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A COMPETITIVE RATIO FOR QUANTIFYING COMPETITION BETWEEN INTERCROPS†

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SUMMARY

A simple *competitive ratio* (CR) is proposed as a measure of *inter*crop competition, to indicate the number of times by which one component crop is more competitive than the other. Intercropping data show that this CR term could be useful in (i) comparing the competitive ability of different crops, (ii) measuring competitive changes within a given combination, (iii) identifying which plant characters are associated with competitive ability, and (iv) determining what competitive balance between components is most likely to give maximum yield advantages.

Although intercropping research has greatly increased during recent years there has been little attempt to produce any simple and meaningful measure of the competition which occurs between component crops. The broad effects of competition are of course frequently examined by comparing intercropping with sole crop yields, and this can be particularly useful if yields of the different crops are put on a valid comparable basis by using some relative measure such as the Land Equivalent Ratio (LER – e.g. Rao and Willey, 1980). But these general comparisons have not produced any measure which can be used to define quantitatively the exact degrees of competition in any given situation.

Some quantitative measures of competition have in the past been suggested in ecological or pasture research, but they have usually been proposed for limited situations, and there have been problems in interpreting what a given measure of competition actually means in practice. This paper examines the problems of some of these competition functions and develops the concept of a simple *competitive ratio* (CR), as well as suggesting preliminary ways in which this ratio might be useful.

THE CONCEPT OF A COMPETITIVE RATIO

The competition function which has been most widely used in ecological research is the *relative crowding coefficient* proposed by de Wit (1960). In its original form this compared, for any given species, the actual yield per plant in a mixture with an 'expected' yield per plant, which was the yield which would be achieved if the species experienced the same degree of competition in mixture as in pure stand. Because it was based on yield per plant, however, population pressure had to be constant across mixtures and pure stands and it was

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thus proposed only for use with 'replacement' mixtures (i.e. mixtures which are formed by 'replacing' a proportion of one crop with an equivalent proportion of another). As originally proposed, therefore, it can only be of limited use in intercropping because it cannot be applied to the many 'additive' situations where the total population in intercropping is greater than that of either sole crop. Yet these 'additive' situations can be extremely important because of the evidence that, at least for some combinations, the required optimum populations may be higher in intercropping than sole cropping (Willey, 1979).

It is possible to broaden the use of the relative crowding coefficient simply by basing it on yield per unit area, calculating 'expected' yields on the basis of how much of the area is initially allocated to each crop. Thus for an 'additive' alternate row situation of constant row width the 'expected' yield for either crop would be 50% of its sole crop yield. On this yield per unit area basis, the coefficient can be written:

$$k_{ab} = \frac{Y_{ab}}{Y_{aa} - Y_{ab}} \times \frac{Z_{ba}}{Z_{ab}} \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

where k_{ab} = relative crowding coefficient of crop a intercropped with crop b,
Y_{ab} = yield per unit area of crop a intercropped with crop b (expressed over the area occupied by both crops),
Y_{aa} = yield per unit area of sole crop a,
Z_{ab} = proportion of intercropped area initially allocated to crop a, and
Z_{ba} = proportion of intercropped area initially allocated to crop b.

For a given crop, this coefficient will be greater than, equal to, or less than unity, respectively, if its intercrop yield is greater than, equal to, or less than its 'expected' yield. Moreover, if the *product* (usually designated K) of the coefficients of each crop is greater than, equal to, or less than unity it indicates that there is a yield advantage, 'no effect', or yield disadvantage for intercropping respectively.

In situations where there is 'no effect' of intercropping (i.e. where K = 1 and, of course, LER = 1) an individual coefficient of greater than, equal to, or less than unity means that the given crop is more, equally, or less competitive than its associated crop. However, if there is a yield advantage of intercropping (i.e. if both K and LER are greater than unity), which is after all the situation of most interest, this relationship breaks down because both crops can exceed their 'expected' yield and thus have coefficients greater than unity. As an example of the importance of this aspect, a paper presented elsewhere in this journal (Rao and Willey) cites 13 of 21 pigeonpea combinations and 8 of 21 sorghum combinations that produced yields where both coefficients were greater than unity. In such situations the more competitive crop can still be identified as the one with the higher coefficient, but this highlights a major limitation of these coefficients, which is that a given value for one crop can mean quite different things depending on the coefficient value of the other.

This is because each crop's coefficient indicates the degree of intercrop competition relative to sole cropping and does not really indicate the *between*, or *inter*crop competition. Even comparison of the coefficients for each crop cannot give a quantitative measure of this *inter*crop competition but can only indicate that a given crop is 'more' or 'less' competitive.

A function which has attempted to measure the *inter*crop competition, by relating the yield changes of both component crops, is the *aggressivity* proposed by McGilchrist (1965), originally for replacement situations, though it can be generalized in the yield-per-unit-area form given earlier:

Aggressivity of crop a with $b = A_{ab}$

$$= \frac{\text{Actual yield of } a \text{ when intercropped}}{\text{`Expected' yield of } a \text{ when intercropped}} - \frac{\text{Actual yield of } b \text{ when intercropped}}{\text{`Expected' yield of } b \text{ when intercropped}}$$

$$= \frac{Y_{ab}}{Y_{aa} \times Z_{ab}} - \frac{Y_{ba}}{Y_{bb} \times Z_{ba}} \quad . \quad . \quad . \quad (2)$$

Thus this term indicates the simple *difference* between the extent to which crops a and b vary from their respective 'expected' yields. However, because it is based on a simple difference, there may be difficulties in interpreting it meaningfully when comparing intercropping situations that give different levels of yield advantage. Consider, for example, a range of situations sown with an initial area allocation of 50:50, and achieving relative yields (or LER values) of 0.6:0.4, 0.7:0.5, 0.8:0.6 etc. These would all give the same aggressivity value for the first crop of 0.4. And yet it is difficult to argue that the competitive ability of the first crop, relative to the second crop, is constant across all these situations.

It is therefore suggested that, although aggressivity has the merit of trying to relate the yield changes of both crops, it might be more meaningful to calculate the *ratio* of the two terms in Equation 2 (i.e. the *competitive ratio*, or CR):

$$\mathrm{CR}_a = \frac{Y_{ab}}{Y_{aa} \times Z_{ab}} \div \frac{Y_{ba}}{Y_{bb} \times Z_{ba}} \quad . \quad . \quad . \quad (3)$$

The merit of doing this is more readily seen if the relation is rewritten:

$$\mathrm{CR}_a = \left(\frac{Y_{ab}}{Y_{aa}} \div \frac{Y_{ba}}{Y_{bb}}\right) \times \frac{Z_{ba}}{Z_{ab}} = (\mathrm{LER}_a/\mathrm{LER}_b) \times \frac{Z_{ba}}{Z_{ab}} \quad . \quad . \quad (4)$$

The CR term is therefore simply the ratio of the individual LERs of the two component crops, but correcting for the proportions in which the crops were initially sown. For example, a situation sown at 50:50, which achieved LERs of 0.8:0.4, would give a CR value for the first crop of 2. Since this indicates that the first crop produced relatively twice as much yield, it can be logically taken to mean that the first crop was *twice* as competitive. In other words the CR value gives the exact degree of competition by indicating the number of times one crop is more competitive than the other. Moreover, in contrast to the problems experienced with the two methods above, this relationship will hold true whatever level of yield advantage is being achieved by intercropping (i.e. for any total LER value). Since the CR values of the two crops will in fact be the reciprocals of each other, it will often be sufficient to consider the values of only one of the crops. The following sections examine some intercropping data to illustrate ways in which this CR term might be useful.

SOME POSSIBLE USES OF THE COMPETITIVE RATIO

The competitive abilities of different crops

An earlier paper (Rao and Willey) described experiments in which various 'intercrops' were grown in alternate row combinations with a 'base' crop of long-season pigeonpea or short-season sorghum. Competitive effects were discussed in general terms, but could be examined more precisely using CR values. Thus in Fig. 1, for example, the CR values of the intercrops clearly show that

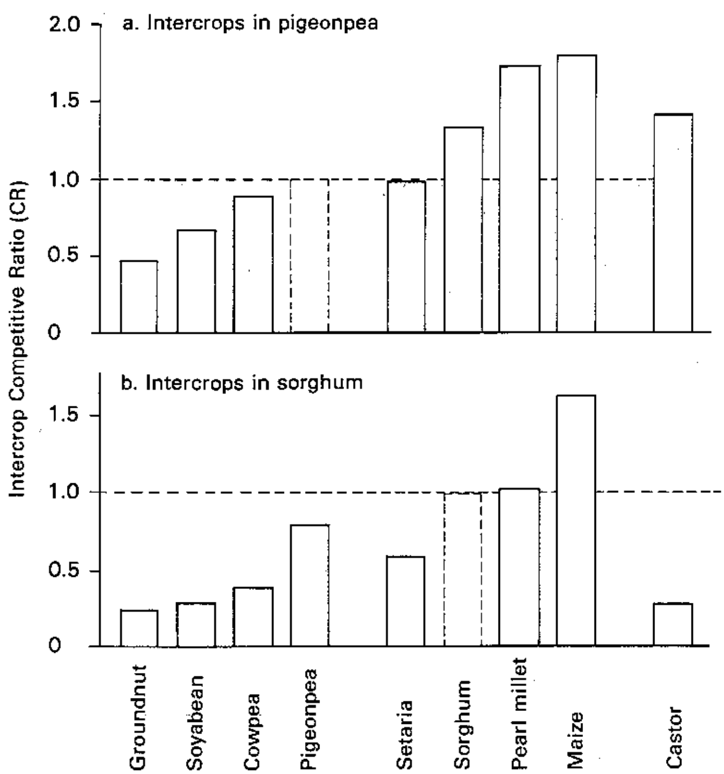

Fig. 1. Competitive ratios of different intercrops grown with a base crop of long-season pigeonpea or short-season sorghum (after Rao and Willey, 1980).

legume intercrops grown with a pigeonpea base crop were less competitive than cereal intercrops, whereas all intercrops were less competitive when grown with a sorghum base crop than with pigeonpea. The most striking feature, however, was that the ranking of competitive abilities for the legume and cereal intercrops was exactly the same with both base crops though this had not been apparent in the earlier examination. The differences in competitive ability of castor, depending on the base crop with which it was grown, were sufficiently large to have been clearly observed earlier, but even here the CR term would be helpful in providing a quantitative measure of these effects.

Competitive changes within a given combination

Many workers have observed changes in competitive abilities of components because of changes in such factors as plant population and spatial arrangement. Such effects might be appropriately examined using CR values, e.g. Fig. 2a and b shows data from Makerere University, Uganda, where either maize or sorghum

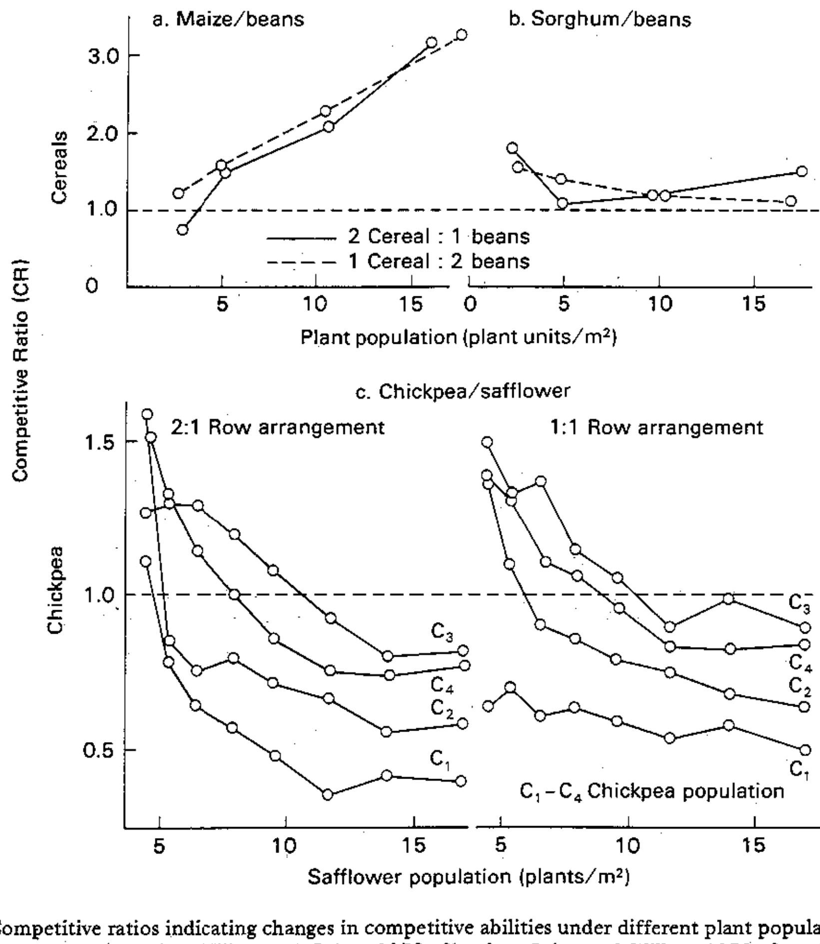

Fig. 2. Competitive ratios indicating changes in competitive abilities under different plant populations and row arrangements (2a after Willey and Osiru, 1972; 2b after Osiru and Willey, 1972; 2c – ICRISAT unpublished data).

was grown with Phaseolus beans, and where CR values again indicate some of the generally observed effects more precisely. Thus with maize/beans, increasing the total plant population markedly increased the competitive ability of the maize at both row arrangements. With sorghum/beans the changes in competitive ability were much smaller, though increasing the total plant population pushed the balance of competition more in favour of the sorghum at the 2:1 row arrangement and more in favour of the beans at the 1:2 arrangement.

A more detailed experiment examined four populations of chickpea at two row arrangements against a wide range of fifteen safflower populations (in a systematic arrangement, though for simplicity only alternate populations are presented here: ICRISAT unpublished data, Fig. 2c). Population changes had similar effects at the two row arrangements, and the competitive ability of chickpea tended to increase with increase in its population (except for a decline at C4) but decreased with increase in the safflower population. These are quite logical effects, which the CR term helps to identify.

Identification of characters determining competitive ability

A further use of the CR term could be in helping to identify plant characters which determine competitive ability. Because it is quantitative, a particular advantage of the term could be that it can be correlated with changes in a given character. This is illustrated in Fig. 3, which shows that CR was positively co-

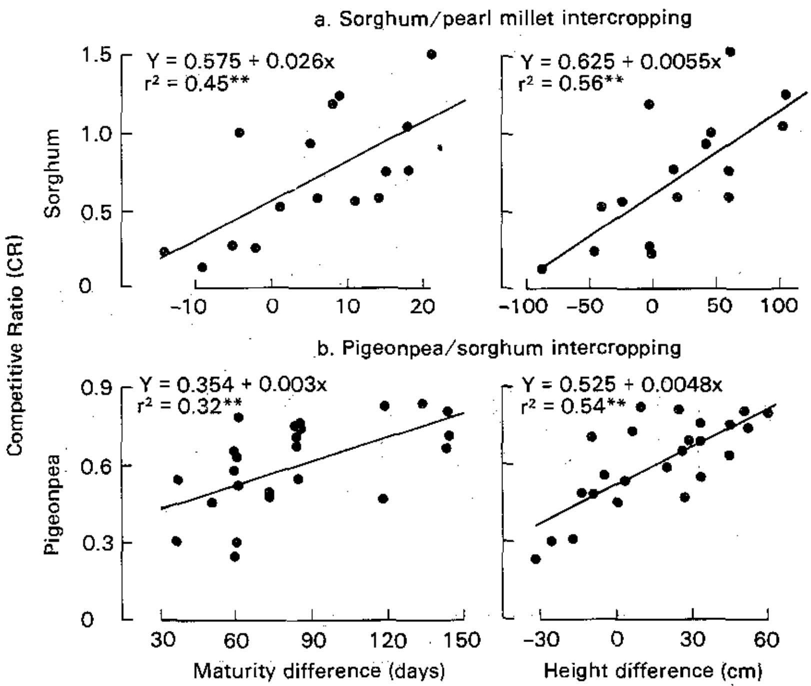

Fig. 3. Competitive ratios indicating the importance of differences in height or maturity as possible determinants of competitive ability (ICRISAT unpublished data).

related with greater height and maturity for the sorghum component in sorghum/millet and for the pigeonpea component in pigeonpea/sorghum. It should however be emphasized that although the CR term may provide a way of defining relations between competitive ability and different plant characters, it does not eliminate some of the problems of interpreting these relations in biological terms. For example, in the sorghum/millet combination it is difficult to see why longer maturity *per se* should make the sorghum more competitive; in fact the real answer is probably that longer maturity was closely correlated with greater height in the genotypes studied, and the latter character undoubtedly does make for greater competitive ability. For slightly different reasons, the apparently greater competitive ability of pigeonpea with greater maturity difference in pigeonpea/sorghum also needs careful interpretation. In this combination the pigeonpea is much later maturing than the sorghum, and does not in fact usually flower until after the sorghum is harvested. Thus longer maturity does not so much make the pigeonpea more competitive as give it more time to compensate after sorghum competition is removed. In this instance the CR term could be said to be indicating the degree to which pigeonpea 'avoids' competition with the sorghum, thus indicating 'complementary' rather than 'competitive' effects. But these difficulties in interpretation are not a shortcoming of the CR term itself, since it simply provides a quantitative measure of the yield changes that occur in intercropping, whatever their cause; such a measure would seem to be a desirable forerunner to deciding what these yield changes actually mean.

Optimum balance of competition between components

Finally, it is rather tentatively suggested that the CR term may in some combinations help to identify the balance of competition between the component crops that is most likely to give maximum yield advantages. This is examined in the population experiments referred to earlier by plotting yield advantages (as LERs) against CR. The sorghum/beans data (Fig. 4a) show a very sharp peak of LER for both row arrangements at a fairly critical range of sorghum CR values a little over one. The similarity between the row arrangements is particularly interesting, because increasing population *increased* the sorghum CR at the 2:1 arrangement but *decreased* it at the 1:2 arrangement (Fig. 2a); yet despite these opposing trends, maximum yield advantages occurred at a similar balance of competition. This is to some extent supported by the maize/beans data, which also indicated a similar optimum balance of competition for the two row arrangements, though the peak in LER was not so sharp and occurred at a range of maize CR values of about 2.1–2.4.

The chickpea/safflower data are presented in the same way in Fig. 4b, though for simplicity all the population combinations are given as 32 individual points. There was again little difference between row arrangements, but the trend was for an increasing total LER with increase in chickpea CR value. Thus where chickpea was the less competitive crop, with CR values of less than

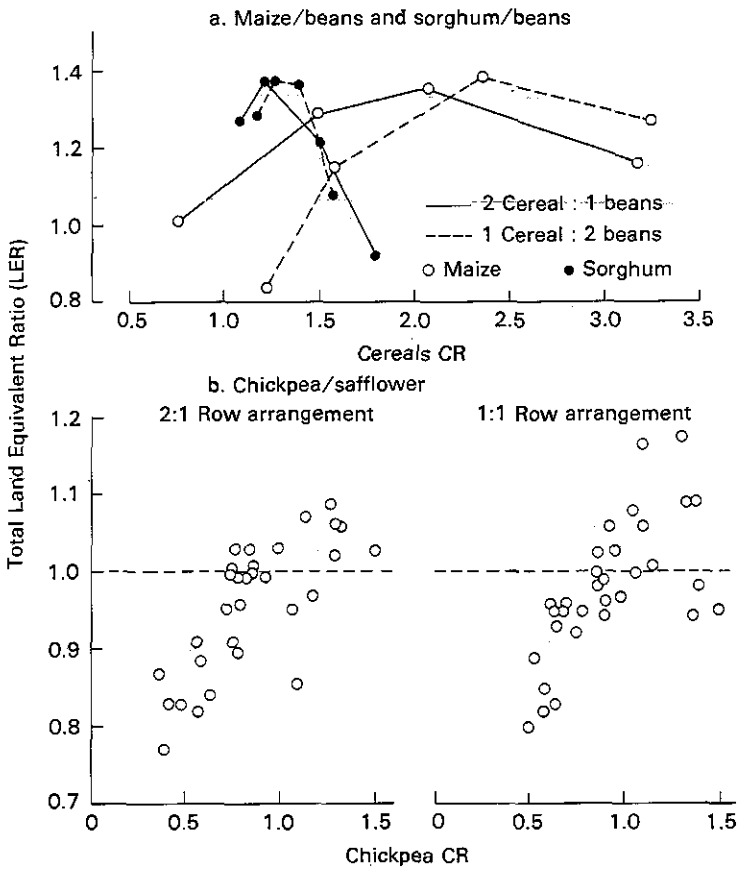

Fig. 4. Relations between yield advantages and competitive ratio (source of data as for Fig. 2).

about 0.8 (in practice, where chickpea population was low and/or safflower high) there were no instances of yield advantages, which only began to occur when the chickpea was at least equally competitive (i.e. with high chickpea and/or low safflower population).

This particular examination of the CR term suggests some extremely interesting relations, but it may not be easy to decide how meaningful they are. The sorghum/beans data indicated that maximum yield advantages occurred where the crops were more or less equally competitive. Assuming that advantages are due in some way to 'complementary' use of resources by the component crops, it can certainly be argued that complementarity could be greatest where each crop exerts a reasonable pressure on resources, i.e. where neither is unduly dominated. This is supported by the chickpea/safflower data which clearly showed that there was no yield advantage if chickpea was dominated (in fact often a marked disadvantage). An especially interesting aspect of this reasoning is that these two combinations showed little effect of row arrangement on the LER/CR relation, though a given crop would have a different final share of the total resources for the same CR value at the two arrangements, e.g. at 1:2 and

2:1, if the first crop had a CR of 1 it would use one-third and two-thirds, respectively, of the total resources. This suggests that maximum yield advantage is not so much determined by the proportion of total resources used by each crop as by the degree of competition between the components, which would emphasize the possible importance of the CR term as a measure of this competition.

The maize/beans data are more difficult to interpret, because they indicated that the highest LERs were where the maize was a little more than twice as competitive. However, even if the reasons for this are not evident, the CR still helps to identify the competitive situation which seems most likely to give maximum yield advantages, on which basis alone it seems to be worth further study.

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