Discussion of "A Review of Statistical Ideas Relevant to Intercropping Research", by R. Mead and Janet Riley, Journal Royal Statistical Society, Series A, 144(4)

by

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BU-739-M

May 1981

ABSTRACT

The authors are reporting on an extremely important topic which will become more important as time goes on. The problem of mixtures, whether with crops, nutrients, drugs, surveys, educational programs, or other entitles, is a sorely neglected one in Statistics. Much work, creativity, and thought will be needed to solve the statistical design and analysis problems for these fixed-ratio mixture experiments.

It appears too simplistic to categorize mixed cropping systems as either intercropping or competition as Doctors Mead and Riley have done. We have found that both agronomic and biological objectives (as described by the authors) are present in a single experiment and that the results for one are useful in interpreting the results for the other objective. We find it more instructive to consider the divisions of comparative objectives and response modeling objectives. As one never knows the true response model, and it is naive to assume that one does, it is necessary to investigate and develop models which are reasonably good approximations to the true situation for any particular intercropping experiment. Also, we have found it quite useful and instructive to consider several statistical analyses for intercropping experiments, including univariate and multivariate analyses on individual crop responses. No one satisfactory statistical analysis procedure has been found. Multivariate analyses have the difficulties described by Doctors Mead and Riley and hence are not the answer. We have found that the LER's are relatively useless for comparative purposes, and feel they should only be used for one particular mixture in connection with the sole crops of that mixture. But, even doing this, we have no confidence interval for the LER. One should note that the LER and K_1 statistics of Section 3.1 can take on the value of infinity and that K_1 could be negative. One wonders at the usefulness of developing LER-related and stability statistics without knowing their distributional properties.

Section 2.6 is full of personalistic beliefs and assumptions. One could simply say that "in experiments involving varying densities and/or spatial arrangments, it may be much more efficient cost-wise and space-wise to use a systematic arrangement of varying densities such as fan-shape, snail-shape, circular-shape, etc., in preliminary studies. It has been shown by R. A. Fisher (Design of Experiments) and others that the error variance is overestimated and that gradients may bias the treatment effects in systematically arranged experiments."

Doctors Mead and Riley make the point that many people, including statisticians, do not understand a split plot design. (I couldn't agree with them more and have written an article entitled "The Misunderstood Split Plot", Applied Statistics (Ed., R. P. Gupta), North Holland, pages 9-39.) However, they appear to be biased against its use. A statistician should only select an experiment design that controls the heterogeneity present in the experiment and that meets the requirements of the experiment.

Discussion of Paper by Mead and Riley

(by Walter T. Federer, Cornell University)

The authors are reporting on an extremely important topic which will become more important in all parts of the world. The problem of mixtures, whether with crops, nutrients, drugs, surveys, educational programs, or other entities, is a sorely neglected one in Statistics. In many types of mixtures the ratio is fixed and the problem is not to estimate the ratio giving a maximum, a minimum, or some other characteristic of the response function, but rather to use a vector of responses for comparing mixtures or modeling responses. Intercropping falls mostly into this fixed-ratio mixture type in that cultivars, genotypes, or species are selected for their performance in a fixed-ratio set-up. The replacement series discussed in Section 2.5 is not of the fixed-ratio type. Additional reasons for growing mixtures of crops will surface as the cost of energy increases. In fact, several experiments being conducted by EMBRAPA in Brasil, use different types of bacterial inoculations and different crops to replace some or all of the inorganic fertilizer requirements. Much work, creativity, and thought will be needed to solve the statistical design and analysis problems for these fixed-ratio mixture experiments.

It appears too simplistic to categorize mixed cropping systems as either intercropping or competition as Doctors Mead and Riley have done. We have found that both agronomic and biological objectives (as described by the authors) are present in a single experiment and that the results for one are useful in interpreting the results for the other objective. We find it more instructive to consider the divisions of comparative objectives and response modeling objectives. As one never knows the true response model, and it is naive to assume that one does, it is necessary to investigate and develop models which are reasonably good approximations to the true situation for any particular intercropping experiment. The "general linear model" does not suffice.

Model development is essential to the understanding of a phenomenon. Little has appeared in statistical literature on model development and selection, but tools like exploratory data analyses are useful to check the adequacy of a proposed model. Also, we have found it quite useful and instructive to consider statistical design and analyses for intercropping experiments as follows:

A. <u>Mixtures of two crops</u>

a) one main crop.

b) both crops main crops, density constant.

c) both crops main crops, densities variable.

d) modeling responses for both of the crop responses when responses are separable and when they are not.

e) spatial arrangements for the above.

B. <u>Mixtures of three or more crops</u>

a) one or two are main crops.

b) all are main crops, density constant.

c) all are main crops, densities variable.

d) modeling responses both when individual responses are available and when they are not.

e) spatial arrangements for the above.

For each category we perform a variety of statistical analysis involving univariate and multivariate analyses on individual crop responses. Here most problems can be handled with available statistical theory. The majority of papers on results from intercropping experiments use this approach and do no further analyses. Then, we use combined responses from all crops in the mixture using several methods such as total economic value, total profit, total calories, total protein, multivariate analyses procedures, and land equivalent ratios. Another form of combined analyses not used to date is a farmer's value for a crop. For example, a farmer growing barley for beer has a different value than one growing barley for chicken feed; a farmer whose family does not like to eat maize has a different value from one whose family loves all types of maize food; the farmer who wishes to have produce to sell at the marketplace every week most likely will grow different crops than the farmer who only wants to produce enough food for his family; etc. One could most likely handle this problem in the same manner as one does for total economic value.

We have found no one satisfactory statistical analysis procedure, and hence have resorted to using several for each experiment. Multivariate analyses have the difficulties described by Doctors Mead and Riley and hence are not the answer. We have found that the LER's are relatively useless for comparative purposes. An analysis of variance and resulting F statistics on LER values are fraught with many statistical, philosophical, and practical difficulties. We feel LER's should only be used for one particular mixture in connection with the sole crops of that mixture. But, even doing this, we have no confidence interval for the LER. One should note that the LER and K_1 statistics of Section 3.1 can take on the value of infinity and that K_1 could be negative. One wonders at the usefulness of developing statistics without knowing something of their distributional properties. It appears that a lot of work is being expended on LER-related statistics and stability statistics, and one wonders to what end. A thorough investigation of the objectives and proposed statistics of the above type appears in order. For one of the stability "correlations", it will be necessary to obtain the distribution of the correlation coefficient, given that the pairs of values are themselves correlated. An analysis of variance on LER's will involve various types of correlations among the LER's. Statistics textbooks, in general, do not indicate how to handle correlated as opposed to independent data. Statisticians enjoy their IID classroom world!

As I have told Dr. Mead, I would trust him with what he writes about systematic designs, but I would not trust experimenters to read his writings and draw conclusions about using systematic designs. An experimenter could easily draw the conclusion from this paper that there is no need for randomization in experimentation because Doctors Mead and Riley said so. Also, I find Section 2.6 full of personalistic beliefs and assumptions. One could simply say that "in experiments involving varying densities and/or spatial arrangements, it may be much more efficient cost-wise and space-wise to use a systematic arrangement of varying densities such as fan-shape, snail-shape, circular-shape, etc., in preliminary studies. It has been shown by R.A. Fisher (Design of Experiments) and others that the error variance is overestimated and that gradients may bias the treatment effects in systematically arranged experiments." Experimenters are citing the Nelder (1962) paper as a reason for not randomizing in experiments. Hence, it is necessary to point out the possible problems of using systematically increasing densities (or amount of water, insecticide, etc.), but that it certainly can be used in a preliminary experiment to obtain an idea of what densities and arrangements to use in the next experiment. This is what B.N. Okigbo does with his circular-shape plot (personal communication). Hence, most of Section 2.6 could be omitted without loss.

Doctors Mead and Riley make the point that many people, including statisticians, do not understand a split plot design. (I couldn't agree with them more and have written an article entitled "The Misunderstood Split Plot", Applied Statistics (Ed., R.P. Gupta), North Holland, pages 9-39.) However, they appear to be biased against its use. A statistician should only select an experiment design that controls the heterogeneity present in the experiment and that meets the requirements of the experiment.

Statisticians interested in the challenge offered in this area should be open to the problems of model development and selection, should be able to delineate a population for inference purposes by an experimenter, should be expected to have creativity in developing response models, should realize that there is more to Statistics than inference, and may need to have considerable mathematical ability to solve some of the distributional problems. Present procedures may need to be extended or new ones developed.