ERRATA

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EVALUATING TECHNICAL INNOVATIONS UNDER LOW-RESOURCE FARMER CONDITIONS

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The following corrections should be made to Table 3:

1. To be consistent with the text, the two column headings Bi should read bi.
2. The constant terms reported are log b_0; the antilogs of these values – which are extremely close to 1.0 – should have been reported in the table as the estimated partial regression coefficients for the constant X_0.

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METHODOLOGY OF
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THE CONCEPT OF A 'LAND EQUIVALENT RATIO' AND ADVANTAGES IN YIELDS FROM INTERCROPPING

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SUMMARY

Criteria for evaluating different intercropping situations are suggested, and the Land Equivalent Ratio (LER) concept is considered for situations where intercropping must be compared with growing each crop sole. The need to use different standardizing sole crop yields in forming LERs is discussed, and a method of calculating an 'effective LER' is proposed to evaluate situations where the yield proportions achieved in intercropping are different from those that might be required by a farmer. The possible importance of effective LERs in indicating the proportions of crops likely to give biggest yield advantages is discussed.

It has become widely recognized during recent years that intercropping (i.e. growing two or more crops together on the same area of ground) can often produce higher yields than sole crops, but there can be problems in assessing the degree of yield advantage. Yet such an assessment is essential to determine whether a given intercropping combination is indeed better than sole cropping and whether, within that combination, one intercropping practice is better than another.

One aspect which has not been recognized sufficiently is that, at the farmer's level, different intercropping combinations may have to satisfy different requirements (Willey, 1979). A fairly straightforward situation is where the component crops are equally acceptable and there are no constraints which determine that both have to be grown, in which case the intercropping advantage can be assessed as the amount by which the combined intercrop yield (i.e. the total of both crops) exceeds that of the higher-yielding sole crop. This type of assessment, which has commonly been made with grass mixtures (Donald, 1963), may also apply to field crop situations where the component crops are very similar, e.g. different cultivars of the same crop, similar cereals, etc.

Such an assessment presents no conceptual difficulties, but an interesting practical aspect is illustrated by the UK work of Daniel (1955) on oats and barley, where the yield of a 50:50 mixture in a given season was not as high as the higher-yielding sole crop but usually higher than the mean of the sole crops. However, it was not possible to predict which sole crop would be higher yielding in any given season, showing that higher yields would be achieved from a 50:50 mixture over a number of seasons than from either sole crop or from a

50:50 partitioning of the area between the crops. This emphasizes that the interpretation of a yield advantage in a given situation or season may be quite different from that of longer-term effects. These longer-term effects can be extremely important (though not considered further in this particular paper) especially in view of the general belief that intercropping yields are more stable.

A second type of assessment is required where the intercropping situation has to produce a *full* yield of a main crop (i.e. as much as in sole cropping) and some *additional* yield of a second crop. This situation is seldom referred to in the international literature but seems surprisingly common in practice; e.g. it frequently occurs in India where the farmer requires a full yield of his staple cereal and is only prepared to add a second crop if yield of the cereal is not sacrificed; and is common where the main crop is a highly-valued source of cash which the farmer is not prepared to sacrifice. Under these conditions the yield advantage is particularly easy to assess, because it is simply the yield of the second crop. However, experiments on such situations, will usually include some treatments where yield of the main crop is not wholly maintained, in which case it may be useful to apply some elements of the techniques necessary for another situation.

This third situation, much the commonest yet presenting the greatest difficulties, is where the farmer needs to grow more than one crop, whether intercropped or not, to spread labour peaks, to reduce marketing risks, or to satisfy different dietary requirements. In this situation intercropping gives a yield advantage if two of the required crops produce more yield as an intercrop combination than when grown separately. Assessment of this yield advantage must therefore involve a comparison between the combined intercrop yield and the yield of some combination of sole crops (i.e. the total from *each* sole crop). A number of problems have arisen in deciding exactly what this combined sole crop yield should be.

THE LAND EQUIVALENT RATIO CONCEPT

Willey and Osiru (1972) pointed out the danger of comparing a combined intercrop yield with a combined sole crop yield on the basis of the same *sown* proportions, because competition in intercropping usually results in a different proportion of final yields than from sole cropping. Of the possible ways available to overcome this problem, Willey (1979) concluded that the most generally useful single index for expressing the yield advantage is probably the Land Equivalent Ratio (LER), defined as the relative land area required as sole crops to produce the same yields as intercropping. This is exactly analogous to the Relative Yield Total which has been used for many years in competition studies (de Wit and van den Bergh, 1965). Using a rather simpler notation from the earlier competition studies, LER can be written:

$$\mathrm{LER} = L_A + L_B = \frac{Y_A}{S_A} + \frac{Y_B}{S_B}$$

where L_A and L_B are the LERs for the individual crops, Y_A and Y_B are the individual crop yields in intercropping, and S_A and S_B are their yields as sole crops.

The advantages of the LER are that (a) it provides a standardized basis so that crops can be added to form 'combined' yields; in theory this also means that LER's themselves can be compared between different situations, and even between different crop combinations, but this presents some problems that will be discussed later: (b) comparison between individual LERs (L_A and L_B) can indicate competitive effects (Willey, 1979): (c), of primary importance, the total LER can be taken as a measure of the relative yield advantage, e.g. an LER of 1.2 indicates a yield advantage of 20% (or, strictly speaking, that 20% more land would be required as sole crops to produce the same yields as intercropping). However, there can be practical reasons why the yield advantage indicated by the LER may not be fully attainable by a farmer (see later), and a preferable interpretation is that LER represents the increased *biological efficiency* achieved by growing two crops together in the particular environment used.

Before considering further aspects of the LER it is pertinent to consider the practice of standardizing the yields of different crops by other means, e.g. by using some 'common denominator' such as money, protein or calories. This can be very useful but in no way eliminates the need to satisfy the farmer's requirements referred to earlier. It is essential to avoid the common practice of claiming, say, a 20% relative yield advantage on the basis of an LER which assumes the need for both crops, and then pointing out that there is no economic advantage because returns from intercropping do not exceed those from growing only the high-value sole crop.

There are two difficulties with the simple LER as defined in the first section of this paper, and both arise from its use as a measure to compare different intercropping situations. Because the LER is defined as a ratio, large values can be obtained because of large yields in intercropping but also because of small yields in corresponding sole crops. The second difficulty in using LERs as a measure of biological efficiency to compare different situations is the implicit assumption that the harvested proportions of the two crops are exactly those that are required in each situation.

CHOICE OF STANDARDIZING SOLE CROP YIELDS TO FORM LER

We can regard the calculation of an LER value as essentially standardizing the two component crop yields, but there are several possible choices for the standardizing yields. Using the sole crop yield which corresponds exactly to the form of the crop in intercropping can lead to large differences in LER, due not only to the success of the intercrop but also to the success or failure of the sole crop, as was shown in an experiment comparing 17 different pigeonpea genotypes intercropped with sorghum (Table 1). LER values calculated for

Table 1. *Yield and LERs of 17 genotypes of pigeonpea intercropped with one of sorghum, using constant sole crop yield for sorghum (3952 kg/ha) but (a) sole crop yield of appropriate individual genotypes for pigeonpea, and (b) sole crop yield of best pigeonpea genotype*

Yield (kg/ha)			(a) LER using appropriate individual pigeonpea genotype			(b) LER using best pigeonpea genotype			Intercrop benefit of adding sorghum (Cols 9–7)
	Intercrop								
Sole pigeonpea (1)	Sorghum (2)	Pigeonpea (3)	Sorghum (4)	Pigeonpea (5)	Total (6)	Sole pigeonpea (7)	Intercrop pigeonpea (8)	Sorghum/ pigeonpea total (9)	
1699	3804	850	0.96	0.50	1.47	1.00	0.50	1.46	0.46
1525	3931	842	0.99	0.55	1.56	0.90	0.50	1.49	0.59
1428	3640	740	0.92	0.52	1.44	0.84	0.44	1.36	0.52
1407	3630	815	0.92	0.58	1.50	0.83	0.48	1.40	0.57
1389	3386	757	0.86	0.54	1.43	0.82	0.45	1.31	0.49
1376	3344	885	0.85	0.64	1.48	0.81	0.52	1.37	0.56
1323	3899	799	0.99	0.60	1.62	0.78	0.47	1.46	0.68
1296	3381	619	0.86	0.48	1.45	0.76	0.36	1.22	0.46
1264	3973	585	1.01	0.46	1.44	0.74	0.34	1.35	0.61
1226	3757	619	0.95	0.50	1.45	0.72	0.36	1.31	0.59
1222	3232	512	0.82	0.42	1.24	0.72	0.30	1.12	0.40
1185	3500	463	0.89	0.39	1.25	0.70	0.27	1.16	0.46
1169	3323	503	0.84	0.43	1.27	0.69	0.30	1.14	0.45
1148	3930	661	0.99	0.58	1.58	0.68	0.39	1.38	0.70
1106	3198	718	0.81	0.65	1.47	0.65	0.42	1.23	0.58
1063	3645	530	0.92	0.50	1.42	0.63	0.31	1.23	0.60
1058	3677	720	0.93	0.68	1.66	0.62	0.42	1.35	0.73

intercrop yields, a constant sole crop yield for sorghum, and sole crop yield of the appropriate pigeonpea genotype (Cols 4–6) show that quite large pigeonpea LERs (and thus quite large total LERs) occur where sole pigeonpea yields are poor.

Thus a simple LER provides a measure of biological efficiency for each genotype combination but is not always suitable for comparing combinations. If LER is to be used to compare different situations it is helpful to regard the sole crop yields purely as standardizing factors, making it possible to add yields for the two crops. For the purpose of comparing genotype combinations such as those cited above, it may be sensible to use the same standardizing factors for each combination, which leads to S_A and S_B being defined as maximum or 'average' sole crop yields for the experimental treatments. Columns 7–9 show LERs calculated in this way, using the sole crop yield of the best pigeonpea genotype, which shows which combinations are genuinely more productive. We can also examine, where appropriate, the benefit of intercropping any pigeonpea genotype with sorghum compared with growing that genotype as a sole crop (Col. 10).

The method of standardization should vary according to the form and objective of the experiment. A good example where a single standardizing sole crop yield would be agronomically valid is where treatments consist of different plant populations and spacings because as Huxley and Maingu (1978) have emphasized, all intercrop yields should be compared with the sole crop at its optimum population and spacing. Population and spacing are easily and cheaply adjusted (at least in theory) and intercropping should therefore be compared with sole plots which are at maximum productivity in this respect.

There are other situations where it seems sensible to use more than one measure of sole crop yield. In an experiment designed to examine the advantage of intercropping at different levels of fertility it could thus be appropriate to standardize at any given intercrop yield against the sole crop yield at the same fertility level. Farmers may not be able to change their fertility level and it is pertinent to know how intercropping and sole cropping compare at any given level of fertility.

A third situation which may benefit from both approaches, is for experiments combining different genotypes of each crop. To determine the highest-yielding combinations overall, comparison might be made with the highest-yielding genotypes of each crop, but the relative biological efficiency of a given combination would require comparison with the specific sole genotypes of that combination.

HOW FAR ARE YIELD ADVANTAGES INDICATED BY ATTAINABLE LER?

A valid criticism of the LER concept is that the proportional areas of combined sole cropping (which are assumed to be the alternative to intercropping) are based on the harvested yield proportions ($L_A : L_B$) achieved in intercropping. It can thus be argued that a farmer cannot predict exactly what the areas of sole cropping should be in any situation and the assumed combination of sole crop areas can hardly be regarded as a realistic alternative. However, it seems likely that a farmer would be familiar with the relative probable yields from crops, whether intercropped or sole cropped and could adjust sowing areas to achieve the yield proportion he required; and which would presumably be the same whichever system was used.

More seriously, if LER is taken as a measure of the available yield advantage, there is an implicit assumption that the yield proportions embodied in that LER are those required, or acceptable, by the farmer, which raises particular difficulties in comparisons between LERs with different yield proportions; a straight comparison implies that either yield proportions are equally acceptable. For example an experiment at ICRISAT on maize/pigeonpea gave results, (kg/ha) for the two 'best' intercrops (as indicated by the highest LER) of:

	Intercrop 1	*Intercrop 2*
Intercrop maize	2234	3130
Intercrop pigeonpea	896	571

Maximum sole crop yields for maize and pigeonpea were 3398 and 1035, respectively. Thus LERs were:

	Intercrop 1	*Intercrop 2*
LER maize (L_M)	0.66	0.92
LER pigeonpea (L_P)	0.87	0.52
Total LER	1.53	1.47
Yield proportion of maize $[L_M/(L_M+L_P)]$	0.43	0.63

It could be misleading to argue that Intercrop 1 is better than 2 on the basis of a higher LER because Intercrop 2 might be preferred if the yield proportion of maize desired by a farmer was 0.60. Thus it may be relatively easy to interpret a single LER value, but there are difficulties in comparing different ones, likely to be accentuated as the number of LERs available for comparison increases. For example, the maize/pigeonpea experiment referred to above contained nine intercrop treatments in all which is still comparatively few, yet Fig. 1 shows that LERs varied between 1.10 to 1.53 and the yield proportion of maize from 0.32 to 0.63.

What is required is a method of comparing LERs which takes account of their different yield proportions and can relate these to the farmer's requirements, and such a method is outlined below. However, unavoidable problems may occur and some assumptions will have to be made in any attempt to interpret intercropping advantages by a single index; as pointed out by Mead and Stern (1979), different aspects of intercropping data should perhaps be interpreted by different indices.

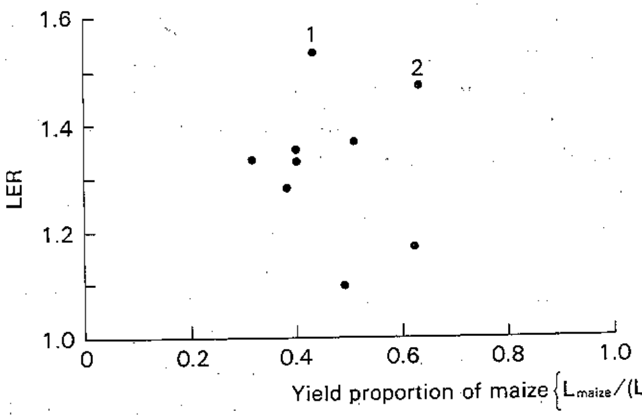

Fig. 1

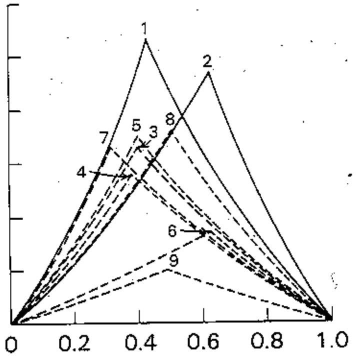

Fig. 2

Fig. 1. LER values of maize/pigeonpea intercropping treatments with different proportions of maize in the final yield (from ICRISAT unpublished data, 1977).

Fig. 2. 'Effective LER' curves for the intercropping treatments shown in Fig. 1.

AN EXTENSION OF THE LER CONCEPT

Consider again the results for Intercrops 1 and 2. Suppose that the farmer's requirement is for a maize/(maize + pigeonpea) proportion of 0.63, but for some practical reason he has to grow Intercrop 1 which gives a proportion of only 0.43. He could obviously achieve the right overall proportion by growing Intercrop 1 on part of the area and sole maize on the remainder. To illustrate how the required proportions of intercropping and sole maize should be calculated it is easiest to consider how much extra sole maize would have to be grown with 1 hectare of intercropping. For example, if E is designated the additional sole maize area

$$\text{the required proportion } \frac{\text{maize}}{(\text{maize}+\text{pigeonpea})}=\frac{L_M+E}{\text{LER}+E}$$

where L_M and LER refer to the intercrop actually being grown. In this particular example the calculation would be

$$0.63=\frac{0.66+E}{1.53+E}, \qquad \text{therefore } E=0.82$$

Thus the required proportion of 0.63 would be achieved from 1 hectare of Intercrop 1 and 0.82 ha of sole maize; on a unit area basis this would be equivalent to proportional areas of 0.55 to 0.45. The biological efficiency of this system, as an 'effective LER' would be calculated:

	Yield	*LER*	*Proportion*
From 0.55 ha intercropping			
(Intercrop 1)			
Pigeonpea	493	0.48	0.37
Maize	1229	0.36	0.63
From 0.45 ha sole maize			
Maize	1529	0.45	
'Effective LER'		1.29	

On this basis, for a required maize proportion of 0.63, Intercrop 1 provides a biological efficiency of only 1.29 compared with the biological efficiency of 1.47 for Intercrop 2.

A general method of obtaining the proportion of intercropping (k) for a required proportion (p) of crop A can be written:

$$k=\frac{(1-p)}{pL_B-(1-p)L_A+(1-p)}$$

Once this proportion is known, the Effective LER can be calculated as shown above or directly calculated:

$$\text{Effective LER} = \frac{L_B}{(1-L_A)+(\text{LER}-1)p}$$

These general equations assume that (a) the land area allocated to sole cropping would produce the same level of yield as the sole crop used in the L_A calculation, and (b) crop A is whichever of the two that has to be *increased* in proportion and of which there must therefore be some sole crop.

To illustrate this approach, the Effective LER for the two intercrop treatments referred to earlier is plotted against the required proportions (p) of maize in Fig. 2. The highest LER for a given intercrop is achieved when the whole area is intercropped. The Effective LER is lower for any other proportion and, since the required proportion tends towards one or zero, the effective LER tends towards 1, indicating the use of either sole crop. For these two particular intercrop treatments Intercrop 1 has a higher Effective LER, and thus a greater biological efficiency, than Intercrop 2 if the required maize proportion is less than about 0.55.

The other seven treatments included in the experiment suggest that the curves belong to a single 'envelope' of which the apex might indicate the area of maximum efficiency (Fig. 2) and help to identify, or even predict, the proportions likely to give maximum LER and possibly the general magnitude of this LER. Optimum treatments in this experiment are likely to be those giving a maize proportion of about 0.50–0.55, with a maximum achievable LER higher than has so far been achieved with Intercrops 1 and 2.

No further detailed studies have been carried out on maize/pigeonpea at ICRISAT but recent data on a very similar sorghum/pigeonpea combination support the above prediction. The cereal is harvested after about 90 days while the pigeonpea continues for a further 90 days, and it is becoming evident that this combination can produce a full yield of cereal (i.e. equal to a sole crop) with a large additional pigeonpea contribution. A typical 'best' treatment over several ICRISAT experiments in 1978 produced a sorghum LER of 1.0 and a pigeonpea LER of 0.9. As predicted, therefore, the total LER could be increased considerably (i.e. 1.9) and the optimum cereal proportion proved to be between 0.50–0.55 (i.e. 0.53).

The same method of presentation is used with similar data on sorghum/beans in Fig. 3, based on different populations and two row arrangements which appear to produce two envelopes of curves, with each arrangement confining the crop proportions to fairly specific limits. The 2:2 treatments were better than 2:4 when a sorghum proportion greater than about 0.50 was required whereas the 2:4 treatments were better for lower proportions. Assuming that sorghum/beans treatments could generally fall into one overall envelope, it is interesting to speculate that an even more efficient area could be the relatively unexplored sorghum proportion of about 0.50–0.60. Judging from the treatments so far tried, a row arrangement of 2 sorghum:3 beans, or at least some spatial arrangement giving these crop proportions, might come near to fulfilling this objective.

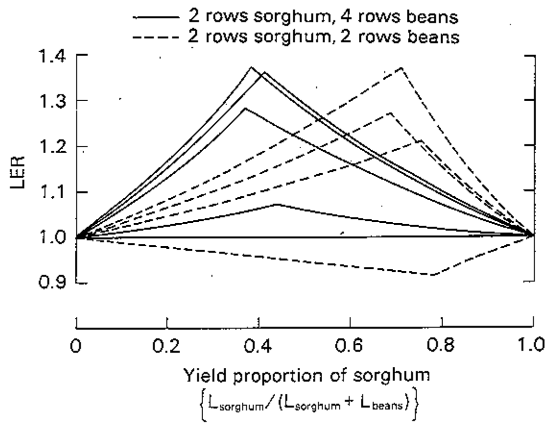

Fig. 3. 'Effective LER' curves for sorghum/beans intercropping at two row arrangements (data from Osiru and Willey, 1972).

A FURTHER GENERALIZATION

In calculating these Effective LERs we have assumed that the sole crop areas which are to be mixed with the intercropped area to obtain the required harvest proportions of the two crops, will comprise the form of sole crop which gives maximum yield. We have also assumed that the maximum sole crop yields are used as the standardising measures in calculating all LERs.

However, it was pointed out earlier that there can often be merit in having different sole crop situations to compare different intercropping treatments; for example, different genotype combinations might logically have their own genotypes as sole crop comparisons, or intercropping treatments at different nitrogen levels might be compared with sole crops at similar levels. Where this is done, each group of treatments with its own sole crop treatment is put on the same relative scale, though all Effective LERs still tend to 1 at each extreme; this is shown in Fig. 4 for an ICRISAT trial on four genotypes of pearl millet in all combinations with four genotypes of sorghum. Each curve shows the *relative* efficiency, or Effective LER, for a given genotype combination assuming that the same genotypes are used for the sole crop comparisons and for the sole crop area included to change the crop proportions. This particular presentation probably does not help practical interpretation as much as in the previous experiments, though it may suggest the possibility of higher LERs with a millet proportion around 0.60.

The groups of treatments related to each sole crop treatment are not clearly identifiable in this form of presentation. However, it may be sensible to standardize this type of genotype data by using only single (maximum) genotype

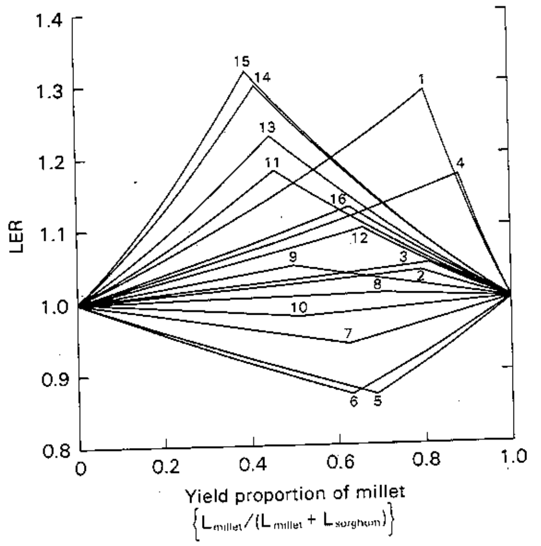

Fig. 4. 'Effective LER' curves for four genotypes of sorghum in all combinations with four genotypes of pearl millet; for any given combination, the standardizing sole crop yields are those of the specific genotypes involved (from ICRISAT unpublished data, 1977).

yields for sorghum and millet. If for each combination it is assumed that the sole crops included to modify the harvested proportions are the genotypes used in that combination (on the basis that each Effective LER curve then examines the efficiency of using only those two genotypes) then we must modify the form of the calculations given earlier. The required proportion of land for intercropping (k) becomes

$$k = \frac{C_A(1-p)}{pL_B-(1-p)L_A+(1-p)C_A}$$

and the Effective LER is

$$\frac{L_BC_A}{(C_A-L_A)+(L_A+L_B-C_A)p}$$

where C_A is the LER value of crop A grown as a sole crop to modify the harvested proportions. This is simply a generalization of the earlier set of equations which are obtained by setting $C_A=1$.

The sorghum/millet genotype data are plotted in Fig. 5 using this alternative approach, each curve tending towards its appropriate C_A values at the extremes, The curves show that only three combinations do better than the best sole crop alternatives, but the overall pattern offers little information on what proportions are likely to produce the highest combined yields.

Another example of this second approach, shown in Fig. 6, uses the data discussed earlier in Table 1 from an experiment comparing seventeen pigeonpea genotypes grown with a single sorghum genotype. There is quite a restricted envelope of curves, with genotypes giving the highest maximum LERs tending to be the best over a wide range of required proportions. The tendency for low maximum LERs to be associated with a high proportion of sorghum reinforces the point that this crop combination tends to give an almost full crop of sorghum with variable amounts of additional pigeonpea; thus a higher pigeonpea yield tends to increase the total LER but decrease the sorghum proportion.

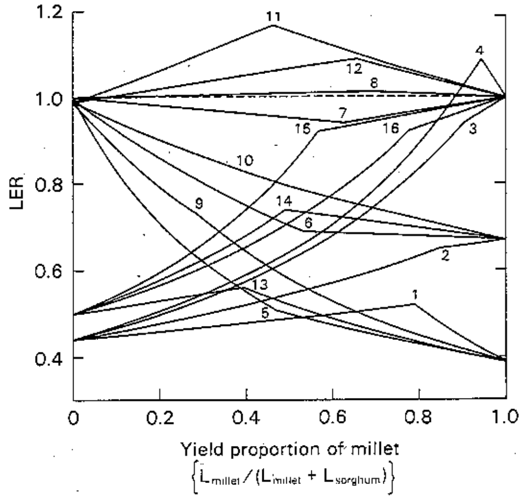

Fig. 5. 'Effective LER' curves for data given in Fig. 4 but with standardizing sole crop yields taken as the highest yielding genotype of each crop.

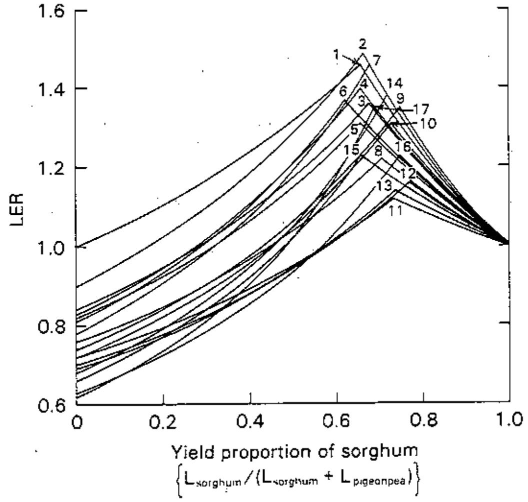

Fig. 6. 'Effective LER' curves for seventeen genotypes of pigeonpea intercropped with a single genotype of sorghum; standardizing sole crop yield for pigeonpea taken as the highest yielding genotype (from ICRISAT unpublished data, 1977 – see Table 1).

CONCLUSION

We believe that the philosophy of the Land Equivalent Ratio is often useful in interpreting data from intercropping experiments, but there is much scope for further investigation. The different methods discussed in this paper should obviously be examined over a wide range of intercropping experimental data and we hope that other research workers will try out these methods. It is also necessary for the statistical properties of the methods to be examined. With data from a wide range of intercropping experiments it should be possible to identify which systems of standardization are more precise. The use of separate replications may be important here, but the validity of analyses of variance may be in question for systems which employ more than one pair of standardizing yields. Another extension of the effective LER curve which could be useful arises from the practical possibility of growing a combination of two intercrops that give different yield proportions instead of a combination of one intercrop and one sole crop.

We believe that the concept of an 'envelope' of effective LER curves may be important in indicating what proportions of crops will give greatest biological efficiency. The tendency for the envelopes observed so far to pack round the 50:50 LER split could suggest that greatest biological efficiency occurs where there is a reasonably equitable sharing of growth resources though it could be due to equal weighting of the two component LERs and only further investigation will resolve this matter. The questions remaining to be answered are many, but they should not be allowed to divert attention from the effective LER curve, which we believe to be a useful practical method for looking at the results of intercropping experiments.

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METHODOLOGY OF
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RECIPROCAL GRAFTS BETWEEN LARGE PLANTS: TECHNIQUE AND EVALUATION WITH COWPEAS†

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SUMMARY

A technique has been developed and tested for successfully grafting large, leafy cowpea shoots onto roots, which may be nodulated or not. Grafting *per se* had no significant effect on either the production or distribution of vegetative or reproductive dry matter compared with control plants left intact throughout growth. Furthermore, numerical components of yield and the concentration (%) and content (mg) of nitrogen in respective plant components were remarkably invariant. Examples are discussed of the variations in nitrogen nutrition which can be achieved and the potentials of the technique in general.

Reciprocal grafts have been used as an experimental tool in a number of studies on grain legumes: to assess the relative importance of roots and shoots in mineral nutrition and in the regulation of protein and oil accumulation in seeds, to measure the effects of variations in shoot:root ratio on growth, nutrient uptake and seed yield, and to quantify the relations between carbon metabolism and dinitrogen fixation. These studies have one thing in common – grafts have been made between young seedlings, sometimes before the first pair of unifoliate leaves were fully expanded, using the general procedure first described by Kleese (1967) and later modified by Bezdicek *et al.* (1972).

During a series of experiments designed to quantify the temporal relations between carbon metabolism and dinitrogen fixation in cowpeas (*Vigna unguiculata* L. Walp.), we particularly wished to use variations in nodulation to complement studies in which the supply of inorganic nitrogen had been varied (by applying large or small concentrations in appropriate nutrient solutions for relatively longer or shorter periods at successive stages of development). The relations between dinitrogen fixation activity; symbiotic longevity, mobilisation of nitrogen from vegetative to reproductive structures, leaf senescence and death, and fruit growth are undoubtedly important (e.g. Pate and Minchin, 1980). However, it is prudent to use a number of techniques and attempt to compile a comprehensive picture from mutually-supporting evidence before advocating a possible scenario – if, indeed one exists. Unfortunately, once present, nodules can neither be 'switched off' or physically removed from the host root without imposing undesirable stresses that are likely to seriously confound the interpretation of data. Clearly, a technique for successfully

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