. These data have the limitation that they do not take into account inherent soil-fertility differences and P levels between experiments, but these differences may have less influence on yields than the added N, especially in dryland conditions. All the trials received one application of P within moderate limits. In spite of this, it is clear that the level of N stress did not affect the relative advantage. A slight decreasing trend from 0 to 80 kg N/ha still only showed a decrease in LER from 1.57 to 1.44, and the differences were not statistically significant. One of the ICRISAT experiments in 1977, which examined 0, 40, 80, and 120 kg N/ha, gave LER values of 1.46, 1.52, 1.38, and 1.46, respectively, which gives support to the trend observed in Figure 2 (Rao and Willey 1978). It should be noted, however, that the monetary value of the relative advantage would be high at high levels of fertility because of higher yields. Palada and Harwood (1974) also observed similar results in a maize/soybean intercrop.

In dryland conditions, rainfall variability from season to season is high, and it might show a greater influence on yields than fertility; the farmer's interest in stability may be more related to the effect of moisture stress than nutrients. This aspect has not been studied at any length. Fisher (1977a) reported advantages for a maize/bean intercrop in good rainfall seasons and no advantage in a drought year. However, in contrast, an ICRISAT experiment in the postmonsoon season of 1977 on sorghum/groundnut and sorghum/millet showed LER advantages of 1.2 and 1.23, respectively, under stress conditions, but 0.95 and 1.08 under no stress. The effect might have been because the combined root systems were able to make better use of moisture, which would only have been beneficial under conditions of moisture stress. However, it was observed that the dominant crop became even more dominant under no stress, which may have resulted

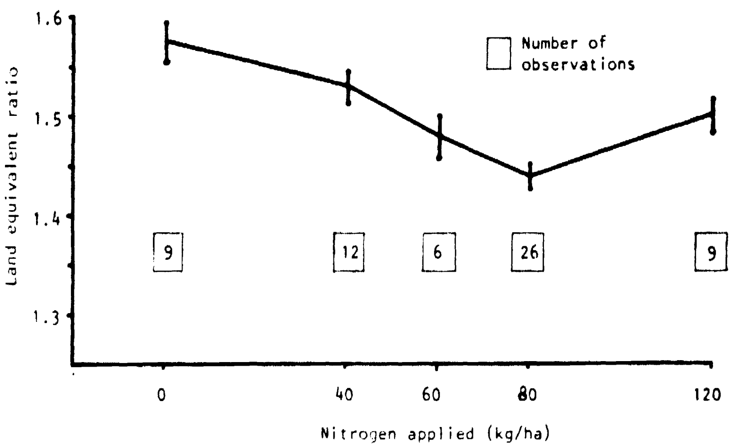

Figure 2. Effect of nitrogen on the relative advantage of sorghum/pigeonpea intercropping (Source: see Appendix I).

in an adverse effect of competition (Rao and Willey 1978). Moisture effects in the case of sorghum/pigeonpea were examined by calculating the relationship between relative advantage and moisture availability from 32 experiments (Fig. 3). This is the estimated evapotranspiration during the growing period based on a soil/water balance model which takes into account rainfall, evaporation, and soil characters (Reddy 1977). The results do not show any observable relationship between yield advantage and water availability. The intercrop performance is more or less independent of water availability within the range of 190–750 mm water used.

Evidence for Greater Stability of the Intercrop

For stability analysis, results of 40 experiments conducted during 1972–77 were used. These contained constant optimum populations of both the components in sole and intercrop, and the pigeonpea genotype was in the medium maturity group of 150–180 days. As a first approximation of stability, CV in yields were calculated (Table 2). The variation in yields of either sorghum or pigeonpea in the intercrop, although they experienced competition with each other, was of the same magnitude as that from sole crops. But the combined yields of the

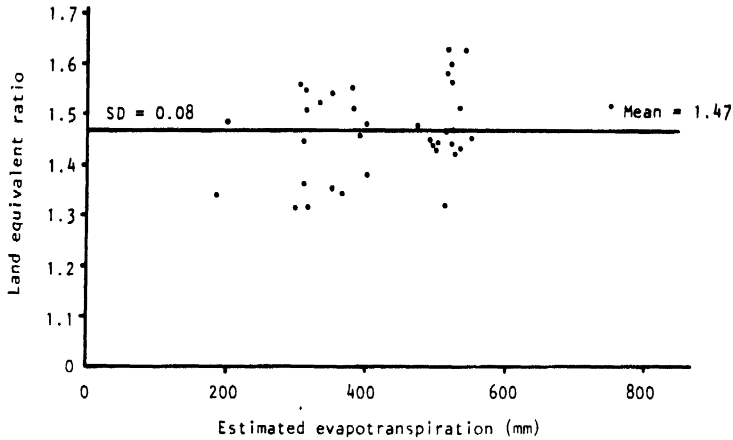

Figure 3. Effect of moisture availability on the relative advantage of sorghum/pigeonpea intercropping.

Table 2. Variability in yields (kg/ha) of sorghum and pigeonpea as sole crops and in intercrop. (Mean of 49 observations from 40 experiments.)

	Sole crop		Intercropped			
	Sorghum	Pigeonpea	Sorghum	Pigeonpea	Total	LER
	3278	1450	2893	815	3708	1.46
SE ±	2.23	0.93	1.94	0.50	2.04	0.02
CV (%)	47.73	45.15	46.90	43.55	38.53	9.60

intercrop showed a noticeably lower CV, which should indicate a likelihood of less fluctuation over different seasons. However, this reduction in variability indicated by this particular method seemed to be rather small.

The stability of a genotype or a system across environments could be more easily studied if an index integrating the various factors affecting growth were available. Eberhart and Russell (1963) suggested an environmental index based on yield itself as an integrator of these factors. The standard technique that has been in use for finding the stability of genotypes in sole crops is to fit a linear regression of yield of any given genotype against the environmental index for each location. This index is calculated by subtracting the mean of all the locations from the treatment mean of any given location; a positive value signifies that location is better than average, a negative index, poorer than average. The performance of any gentoype is then given by the mean yield ($\bar{x}$), the slope of the regression (b), and the squared deviations of the residual (S^2_{di}). The genotype which has high mean, a slope of 1, and minimum residual is considered more "stable." Such a "stable" system responds well proportionately to the environment. This may seem to be in contrast to what "stable" commonly denotes—i.e., a similar performance in various environments as indicated by b equal to zero. But this means that a stable system does not respond to a good environment. In many respects, a system that shows this lack of fluctuation over seasons is important for small farmers, but in practice this may be more likely to happen with crops that have potentially very low yields. And part of the objective of any cropping-systems research program should presumably be to develop systems that use available resources efficiently and yield well in a favorable environment but, at the same time, provide reasonable returns even under unfavorable situations. However, for the systems having the same mean, the one with a lower b value would be more stable.

Figure 4 shows the stability of sole crops vs intercrops measured in absolute yields, but in Figure 5 yields were calculated relative to the yields of the sole crops meaned over all the locations; the latter method allows yields of both crops to be put on the same scale. The analyses of variance for these characters illustrating the model are presented in Table 3. The fitted regressions have shown high goodness of fit for sorghum sole and intercrop (Table 4). The slopes higher than 1 for these situations suggests that these are more responsive to a favorable environment than is pigeonpea,

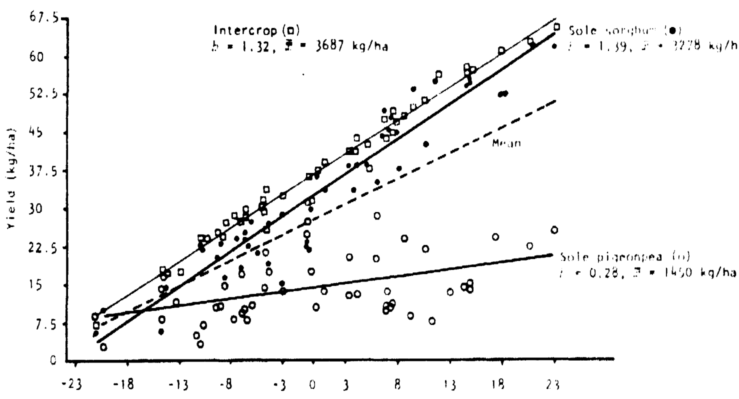

Figure 4. Performance of sorghum and pigeonpea in sole and intercrop systems in different environments as indicated by the environmental index.

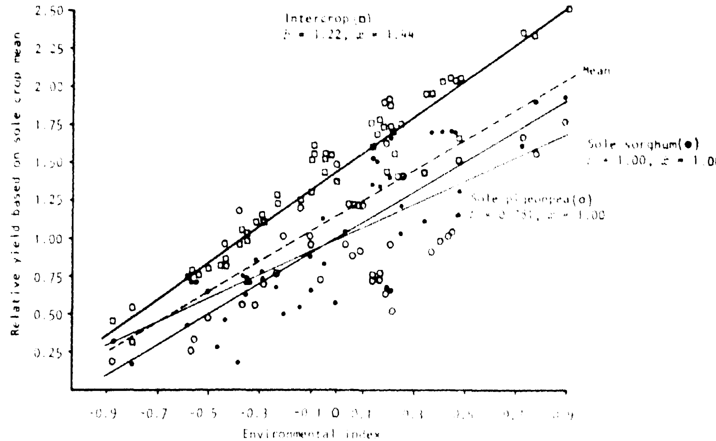

Figure 5. Performance of sorghum and pigeonpea in sole and intercrop systems (sole crop mean yield = 1.0) in different environments as indicated by the environmental index.

Table 3. Analysis of variance when stability parameters are computed.

	Yield (1 000 kg/ha)			Relative yield	
	df	SS	MSS	SS	MSS
Total	146	37 592 14		39 1970	
System (s)	2	13 980 76	6 990 38*	6 442	3 2211*
Environment (*L*)	1	16 517.47	16 517 47*	22.9644	22.9644*
Systems × environment (L)	2	4 244 72	2 122 36*	0 7877	0.39385*
Pooled deviations	141	2 849 39	20.21	0 0027	0.0639

* = Significant at the 5% level

Table 4. Stability parameters of fitted regressions on yields and relative yields based on sole crop mean.

	Yield (kg/ha)				Relative yield			
System	$\bar{x}$	*b*	S^2_{di}	r^2	*x*	*b*	S^2_{di}	r^2
Sole sorghum	3278	1 39*	22 0616	0 91	1 00	1.00	0 07043	0.63
Sole pigeonpea	1450	0 28*	24 3580	0 18	0.00	0 78	0 10915	0.45
Intercrop	3687	1 32*	4 5879	0 98	1 44	1 22*	0 01197	0 95
Mean	2805	1.00*			1 15	1 00		
SE ±	64 2				0 04			
LSD (0.05)	178				0 10			

* These *b* values are significantly different from 1 0

which shows little response to the environment. In fact, it is evident from Figure 5 that under an unfavorable environment pigeonpea performs better than sorghum. The intercrop showed a higher mean ($\bar{x}$ = 1.44) and maintained its superiority over both the soles in the entire range of yield levels. In fact, better performance of the intercrop is much more evident in a better environment than in poorer ones. From the three parameters of regression, the intercrop can be regarded as more widely adaptable than any of the sole crops. It has combined the advantages of sorghum, which yields well and has average stability ($\bar{x}$ = 1.0, b = 1.0), as well as of pigeonpea, which is relatively unresponsive to changes in environment but yields well in poorer areas ($\bar{x}$ = 1.0, b = 0.78). However, the intercrop assumed the characteristics of sorghum rather more because this is the dominant crop. This illustrates particularly clearly that intercropping can be responsive to better conditions and that, for this combination at least, an improved level of resources should not necessarily be associated with a need for sole cropping.

One limitation in the above analysis could be that characterization of the location is based on the mean yield of all three systems. Unlike genotypes of the same species, which mature more or less at the same time, sorghum and pigeonpea are separated in time markedly and mature at different times of the year. Thus, a season unfavorable to one crop may not be unfavorable to the other. As a result, mean yields of the three systems may not give an accurate idea of the environment. However, correlations worked out between the relative advantage and the absolute yields of sole sorghum (r = - 0.07) or sole pigeonpea (r = - 0.08) have not shown any discernible relationship.

Stability of Income

Figures 6, 7, and 8 show the comparison of intercrop and sole crops for stability of returns

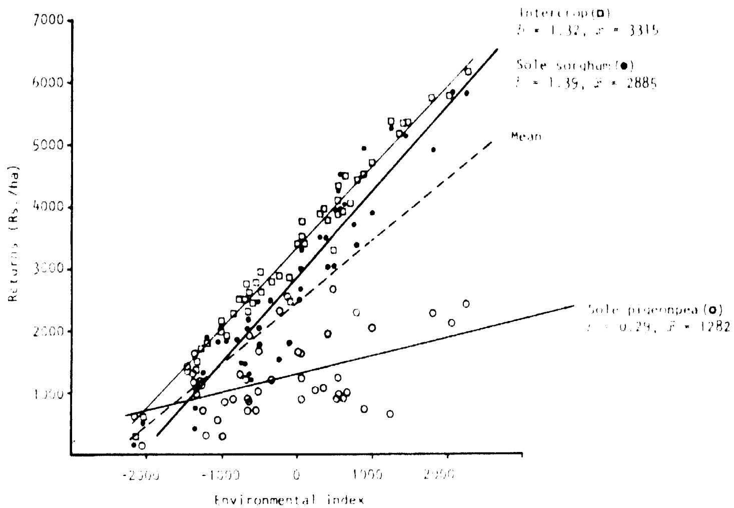

Figure 6. Returns from sorghum and pigeonpea in sole and intercrop systems in different environments as indicated by the environmental index (market price: sorghum Rs. 100/100 kg and pigeonpea Rs. 100/100 kg).

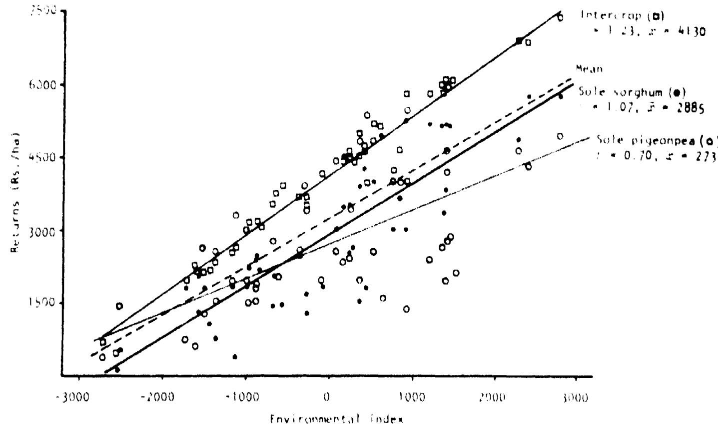

Figure 7. Returns from sorghum and pigeonpea in sole and intercrop systems in different environments as indicated by the environmental index (market price: sorghum Rs. 100/100 kg and pigeonpea Rs. 200/100 kg).

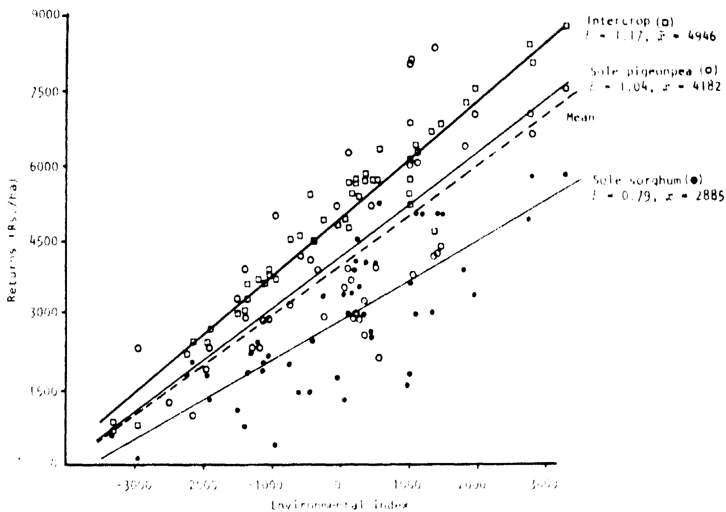

Figure 8. Returns from sorghum and pigeonpea in sole and intercrop systems in different environments as indicated by the environmental index (market price: sorghum Rs. 100/100 kg and pigeonpea Rs. 300/100 kg).

calculated at three different price ratios. The parameters of the regressions are in Table 5. Returns were computed deducting the costs of the fertilizer. These show more or less the same trend as in the case of yields; however, as the price ratio increased in favor of pigeonpea, the slope of its regression line increased, whereas that for sorghum decreased. Except at the narrow ratio, where the returns from sole pigeonpea were greater than those from sole sorghum and the intercrop at very low environments, the intercrop showed superiority at all levels of return; a greater increase occurred in good environments than in poorer environments.

The variability in returns from the soles and intercrop and the expected risks associated with these systems for obtaining any specified level of income are given in Table 6. Returns from "shared crops" were also computed. "Shared crops" represent a situation where sorghum and pigeonpea as sole crops share 1 ha of land. Returns of shared sole were calculated from the respective soles on the yield-proportional basis as sorghum and pigeonpea in intercropping (0.61 ha S : 0.39 ha PP). Shared sole compared to intercrop provides an objective comparison, because both involve the two components in the same proportion, but, in the latter situation the crops are intercropped. The results show that, although the intercrop as such has not shown marked difference from the shared crop, intercrop returns showed substantially less variability than either of the sole crops at all three price ratios. With an increase in the price of pigeonpea, returns from sole pigeonpea, shared and intercropped, revealed much less variability because of the same cost of fertilizer deducted at all prices. However, the probability (by normal deviate test) of returns falling below any specified disaster level shows the superiority of the intercrop over any of the sole crops. For example, at a market price of Rs. 100/100 kg of sorghum and 200/100 kg of pigeonpea, the probability of returns falling below Rs. 1000, is once in 9 years from sorghum sole, once in 11 years from pigeonpea sole, once in 20 years from shared crop, but only once in 50 years from the intercrop. In the above, returns were based on constant prices for components, which is rather unlikely to prevail over several years. Figure 9 shows the risk from these systems when the price ratios between sorghum and pigeonpea vary randomly between ratios of 1:1, 1:2, and 1:3. At lower disaster levels (i.e., lower required income), the inter-

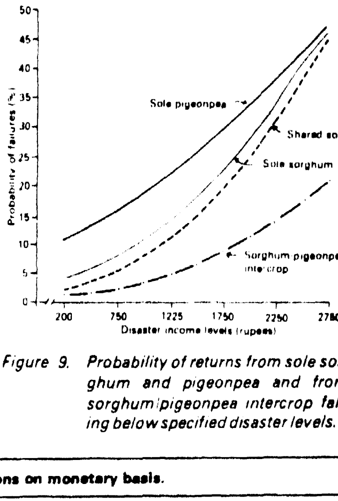

Figure 9. Probability of returns from sole sorghum and pigeonpea and from sorghum/pigeonpea intercrop falling below specified disaster levels.

Table 5. Stability parameters for fitted regressions on monetary basis.

	Sorghum — Rs. 100/100 kg Pigeonpea — Rs. 100/100 kg				Sorghum — Rs. 100/100 kg Pigeonpea — Rs. 200/100 kg				Sorghum — Rs. 100/100 kg Pigeonpea — Rs. 300/100 kg			
	$\bar{x}$	b	S^2_{di}	r^2	$\bar{x}$	b	S^2_{di}	r^2	$\bar{x}$	b	S^2_{di}	r^2
Sole sorghum	2885	1.39	222229	0.90	2885	1.07	641803	0.72	2885	0.79	1027050	0.55
Sole pigeonpea	1282	0.29	337082	0.18	2732	0.79	990869	0.40	4182	1.04	1597650	0.57
Intercrop	3315	1.32	39721	0.98	4130	1.23	105602	0.95	4946	1.17	199441	0.93
SE ±	99				117				142			
LSD (0.05)	275				325				393			

Table 6. Risk associated with sorghum and pigeonpea in sole and intercrop systems at specified levels of returns.

System	Mean income (Rs./ha)	SD	CV%	Probability of income falling below disaster levels (Rs./ha) 500	1000	1500
Sorghum 100 : Pigeonpea 100						
Sole sorghum	2885	1528	52.95	0.06	0.11	0.18
Sole pigeonpea	1282	650	50.64	0.11	0.33	0.63
Shared sole[a]	2261	1009	44.63	0.04	0.10	0.23
Intercrop	3315	1394	42.06	0.02	0.05	0.09
Sorghum 100 : Pigeonpea 200				Disaster levels 1000	1500	2000
Sole sorghum	2885	1528	52.95	0.11	0.18	0.28
Sole pigeonpea	2734	1304	47.70	0.09	0.17	0.29
Shared sole	2826	1140	40.33	0.05	0.12	0.23
Intercrop	4130	1543	37.36	0.02	0.04	0.08
Sorghum 100 : Pigeonpea 300				Disaster levels 1000	1500	2000
Sole sorghum	2885	1528	52.95	0.11	0.18	0.28
Sole pigeonpea	4182	1958	46.80	0.05	0.08	0.13
Shared sole	3392	1308	38.56	0.03	0.07	0.14
Intercrop	4946	1753	35.44	0.01	0.02	0.04

a. Shared sole is 0.61 ha sorghum and 0.39 ha pigeonpea — i.e., the same as the mean proportions of sorghum and pigeonpea in intercropping.

crops did not show marked superiority in stability over the shared crops, but at higher levels, failures due to intercropping are much less frequent than with any of the sole crops. Higher risk from shared sole compared to the intercrop, although it has the benefits of having both crops, is presumably because of the lack of compensation that could occur in intercropping.

Appendix I. Source of Data

AICRPDA (All-India Coordinated Research Project for Dryland Agriculture). 1973–74 to 1977–78. Progress Reports. Hyderabad, India: ICAR.

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