

Design and Analysis of Mixed Cropping Experiments for Indigenous Pacific Island Agroforestry¹

Mareko P. Tofinga²

Abstract: Mixed cropping (including agroforestry) often gives yield advantages as opposed to monocropping. Many criteria have been used to assess yield advantage in crop mixtures. Some of these are presented. In addition, the relative merits of replacement, additive and bivariate factorial designs are discussed. The concepts of analysis of mixed cropping are applied to an example of an alley cropping (a type of agroforestry) experiment, and a basic agroforestry research guide is described.

Mixed cropping is the growing of two or more crops simultaneously on the same land, either with or without distinct row arrangement (Andrews and Kassam 1976), and includes the practice of agroforestry. Mixed cropping was probably the first type of organized crop production (Francis 1986, Plucknett and Smith 1986) and is still widely practiced in the developing world (Osiru and Willey 1972). The fact that intercropping is still widely used in developing countries indicates that the advantages of mixed cropping commonly outweigh the disadvantages in regions where mechanization is rare, inputs are low, and stability of yield is important (Andrews and Kassam 1976, Harwood and Price 1976, Okigbo and Greenland 1976, Francis and others 1976). The fact that mixed cropping is also being seriously considered for certain conditions in developed countries further indicates that this strategy may also be applicable to some forms of mechanized agriculture.

Measuring Yield Advantages

Nazer and others (1987) have commented on the confusingly large number of indices for assessing the yield advantage of crop mixtures compared to pure stands. The large number of indices partly reflects the differences in criteria used to appraise "advantages," often encompassing aspects of quality or value as well as yield, but also reflect the different reasons for which an assessment is made, i.e., an ecological vs. an agronomic assessment.

Ecological Criteria

Probably the oldest established measure of the yield advantage of crop mixtures is the Relative Yield Total (RYT), introduced by de Wit (1960) and explained more fully by de Wit and van den Bergh (1965). The RYT index was designed as a measure of the extent to which various crop components shared

common resources, rather than as a direct measure of yield advantage. RYT is measured by the expression:

$$(1.1) \text{ Relative Yield Total (RYT)} = \frac{Y_{ij}}{Y_{ii}} + \frac{Y_{ji}}{Y_{jj}} \dots$$

where Y_{ii} and Y_{jj} are the biomass yields per unit area of components I and J in pure stands, and Y_{ij} and Y_{ji} are their respective yields in mixtures with each other. The mixtures

$$\frac{Y_{ij}}{Y_{ii}} \text{ and } \frac{Y_{ji}}{Y_{jj}}$$

are termed the relative biomass yields of I and J respectively. A RYT of 1.0 is said to indicate that the components of the mixture fully share the same limiting resources, i.e., they are fully in competition with each other (de Wit 1960, Trenbath 1974). Values of $\text{RYT} = 1.0$ would also occur in the total absence of competition, e.g., if the density of the monocultures and mixtures were sufficiently low (e.g., Harper 1977, Snaydon and Satorre 1989). A RYT value of 2.0 would indicate that the components did not share limiting resources at all, i.e., they did not compete at all for limiting resources. Values between 1.0 and 2.0 would indicate that the components were only in partial competition with each other. RYT values of less than 1.0 would indicate that the crop components suppressed each other more than could be accounted for by competition alone, e.g., by allelopathy (Rice 1974). RYT values of greater than 2.0 would mean that at least one component actually stimulated the growth of the other, but such values have rarely, if ever, been observed. Values close to 1.0 or between 1.0 and 1.5 are most common (Trenbath 1976).

Agronomic Criteria

The most commonly used index of agronomic yield advantage is the Land Equivalent Ratio (LER), first proposed by Willey and Osiru (1972). This index is in fact identical to RYT, since it is obtained by the expression:

$$(1.2) \text{ LER} = \frac{Y_{ij}}{Y_{ii}} + \frac{Y_{ji}}{Y_{jj}} \dots$$

where the symbols are defined as in equation 1.1, except that Y represents grain yields per unit or economic yield rather than biomass yield. The main difference between the two indices is in interpretation, rather than expression, since LER is considered a measure of the efficiency of grain or economic yield production of the crop mixture, compared with sole crops, and based on land use. An LER value of 1.0 indicated that the same amount of land would be required to obtain a given amount of economic yield of each component, regard-

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² Lecturer (Crop Science), School of Agriculture, University of the South Pacific, Alafua Campus, Apia, Western Samoa.

less of whether the two components were grown in mixtures or pure stands. An LER value of 1.2, for example, would indicate that 20 percent more land would be needed to produce a given amount of each of the two crop components in pure stands as in mixtures. The main disadvantage of this index is that it assumes that the proportion of components harvested in the mixture is the required proportion. Several suggestions on assessment of yield advantages have been proposed where a pre-determined amount of one component is required, e.g., a given yield of a staple crop (Willey 1979).

Design and Analysis of Mixed Cropping Experiments

Both replacement and additive experimental techniques have been used in studies of plant competition and mixed cropping (Snaydon and Satorre 1989), though replacement techniques have been more widely used, probably because of the impetus given by de Wit (1960) and the criticisms of the

additive technique made by Harper (1977). However, recent work suggests that the replacement technique may be inadequate to assess competitive interactions and can give misleading results (Firbank and Watkinson 1985, Connolly 1986, Snaydon and Satorre 1989), since the conclusions depend on the density used in monocultures.

The basic problem with the replacement technique is that it confounds intercomponent and intracomponent competition, i.e., whenever the density of component I is increased, that of component J is decreased accordingly, and vice versa. This is equivalent to carrying out an experiment with, say, N and P fertilizer and whenever more N is applied, less P is applied. Clearly, if the separate effects of I and J on each other are to be identified, the densities of the components must be varied independently, i.e., an additive design used. Other designs will be considered in more detail later.

The hypothetical examples shown in figure 1.1 indicate that replacement designs confuse the interpretation of RYT (or LER). When the components compete with one another, RYT (or LER)

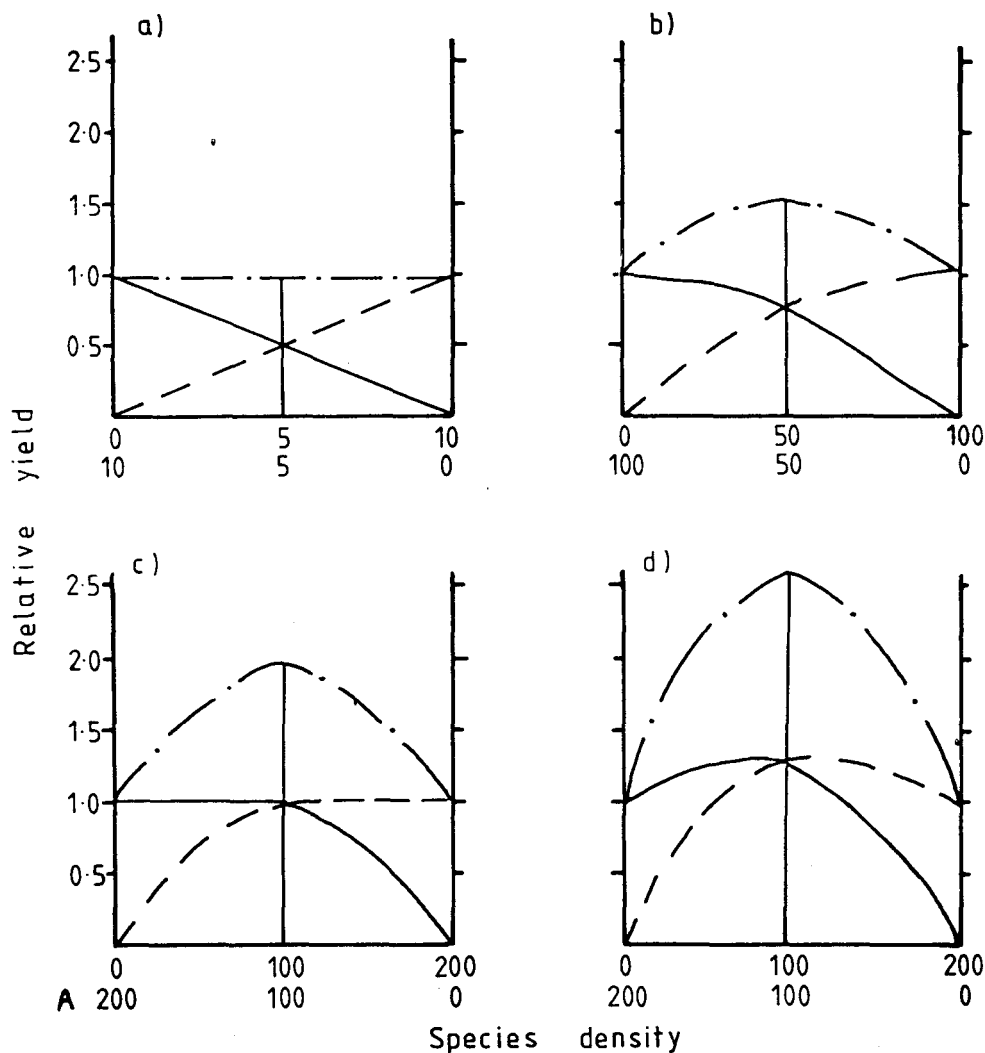


Figure 1.1a-1.1d

values can vary between 1.0 and >2.0 , depending on the density of the monocultures and the nature of the yield-density relationship. Assuming that the density-yield response is asymptotic, and that the components do not compete with each other, the RYT values of a 50:50 replacement mixture would be 2.0 as long as the monoculture was equal (or greater than) twice the asymptotic density (fig. 1.1 c). However, the RYT value would be less than 2.0 when the monoculture density was less than twice the asymptotic density (fig. 1.1b), and would be 1.0 if the monoculture density was so low that no competition occurred between plants in each component (fig. 1.1 a). Conversely, RYT values of >2.0 would be obtained (fig. 1.1d) when monoculture density was twice the asymptotic density, and where the yield declined at high density, as often happens with grain crops (Willey and Heath 1969). In contrast to this, the RYT values of 1:1 additive mixtures would always be 2.0, regardless of monoculture density or density response, since the yield of each component in mixture is always compared with the yield at an identical density in monoculture.

Both replacement and additive designs can be thought of as limited samples of a bivariate array based on densities of compo-

nents I and J (fig. 1.2). Replacement series constitute a linear sample running diagonally across the array and normally ending with identical densities for the two components (fig. 1.2), though the pure stand densities of the two components need not be identical. Additive series constitute horizontal and vertical lines, in which the density of one component is held constant, while that of the other is increased (fig. 1.2); a 1:1 mixture therefore occurs when the density of both components in the mixture is the same as that in its pure stand (fig. 1.2). Both replacement and additive series can be used at a wide range of overall densities. By presenting density combinations as bivariate arrays (fig. 1.2), it becomes apparent that, by including two pure stand densities for each component in an experiment, where one density is double the other, than the experiment can be analyzed as both a replacement and an additive design. However, it is also clear that such restricted sampling of bivariate array gives only a limited interpretation of the whole response pattern, and that ideally it would be better to use a bivariate factorial design, in which all possible combinations of several densities of each of the component is included.

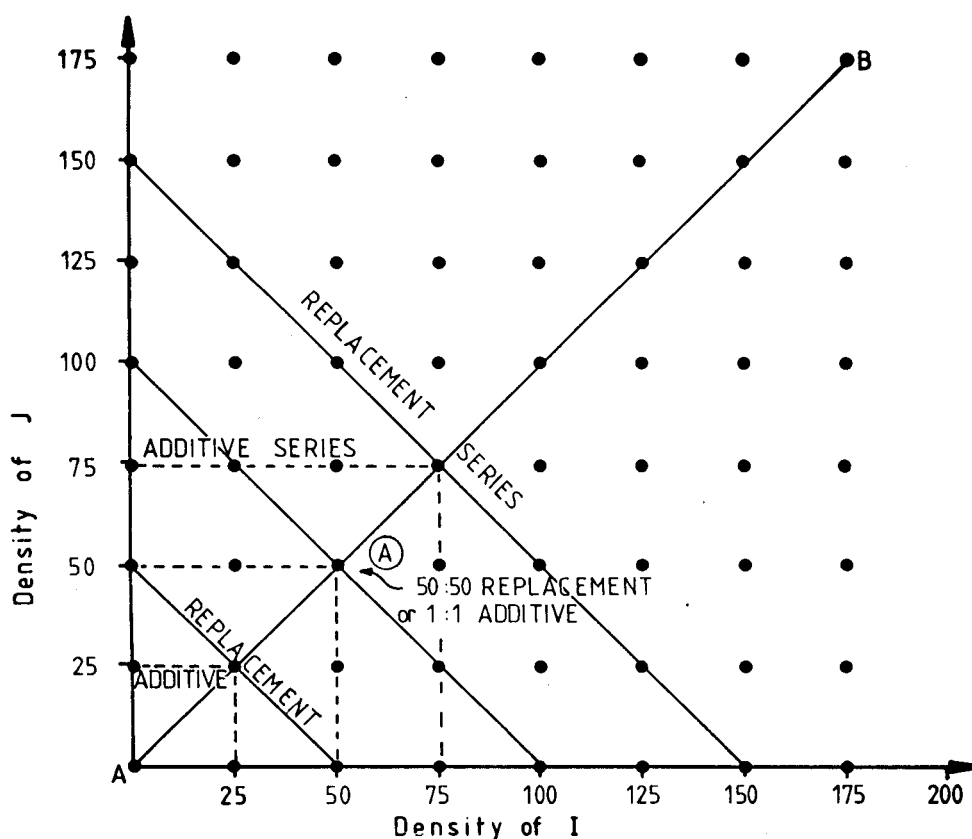


Figure 1.2-A A bivariate array of the densities of two components (I and J) grown in monocultures and various mixture combinations. The diagram shows how replacement and additive series are limited samples of a much wider bivariate factorial array, and how a single mixture A can be seen either as a 50:50 replacement mixture or a 1:1 additive mixture.

Mixed Cropping Design and Analysis for Pacific Island Agroforestry

Agroforestry in the Pacific Islands may be classified as the simultaneous cropping of perennial and annual crops along with animals (Raynor 1987) or without animals (Finlay 1987). A modified form of an experiment involving the growing of taro (*Colocasia esculenta*) between alleys of trees (*Gliricidia sepium* and *Calliandra calothyrsus*) and using mulch from the trees to mulch taro (Clements and others 1987) is presented as an example of an agroforestry experiment, where use of designs and analysis in mixed cropping studies may be applied. Modification of the experiment is necessary since agroforestry in the Pacific normally involves many crops grown between perennials.

The modified form consists of the addition of maize to the experiment, alternating with the rows of taro. The experiment is a 2 x 3 factorial in Randomized Block Design replicated three times. The treatments consist of a) 2 tree species (*Gliricidia* and *Calliandra*), b) 3 tree spacings (4, 5, and 6 m between rows), c) one crop stand (taro and maize). In addition, a pure stand of taro and a pure stand of maize were included. The densities of the crops (taro and maize) in mixtures is the same as their densities in pure stands, i.e., an additive design.

Analysis of variance can be performed separately for each crop (taro and maize) on all measures, log transformation can be used where necessary to homogenize the variance. Analysis of variance (ANOVA) can also be carried out on derived measures, such as Relative Total Yield (RYT) and Land Equivalent Ratio (LER) on data from taro and maize. ANOVA can be computed using the methods of Snedecor and Cochran (1980). Yield advantages of mixtures (taro and maize) can be expressed as Relative Yield Total for biomass (de Wit 1960, de Wit and van den Bergh 1965) or Land Equivalent Ratio for economic yield (Willey and Osiru 1972, Trenbath 1976.)

Since the function of the tree species in the experiment is to provide mulch for the crops through regular pruning, ANOVA can be carried out on the amount of mulch produced. ANOVA of the nutrient contents of the mulch, e.g., N, P, K, would also be useful to assess the performance of the trees for alley cropping and other types of agroforestry.

A Research Guide for Pacific Island Agroforestry

Since tree crop components of agroforestry have already been established in many cases, and yields may not be easy to assess, it seems sensible to concentrate on the annual or semi-perennial components of the system to be studied. Two crop species could be grown between tree crops which should preferably be in rows. Having both tree crops and annual or semi-perennial crops in rows will facilitate some mechanization.

In selecting the annual or semi-perennial species component of the system, crops of contrasting growth habits should be selected, e.g., contrasting canopy types, morphology, and root systems. These contrasting types often give yield advantages when grown together (Tofinga 1990). A range of cultivars of each species may then be grown together in two crop mixtures at

optimum plant densities for each crop. Pure stands of the cultivars of each crop should be included for comparative purposes and for the assessment of yield advantages of mixtures compared with pure stands. The densities of crops in mixtures should be the same as their densities in pure stands, i.e., an additive design should be used.

The crops should be grown in alternate rows. Analysis of this "screening trial" using indices mentioned earlier should indicate the best mixture of the crop species. The selected crop mixture can then be grown in different planting patterns, e.g., both crops can be grown in the same row, in alternate rows, in alternating double rows, and so on. Planting patterns have been known to influence the performance of crops in mixtures (Martin 1979, Tofinga 1990).

Having identified the best planting pattern for each crop, the effects of several densities of both crops and several fertilizer levels could be investigated together or in separate experiments. These various trials should cover the basic research necessary to establish an agroforestry system based on scientific methodology. Such agroforestry systems should give larger yield advantages compared with growing the crops in monocultures. Growing crops in monocultures is an introduced practice which has generally been found to be unsuitable for the Pacific islands, mainly because it gives less overall yield compared to growing crops in mixtures (Tofinga 1990). The basic research method described in this paper may be adapted to include three or more crop combinations with perennial trees. The effect of the intercrops on the trees could be assessed by comparing the yield of trees in agroforestry mixtures with yield in pure stands.

Conclusions

Agroforestry will play a major role in the Pacific islands as population continues to increase and the challenge for more efficient food production systems becomes a reality. More research will have to be carried out to improve traditional agroforestry. Improved research depends on the use of improved designs and analysis methods. The use of additive designs is recommended since replacement design can give misleading results. The bivariate design may be too large and complex to manage. Agroforestry experiments should include two or more crops grown between perennial trees (which may or may not be a crop) instead of just one crop grown between non-crop trees. This is because agroforestry in the Pacific involves many crops in mixtures.

Relative Yield Total (RYT) may be a useful index to use in agroforestry experiments since it measures resource use by the mixture. Land Equivalent Ratio (LER) is also useful from an agronomic point of view. Separate analysis of variance of yield and yield-related characteristics for each crop may give an idea of the effect of one crop on another and the time of competition during crop growth. These are useful in deciding which mixtures; complement each other in an agroforestry situation and when to reduce competition between the crop components through appropriate management. The development of basic research methodologies for Pacific island agroforestry is an essential framework for future improvement of these systems.

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