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EVALUATION OF YIELD STABILITY IN INTERCROPPING:† STUDIES ON SORGHUM/PIGEONPEA

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SUMMARY

Data from 94 experiments on sorghum/pigeonpea intercropping were examined for evidence that the stability of yield is greater with intercropping than sole cropping. Stability of the major component (sorghum) was examined by calculating the distribution of yields; stability of the overall intercropping system was examined by calculating coefficients of variation, by computing regressions of yield against an environmental index, and by estimating the probability of monetary returns falling below given 'disaster' levels. All these approaches have some merit; taking the last as an example, it was found that for a particular 'disaster' level quoted, sole pigeonpea would fail one year in five, sole sorghum one year in eight, but intercropping only one year in thirty-six. Intercropping gave yield advantages under a wide range of environmental conditions and there was no significant evidence that advantages were greater under stress. This is discussed in relation to possible mechanisms contributing to greater yield stability.

It is often suggested that improved stability of yield is one of the major reasons why intercropping continues to be an extremely important practice in many developing areas of the world, especially those areas of greater risk (Aiyer, 1949; Jodha, 1979; Norman, 1974). But as yet there is little quantitative information on the magnitude or practical importance of this improvement; indeed, in many situations there is still considerable doubt as to whether improved stability is actually achieved.

Several mechanisms might bring about improved stability - e.g. if one crop fails, or grows poorly, the other to some extent may compensate; such compensation clearly cannot occur if the crops are grown separately. Fisher (1976) observed such compensation when the maize in some maize/bean intercrops suffered damage due to hail and disease. However, Harwood and Price (1976) have questioned this compensation effect, reporting from their experiments at the International Rice Research Institute that if crop failure occurs later in the season, the subsequent compensation may not offset the earlier intercrop competition, thus arguing that sole cropping might often be a more stable system.

Intercropping could also provide greater stability if its yield advantages, compared with sole cropping, were greater under stress than non-stress conditions, since this would mean that intercropping yields in seasons of stress would not decrease as much as yields of sole crops. Greater yield advantages under stress have often been suggested as a probable effect of intercropping but very little information is available on this aspect and its possible relation with yield stability. This is considered in some detail in the data presented later.

A further mechanism for improving stability could occur where intercropping

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provides a buffer against pests and diseases, for example where one crop acts as a barrier against the spread of a pest or disease of the other crop. The limited available information indicates that pest and disease incidence can be less in certain situations, but greater in others where, for example, the presence of one crop alters the microclimate of the other in a way that favours a pest or disease (Trenbath, 1975). This is a very complex field, in which generalizations are difficult, but it is not considered in any further detail in this paper though it is potentially very important in farming practice.

Most of the quantitative work on stability has been limited to mixtures of genotypes within a given crop, mainly examining the possible benefits of a 'multi-line' approach in what is essentially still a sole crop situation. Trenbath (1974) summarized this work and found that, at best, the improvement in stability was only marginal. Greater improvements might however be expected in a genuine intercropping situation where there are bigger differences between crops; for instance, this seems more likely to give rise to situations where the effects of an adverse environment on the two crops are sufficiently different to allow meaningful compensation by the better growing one. This suggestion is supported by evidence of improved stability in oats/barley intercropping (Daniel, 1955; Morrish, 1934) and in cereal/legume intercropping (Gliemeroth, 1950; Papadakis, 1941).

A further problem of past stability studies is that only limited data have been available. The present paper examines a large body of available data on sorghum/pigeonpea intercropping, which is an extremely important combination in many parts of India (Aiyer, 1949). The farmer's objective with this combination is usually to produce a 'full' yield of sorghum (i.e. as much as a sole sorghum crop) and some 'additional' yield of pigeonpea (Krishnamurthy *et al.*, 1978), which has also been the objective in most of the experimental work.

In general, the concept of improved stability is relatively straightforward and can be fairly simply defined as less variability over different seasons or situations. But quantification of the degree of stability is far from straightforward, and the intercropping system itself poses some special problems. In addition to examining the stability of the important sorghum/pigeonpea combination, therefore, the purpose of this paper is to illustrate some of the methods that might be of general use in intercropping studies.

MATERIALS AND METHODS

Results from 94 experiments carried out during the years 1972–78 were collected from a number of sources (Appendix 1). Fifteen of the experiments did not include sole pigeonpea and another 14 did not include sole sorghum. The optimum intercropping population for each crop is generally held to be the same as its sole crop optimum (Krishnamurthy *et al.*) but only 51 of the experiments were conducted at these populations. Row arrangements were either 2 sorghum: 1 pigeonpea or 1 sorghum:1 pigeonpea, and many experiments contained both these treatments. Where possible, information was obtained on sowing and harvesting dates, fertilizer levels, soil moisture characteristics, weekly rainfall and evaporation.

Yield advantages of intercropping

Yield advantages of intercropping were determined by using the Land Equivalent Ratio (LER, i.e. the relative land area required by sole crops to produce the yields achieved in intercropping), which could of course only be determined for the 65 experiments which included sole treatments of each crop.

To determine whether yield advantages from intercropping were affected by stress conditions, advantages were examined against different levels of applied nitrogen and against the level of moisture availability. The latter was estimated evapotranspiration during the growing period, determined from a soil water-balance model which took account of rainfall, evaporation and soil moisture characteristics (Reddy, 1977); this could be determined for 38 experiments.

Stability analyses

Stability analyses were only carried out on the 51 experiments where the intercropping population for each crop was the same as in sole cropping. In these experiments the pigeonpea genotypes were all of medium maturity (150-180 days) and the sorghums mostly high yielding cultivars or recent hybrids of 100-110 day maturity and about 1.5 m in height.

First, a simple examination was carried out on how far intercropping satisfied the farmer's basic objective of producing a 'full' sorghum yield. Then the stability of the overall intercropping system was examined by:

(a) Computing coefficients of variation,
(b) Adapting the regression technique, which has frequently been used to examine the stability of individual genotypes over a range of environments (Eberhart and Russell, 1966; Finlay and Wilkinson, 1963), and
(c) Estimating the probability of monetary returns falling below given 'disaster' levels of income.

To assess the stability of the overall system, intercropping was compared with growing *either* sole crop and *both* sole crops. For the latter a 'shared crop' yield was calculated, i.e. what would have been achieved by dividing 1 ha into sole crops to give the same relative yield proportions as the average proportions in intercropping (which proved to be 0.61 ha of sole sorghum and 0.39 ha of sole pigeonpea). This shared crop treatment was adopted so that comparisons between intercropping and sole cropping were not biassed by changes in the proportions of the crops.

RESULTS AND DISCUSSIONS

Yield advantages of intercropping and the effects of different levels of fertility or moisture availability

The mean relative yield advantage of intercropping, as indicated by the LER, was 42% (LER = 1.42) for the 65 experiments where LER could be calculated. There was virtually no difference in this overall advantage between the row arrangements of 2 sorghum:1 pigeonpea (LER = 1.43, from 64 cases) and 1 sorghum:1 pigeonpea (LER = 1.40 from 40 cases).

A fitted linear regression for the effect of *level of applied nitrogen* on LER gave a b value of -0.0016 ± 0.0005 (Fig. 1), showing a decreasing trend in LER with increase in nitrogen. The goodness of fit of this regression was significant, but the r^2 was still very low at 0.15, presumably because of the big differences in growing conditions and yield levels between the different experiments, and because many other factors besides applied nitrogen probably also influenced yield advantages.

It was suggested that greater advantages under stress situations might provide greater stability than sole cropping. The nitrogen effects cited were not very large, but it is possible that they would still make a useful contribution to improving stability over various fertility conditions. It is also worth noting that even where the relative advantages of intercropping are less at higher fertility levels, the absolute advantages may be higher because of the higher yield levels involved (Harwood and Price). For example, in the experiments reviewed, the fitted regression line gives a predicted yield advantage of 60% at nil nitrogen, at an estimated value of Rs 1126/ha (assuming prices of 1 and 2 Rupees/kg for sorghum and pigeonpea respectively; $1 US = approximately 8 Rupees). At 120 kg/ha nitrogen the predicted yield advantage of 41% was rather less in relative terms, but its estimated value had risen to Rs 1602/ha.

Different levels of *estimated moisture availability* had no observable effect

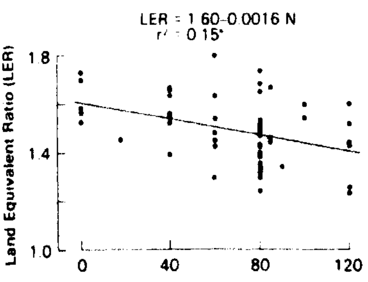

Fig. 1. Effect of nitrogen fertilizer on the relative advantage of sorghum/pigeonpea intercropping.

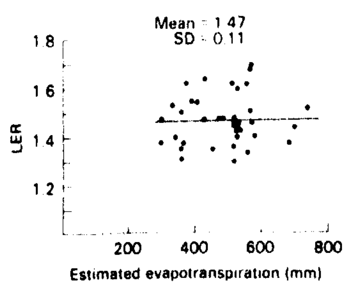

Fig. 2. Effect of moisture availability on the relative advantage of sorghum/pigeonpea intercropping.

on LER (Fig. 2); although the method of estimating moisture availability (see earlier) may have to be treated with some caution, there is thus no evidence that this intercropping combination gives greater relative advantages under conditions of moisture stress. Since sorghum/pigeonpea is a combination which is predominantly grown in the drier parts of India, seasonal fluctuations in moisture availability are probably at least as important a determinant of yield as fertility level. Contrary to the nitrogen effects, however, the data provide no indication that differential responses to moisture stress could provide a stabilizing mechanism against these seasonal fluctuations.

Yield stability

An important objective when farmers intercrop sorghum and pigeonpea is to maintain a full yield of the sorghum crop and a measure of 'stability' for this major component is how often such a full yield is achieved. The frequency distribution of sorghum yield, expressed as an LER (or relative yield) at the two different row arrangements (Fig. 3) shows little difference in yield between the two and both arrangements often gave a sorghum yield appreciably below that of the sole crop; in the 1 sorghum:1 pigeonpea, the average yield was 87% of the sole crop and in the 2 sorghum:1 pigeonpea it was only a little higher at 90%. Moreover, there was only a small difference in the probability of achieving a full sorghum yield; a probability of 12% for 2:1 compared with 7% for the 1:1 arrangement.

Stability of the overall intercropping system was first examined by calculating coefficients of variation (Table 1), which were high for all systems, probably

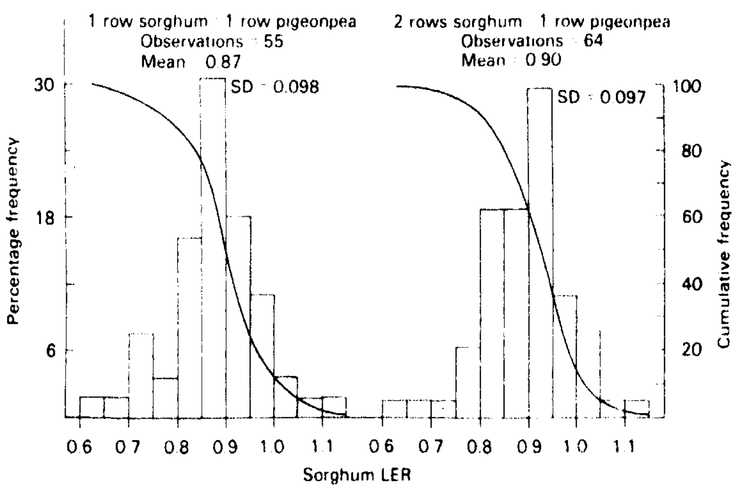

Fig. 3. Distribution of sorghum LER in two arrangements of rows in sorghum/pigeonpea intercropping.

Table 1. *Stability of yields of sorghum and pigeonpea in sole cropping, intercropping and 'shared sole' cropping as indicated by coefficients of variation (based on 63 observations from 51 experiments)*

	Sorghum sole	Pigeonpea sole	Intercrop			Shared sole		
			Sorghum	Pigeonpea	Total	Sorghum	Pigeonpea	Total
Yield (kg/ha)	3208	1446	2839	817	3656	1957	564	2521
SE	198	80	168	44	179	120	31	133
CV (%)	48.9	43.6	47.0	42.7	39.0	48.9	43.6	42.0

again due to the big differences in yield levels across the different experiments. Sole pigeonpea (CV 43.6%) was rather more stable on this basis than sole sorghum (CV 48.9%) but intercropping was more stable than either (CV 39%). It is of some interest that the 'shared sole' treatment described earlier was also more stable than either sole crop, though not as stable as intercropping, probably because of rather different responses of the two crops to the different growing conditions; e.g., if a poor environment for one crop is not always equally poor for the other, then growing both sole crops in all environments provides a buffering mechanism by avoiding the possibility of having only the poorer-yielding crop.

A limitation of this present approach is that calculations were based only on the mean yields of each experiment, since individual replicate data were usually not available. This has the disadvantage that the variability within experiments is ignored, and it would probably be better to use the variability within each experiment to gain a pooled estimate of variability, but the relative merits of this approach will have to await further investigation.

The adaptation of the analysis often used to study genotype stability is illustrated in Fig. 4. For each cropping system, a linear regression has been fitted between yield and an environmental index, calculated for any given 'location' (or experiment) by subtracting the mean yield of all locations from that particular location mean; thus a positive value shows that a location is better and a negative value poorer than average. The figure was calculated as a combined index for all cropping systems, i.e. both of the sole crops, the shared crop, and the intercrop.

These regressions can be rather difficult to interpret, even in sole crops, but some useful conclusions can be drawn. Examining the sole crops first, the slope of the pigeonpea regression line was much less steep than that of the sorghum. In one sense, therefore, the pigeonpea was more stable because its yield was less affected by change in the environment, but this also means that the sorghum gave a much bigger yield reponse to any improvement in the environment, which is agronomically very desirable. The goodness of fit of the regression lines was much better for sorghum ($r^2 = 0.93$) than for pigeonpea ($r^2 = 0.26$), indicating that the sorghum response was very predictable whilst that of the

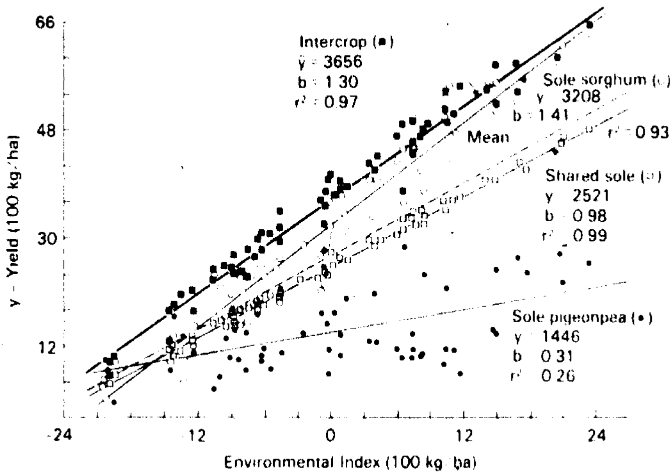

Fig. 4. Regressions of absolute yield on environmental index for sorghum and pigeonpea in different cropping systems.

pigeonpea was not. Thus it can also be stated that the *response* of sorghum to environmental change was more stable than that of the pigeonpea.

The intercropping regression line was above that of either sole crop, emphasizing the occurrence of yield advantages in all environments. The slope of this line was intermediate to those of the sole crops but much nearer that of the sorghum, no doubt partly because sorghum occupies the major portion of the intercropping yield on the basis of absolute yields. However, it was clear that intercropping still gave a very marked response to environmental changes, and the goodness of fit of the regression was just as good as that of sole sorghum. Thus the *response* of intercropping to environmental change was just as stable as sole sorghum, despite the presence of the more variable pigeonpea. It may well be, therefore, that the greater variability of the pigeonpea response was offset by compensation in the sorghum component.

The 'shared sole' regression line was very similar to that of the mean response, presumably because this theoretical situation was calculated from the yields of both the crops that contributed to the environmental index and was not subject to any interactions between the crops which might have modified their combined response. Presumably for the same reason, the shared sole regression line showed an extremely good fit ($r^2 = 0.99$).

This approach still embodies one of the more serious difficulties encountered in the evaluation of intercropping, which is that comparisons are being made between crops which have very different types and levels of yield (Fig. 4). The different yield levels can be taken into account by considering relative

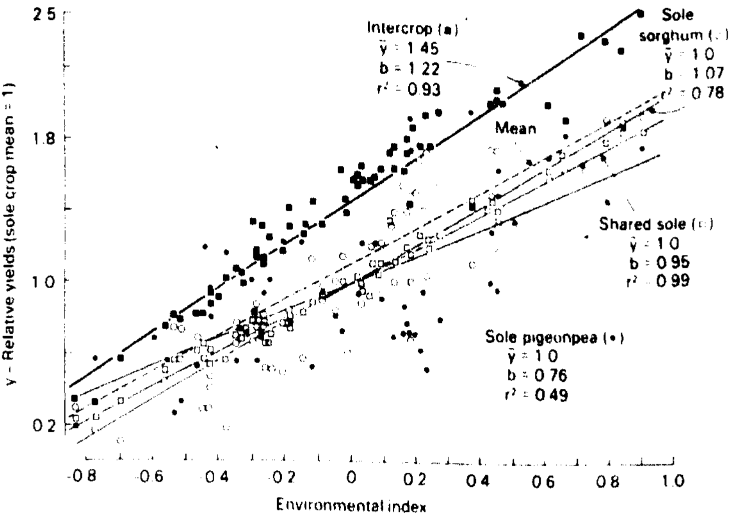

Fig. 5. Regressions of relative yield on environmental index for sorghum and pigeonpea in different cropping systems.

yields, the mean for each crop over all locations being taken as 1 (Fig. 5), on which relative basis pigeonpea was much more responsive than previously indicated, though still somewhat less so than sorghum. Again the stability of this response, as indicated by goodness of fit, was appreciably less than that of sorghum. A further feature of this relative yield approach is that it highlights the yield advantages of intercropping that would commonly be computed using LER, e.g. the mean intercrop relative yield of 1.45 is effectively an LER with an average yield advantage of 45%, on which basis the response of intercropping was greater than either sole crop and the stability of the response was again very high ($r^2 = 0.93$).

Both yield level and yield type can to some extent be taken into account by expressing yields in monetary value and, of course, this approach also has the merit of giving an economic evaluation of the different systems. For this particular crop combination the higher value of pigeonpea roughly offset its lower yield, so monetary values (Fig. 6) showed little difference from relative yields but this approach could highlight important effects for other crop combinations or for different price ratios of the two crops.

As a further comment on the regression approach it should be emphasized that there can be problems in deciding which cropping system should be used to calculate the environmental index. With the sorghum/pigeonpea combination, regression patterns showed little difference whichever system, or combination of systems, was used; thus the index was based on all systems to give the

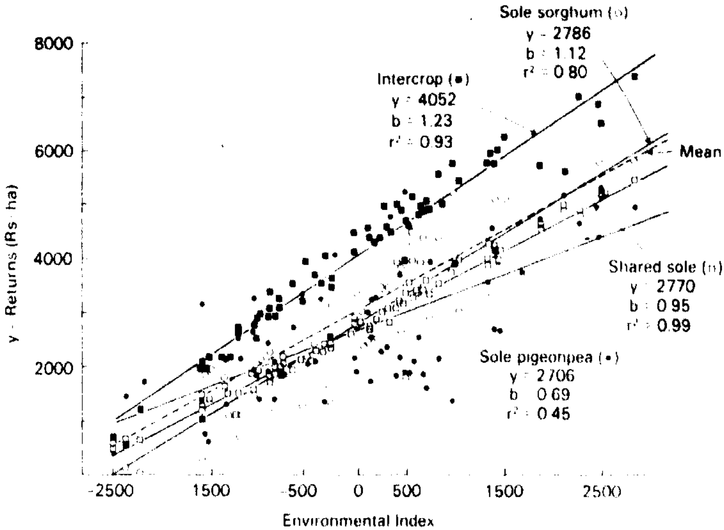

Fig. 6. Regressions of returns on environmental index for sorghum and pigeonpea in different cropping systems (market value Rs 1/kg sorghum, Rs 2/kg pigeonpea).

best aggregate indication of environmental effects. But where the environmental responses of intercrops and sole crops are very different, it can be argued that intercropping effects would be more precisely indicated by using an index based only on the sole crops, since these essentially represent the situation with which intercropping is being compared.

This then raises problems of whether to use only one or both of the sole crops. Where one of the crops has to maintain an intercropping yield equivalent to a full sole crop yield, and where this sole crop is thus effectively the practical alternative to intercropping, it seems reasonable that the index could be based only on this crop. On the other hand, both crops should presumably be included where intercropping aims to achieve some balance of the two crops. It is suggested that in this instance the index should logically be the 'shared sole' situation described above, so that the two crops are given the same weighting as their relative importance in intercropping. As an example, Table 2 gives the regression parameters obtained by fitting the present sorghum/pigeonpea data in this way; comparison with the parameters in Figs 4–6 shows that this approach was little different from basing the index on all the cropping systems.

Despite the possible usefulness of these first two approaches, they leave much to be desired because they still do not indicate in simple practical terms what a given level of 'statistical' stability means to a farmer. On the assumption that a farmer's major concern is to avoid 'disaster' situations, a third approach estimated the probability of each cropping system failing to provide

Table 2. *Stability parameters for fitted regressions, using shared crop yields as the basis for an environmental index*

	Yield (kg/ha)			Relative yield			Returns (sorghum:pigeonpea = 1:2 Rs/kg)		
	$\bar{Y}$	b	r^2	$\bar{Y}$	b	r^2	$\bar{Y}$ (Rs/ha)	b	r^2
Sole sorghum	3209	1.45 ± 0.04	0.95	1.00	1.15 ± 0.07	0.82	2787	1.19 ± 0.07	0.84
Sole pigeonpea	1446	0.30 ± 0.06	0.24	1.00	0.76 ± 0.11	0.45	2706	0.70 ± 0.10	0.42
Intercrop	3656	1.31 ± 0.4	0.95	1.45	1.24 ± 0.06	0.89	4052	1.25 ± 0.05	0.89
Shared crop	2521	1.0	1.00	1.00	1.00	1.00	2770	1.00	1.00
SE ±	85			0.03			96		

given 'disaster' levels of monetary returns (Fig. 7). An additional feature of this presentation is that, because price structures are not static, the price ratio for sorghum:pigeonpea was randomly allocated for each location within the range 1:1 and 1:3, though the data could just as easily be presented for any fixed ratio required. The cost of applied nitrogen was deducted from these returns because it represents the main variable cost at the different locations.

At any given disaster level intercropping showed a much lower probability of failure than either sole crop. Illustrating this for an example disaster level of Rs 1000/-, sole pigeonpea would fail approximately one year in five, sole sorghum one year in eight, shared sole one year in thirteen, but intercropping

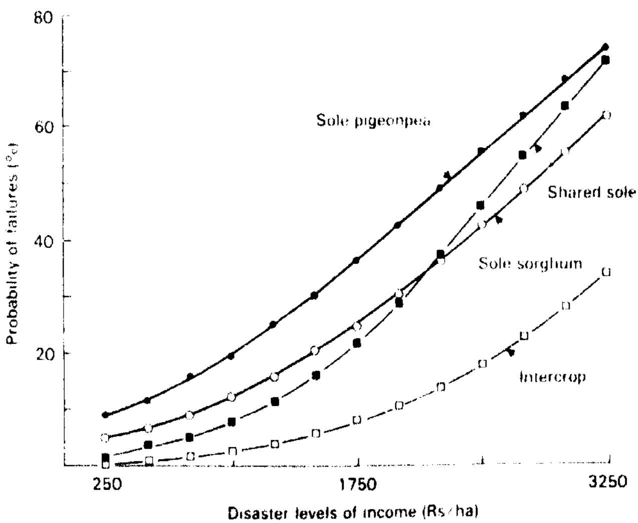

Fig. 7. Probability of failure for sorghum and pigeonpea in different cropping systems at given disaster levels of income.

only one year in thirty-six. Thus in these simple practical terms intercropping did indeed show a much improved stability over any sole crop system, though it should be appreciated that if stability is assessed in this way, a reduced incidence of crop failure can occur partly because of a higher intercropping yield as well as a genuine reduction in the variability of the yield. Of course the farmer still gains the overall benefits depicted in Fig. 7, whether these accrue from higher yield or less variability in yield, on which basis the approach seems useful.

CONCLUSIONS

Of the various aspects discussed in this paper, those of wider interest are the approaches to quantifying the overall stability of the combined intercropping system. All the approaches examined may have some merit and only further examination in other situations will resolve which is likely to prove the most generally useful. The calculation of a coefficient of variation is probably the most limited, giving only a relatively simple expression of the variability around a mean yield; fitting a regression against an environmental index may well be much more fruitful where large environmental responses produce big deviations from this mean.

Estimating the probability of crop 'failures' has considerable appeal because this more closely reflects the farmer's attitude to stability, as well as giving much the clearest indication that intercropping can indeed be appreciably more stable than sole cropping.

As a final comment, it should be emphasized that the usefulness of any approach may be limited by the nature of the data being examined. As indicated earlier, the important effects of stability are probably those which occur over different seasons, yet experimental data are usually from different locations in only a limited number of seasons. Only further examination is likely to show how far these location effects can indicate seasonal effects.

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Appendix 1

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