INTERCROPPING, DEVELOPING COUNTRIES, AND TROPICAL AGRICULTURE

by

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BU-1016-M

March 1989

Problems and considerations associated with conducting intercropping or mixed-cropping experiments in developing countries are discussed. Limited usefulness of standard statistical procedures has been found for analyzing and interpreting the results from intercropping investigations. Some useful linear combinations of crop yields from a mixture are discussed, among them a land equivalent ratio.

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Intercropping and Developing Countries.

Intercropping is defined to be the growing of two or more cultivars either simultaneously or sequentially on the same area of land. It is a centuries-old agricultural practice dating back to before Biblical times (See The Holy Bible, Leviticus 19:19 and Deuteronomy 22:9-11.). Not only is intercropping a way of life in many regions, it is a method of survival agriculture. Intercropping is most popular in developing countries and in tropical agriculture. According to Kass (1978), it may be the predominant type of agriculture in some regions, ranging from 50% to 90%. "Chemical agriculture" using fertilizers, herbicides, and pesticides has become popular and almost universal in temperate zone agriculture. This type of agriculture is highly mechanized and is associated with high labor costs, both of which work against the use of intercropping systems. Certain herbicides may be toxic to some of the cultivars in a mixture, thus ruling out intercropping for this mixture. With present methods of mechanization and costs of chemicals, sole cropping or monocropping may be more profitable than intercropping in some areas. It should be pointed that mechanization has been directed at sole cropping with little attention being paid to mechanizing intercropping systems.

Since most agricultural researchers and statisticians receive advanced training in educational institutions dominated by sole cropping and single response variable mentalities, they often attempt to plan, design, analyze, and interpret intercropping investigations in the framework of what they know about sole cropping investigations. From experimental results that have come to the author's attention, he has been lead to the following rule: *It is often misleading and inappropriate to generalize from single cropping investigations to intercropping investigations for two cultivars and from investigations with mixtures of two cultivars to investigations with three cultivars, from three to four cultivars, etc.* Another rule that has been helpful in the interpreting results from intercropping experiments is: *Expect the unexpected when interpreting the results from an intercropping investigation.* After visiting at the International Institute of Tropical Agriculture (IITA), the International Institute for Rice Research (IIRR), and research centers in Brazil and India which are located in areas where intercropping is prevalent, it has been startling to see the proportion of effort and thinking directed toward sole cropping investigations. Even statistical design and analysis is in this framework. Fortunately, there are some individuals who think as intercroppers. Three outstanding examples are Bede Okigbo at IITA, Charles Francis at the University of Nebraska, and Robert Willey at ICRISAT in India. The author feels that their writings are on a "must read" list for intercropping investigators.

In the same vein as the above, the following statement by Pearce (1988) should be carefully considered by intercropping investigators: "The first rule of overseas development is to respect the local people, their way of life and their religious practices as well as their agriculture." Disrespect for their agriculture is shown when temperate zone practices are recommended to replace age-old tropical agricultural practices. An example is the introduction of chemical agriculture and sole cropping to replace the present system without studying the insect, disease, soil erosion, soil nutrient depletions, and long term effects caused from these procedures.

Likewise, the statistician must don a different thinking cap when giving statistical advice for intercropping investigations. The predominance of emphasis in the teachings and writings on statistical procedures is for single responses normally and identically distributed, none of which holds for intercropping investigations. Of course some of the standard textbook statistical methodology can be used as a first approximation but this should not be carried too far. At first thought, it would appear that statistical multivariate techniques would be useful. However, as pointed out by Federer and Murty (1987), presently available multivariate statistical procedures have limited usefulness for analyzing the results from intercropping investigations.

Tropical Agriculture.

The problems of tropical agriculture are often vastly different from those encountered in temperate zone agriculture and often require quite different solutions. Chemical control of insects has been quite successful outside the Tropics but often is unsuccessful in the Tropics. Some strains of insects develop resistance to chemical compounds in a relatively short period of time, thus making the chemical useless for controlling the insect population. Tropical soils without ground cover and vegetation may suffer severe erosion problems within a short period of time. That the environment in the Tropics is fragile is amply demonstrated in the Amazon Region of Brazil when the natural vegetation was removed and in Ethiopia when the cropping systems were changed and a drought occurred. Adherence to the above quoted statement by Pearce (1988) is considered a necessity for the fragile environmental equilibrium found in Africa and other similar regions of the World.

The majority of the agriculture for developing countries in the Tropics is done on small acreages by farmers growing food mainly for their families and perhaps some for the local markets. This is survival agriculture in that there may be no other source of food for the farmer and if he does not grow it his family starves. Also, the entire family may be involved in the production of food, that is the farm is very labor-intensive. Intercropping systems over the centuries have demonstrated that the probability of crop failures is much lower for these systems than it is for sole cropping systems (See Pearce and Edmondson, 1982, e. g.). The growing of several cultivars allows for diversity of food types and allows for the possibility of producing food continuously for a family and possibly for the local market. In fact, one desideratum of a cropping system in Nigeria is that enough food is produced so that the wife can take some to market each week for sale or barter.

Statistical Procedures.

A common practice in statistical teaching and writing is to use a statistical technique with a particular example. Seldom is more than one statistical analysis used for a given data set. This sometimes leads the student and users of statistical procedures to think that there is only *one* statistical analysis for each data set. They also get the idea that each field or even type of experiment has its own unique statistical procedure. For example, they think that techniques suitable for analyzing an experiment with maize cultivars are not useful for an experiment involving brands of light bulbs. This is the first misconception that needs to be surmounted when considering intercropping investigations. Here, several statistical analyses for the same data set may be, and often are, required. The different users of results from intercropping experiments have different goals and objectives. Different analyses and/or different formulations may be required for each of the objectives.

To illustrate the preceding, suppose that a mixture of three crop species is grown, e. g. maize, beans, and cowpeas, and that several cultivars of each crop species, n_m, n_b, n_c, respectively, are available. Suppose that it is desired to compare the mixtures for

(i) total caloric (or protein) content for the nutritionist,

(ii) total mixture value for the economist,

(iii) efficiency of land use for the agronomist or linear programmer,

(iv) maximum discriminating ability among treatments for the statistician,

(v) assessing the relative general and specific abilities (how well or how poorly a cultivar performs in the different mixtures) for the biological researcher,

and perhaps several others. The only practically defensible and sensible way to combine the responses from the three components of a mixture is to use a *linear combination* of the yields (in pounds, kilograms, or numbers) of the three individual cultivar yields. For mixtures of cultivars which do not allow procurement of the individual component yields (e. g. a mixture of three similar wheat cultivars), the linear combination is simply the sum of the three component yields.

Given that the yields are in kilograms, Y_m = yield of maize, Y_b = yield of beans, Y_c = yield of cowpeas, c_m = the calorie conversion factor for a kilogram of maize, and c_b and c_c be similar factors for beans and cowpeas, the total caloric content for a mixture i would be:

$$c_m Y_{mi} + c_b Y_{bi} + c_c Y_{ci} = C_i \,. \tag{1}$$

It makes no sense to use a transformed version of yields in (1) to satisfy some statistical consideration. Note that Y_{mi}, Y_{bi}, and Y_{ci} belong to a trivariate distribution of nonnegative correlated random variables.

To assess crop value for the farmer or the economist, simply replace c_m with p_m = the value of a kilogram of maize, c_b with p_b = the value of a kilogram of beans, and c_c with p_c = the value of a kilogram of cowpeas in equation (1) above. To study efficiency of land use, replace c_m with $1/Y_{ms}$, c_b with $1/Y_{bs}$, and c_c with $1/Y_{cs}$ in equation (1), where Y_{ms} = sole crop yield of maize, Y_{bs} = sole crop yield of beans, and Y_{cs} = sole crop yield of cowpeas. This form of (1) is known as a land equivalent ratio (LER) (See, e. g. Mead and Riley, 1981). For the statistician, the coefficients in (1) are obtained from a discriminant function analysis where the coefficients are selected to maximize the ratio of the treatment sum of squares for the C_i in (1) to the treatment plus error sums of squares. The coefficients are uninterpretable by the investigator but they do achieve the statistician's goal of maximum discriminating ability (See, e. g., Federer and Murty, 1987).

Since a ratio of prices, values, and yields is more stable than are the actual prices, values, or yields, equation (1) may be rewritten as follows for comparative purposes:

$$Y_{mi} + b_b Y_{bi} + b_c Y_{ci} = C_i^* \tag{2}$$

where $b_b = c_b/c_m$ = a, say, $b_c = c_c/c_m$ = d, say. One of the crop species, in this case maize, needs to be selected to have a coefficient of one and then the other coefficients in (1) are divided by the coefficient for this crop. For prices and yields, a and d would usually be in the range 3 to 7. Thus, statistical analyses for the variable in (2) could be carried for high, average, and low values for a and d in the region where they would be used. For a discriminant function analysis, the appropriate values of a and d would be those which maximize the following quantity:

$$D=\frac{T_{mm}+a^2T_{bb}+d^2T_{cc}+2aT_{mb}+2dT_{mc}+2adT_{bc}}{T_{mm}+E_{mm}+a^2(T_{bb}+E_{bb})+d^2(T_{cc}+E_{cc}+2a(T_{mb}+E_{mb})+2d(T_{mc}+E_{mc})+2ad(T_{bc}+E_{bc})} \tag{3}$$

where T_{jk} is the treatment sum of squares or cross-products and E_{jk} is the error sum of squares or cross-products for j,k = m, b, c. The values for a and d may be obtained by trial and error or using standard multivariate procedures such as, e. g., found in computer software packages.

In order to have statistical distributions for responses in equations (1) or (2) that have finite variances, the coefficients should not be random variables but should be fixed constants. For example with an LER, the yields of the sole crops could be random variables obtained from the experiment or they could be considered as fixed values obtained from crop records for the region over a period of years. If the former, values of zero are possible and in some cases quite plausible. Division by zero is not permissible and leads to distributions with infinite second moments. This certainly holds true for two normally distributed variates. Sums of products and ratios of random variables present distributional dilemmas for the statistician. However, linear combinations of random variables pose no problems for the statistician. Hence, using constants for the coefficients in equations (1) and (2) gets rid of the statistical difficulties.

Spatial, Density, and Intimacy Relations.

Spatial arrangement refers to the arrangement of plants or rows of plants in the area occupied by a mixture; density refers to the number of plants per hectare for each component of a mixture; and intimacy refers to the nearness of plants of the different components of a mixture (See e. g., Mead and Riley, 1981). For example, if the intercrops are maize and beans, the bean and maize plants could be in the same row, the maize rows could be one meter apart and the bean rows one-half meter apart interspersed between the maize rows, the maize could be planted in pairs of rows one-fourth meter apart with one and three-fourths meters between pairs and the bean rows could be planted one-half meter apart interspersed between the pairs of maize rows, or some other arrangement could be used. In the preceding examples, the density could remain constant but the spatial arrangements and intimacy relations vary. For each mixture, it may be necessary to determine the appropriate density, spatial, and intimacy relationships.

Extrapolations for one of the above items may be completely misleading. For example, an intercropping experiment of a maize cultivar with densities at 20,000, 40,000, and 60,000 plants per hectare and a bean cultivar at 0, 40,000, 80,000, 120,000, and 160,000 plants per hectare was grown in Brazil. At 20,000 maize plants per hectare, the addition of bean plants at the above densities, decreased the yield of maize when compared to the sole crop. At 40,000 maize plants per hectare, the amount of the decrease of maize yields with increasing bean densities was not so noticeable. However, at 60,000 maize plants per hectare, all bean densities except 160,000 bean plants per hectare, resulted in increased yields of maize with the 120,000 density of beans resulting in almost 50% increase in yield. If the experiment had been conducted at only the two lower densities of maize, the conclusion could have been that maize yields for this cultivar will always be lowered when intercropping with beans, a conclusion shown to be false by the experiment that was conducted. Although the above happened for this particular cultivar, this does not mean that other cultivars will respond in a similar manner. Examples of cultivar differences have also been encountered.

Some Comments.

In planning intercropping experiments and in analyzing and interpreting the results, it has been the author's experience that the degree of difficulty in going from sole cropping experiments to intercropping experiments with two crops goes up by an order of magnitude.

In going from intercropping experiments for mixtures of two to mixtures of three or more crops, the degree of difficulty goes up by another order of magnitude. The researcher and the statistician must be prepared to do some heavy thinking for each intercropping situation. Reliance on past experiences may be misleading. A person entering the realm of intercropping should first become familiar with the concepts, subtleties, and analyses for intercropping with mixtures of two before moving on to mixtures of three or more. In this vein, the author has written a textbook entitled "Statistical Design and Analysis for Intercropping Experiments, Volume I Two Crops"; the book is in the process of publication. A second volume, Volume II Three or More Crops, has been started with two chapters presently completed and with most of the needed theory having been completed.

Literature Citations.

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