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9. ABSTRACT


The Universities of Hawaii and Puerto Rico have formulated two projects with the assistanc of United States, Agency for International Development (USAID) to undertake some of the necessary research and to design an extension delivery and communications system that will hasten the application of tropical agricultural research.

The purpose of the projects are to correlate food crop yields on a network of benchmark, soils, and to determine scientifically the transferability of agro-production technology among tropical countries.

The benchmark soils will belong to related soil families as defined in The U.S. Soil Taxonomy, because the family is the level in this soil classification system at which transference of technology is providing possible within the United States. They will be red upland soils or soils developed from volcanic ash which in most tropical countries are as yet inadequately used, but have proved highly productive in Hawaii.

The workshop, which is the basis of this report, was held to discuss and hopefully to agree upon the experimental designs and research methodology that would be used in the crop production research in these two projects. Particular attention was paid to designs that could provide valid scientific tests of agrotechnology transfer.


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# REPORT OF THE WORKSHOP ON

# EXPERIMENTAL DESIGNS FOR PREDICTING CROP PRODUCTIVITY

# WITH ENVIRONMENTAL AND ECONOMIC INPUTS

Sponsored by

The Agency for International Development
The University of Hawaii
The University of Puerto Rico

Held from May 20 to 24, 1974 at the University of Hawaii

Honolulu, Hawaii

Prepared by

J. A. Silva

University of Hawaii

and

F. H. Beinroth

University of Puerto Rico

# PREAMBLE

If the world food needs are to be met the agricultural productivity per unit of land must be increased, particularly in the tropics in which so many poorly-fed people live. Research and extension have already enabled the temperate zones to achieve high productivity in agriculture, and presumably can do the same for the tropics. But time is of the essence, if the people alive today are to benefit.

The Universities of Hawaii and Puerto Rico have formulated two projects with the assistance of United States, Agency for International Development (USAID) to undertake some of the necessary research and to design an extension delivery and communications system that will hasten the application of tropical agricultural research.

The purposes of the projects are to correlate food crop yields on a network of benchmark soils, and to determine scientifically the transferability of agro-production technology among tropical countries.

The benchmark soils will belong to related soil families as defined in The US Soil Taxonomy, because the family is the level in this soil classification system at which transference of technology is proving possible within the United States. They will be red upland soils or soils developed from volcanic ash which in most tropical countries are as yet inadequately used, but have proved highly productive in Hawaii.

The workshop, which is the basis of this report, was held to discuss and hopefully to agree upon the experimental designs and research methodology that would be used in the crop production research in these two projects. Particular attention was paid to designs that could provide valid scientific tests of agrotechnology transfer.

The report is in two parts. Dr. F. H. Beinroth of the University of Puerto Rico summarizes the papers presented during the first three days of the project in the Summary of Papers. Dr. J. A. Silva of the University of Hawaii summarizes the discussions of the experimental design and research methodology to be used in the two projects in the Summary of Discussions. A second report will contain the original papers presented at the workshop and an edited transcript of the discussions.

The two Universities acknowledge the assistance of the Research Advisory Committee which suggested that the workshop be held, and of AID which provided most of the funds for participant travel. We are most grateful to the participants who gave of their time to prepare the papers, attend the workshop and take part in the vigorous and stimulating discussions.

The presentations, discussions, conclusions and recommendations of the workshop will have marked influence upon the conduct of the two projects. We believe that they will also influence the direction of future research on experimental design.

L. D. Swindale
Associate Director HAES
Principal Investigator
UH/AID a"Benchmark Soils" Project

# INTRODUCTION

The Workshop on Experimental Designs for Predicting Crop Productivity with Environmental and Economic Inputs is related to two AID-supported research contracts awarded to the Universities of Hawaii and Puerto Rico. The University of Hawaii's contract is entitled "Crop Production and Land Capabilities of a Network of Tropical Soil Families". The University of Puerto Rico's project is designated "Crop Production and Land Potential of Benchmark Soils of Latin America".

Leading scientists from the United States and abroad in the fields of agricultural economics, statistics, soil science, and agricultural research in tropical countries were invited to the workshop. There were thirty-eight invited participants in addition to various members of the Department of Agronomy and Soil Science of the University of Hawaii who attended sessions as their time permitted. A list of the invited participants is attached (Appendix A). Fourteen papers were presented during the workshop (Appendix B). The detailed program attached (Appendix C) lists the speakers and the titles of the papers presented.

As indicated in the program, the first three days of the workshop were set apart for the presentation and discussion of papers of general interest to the projects. The last two days were devoted exclusively to the discussion of the research methodology and the experiment designs to be employed in the two projects. Position papers by the Universities of Hawaii and Puerto Rico provided the framework for discussion of various aspects of approach and design of the experiments to be implemented.

## SUMMARY OF PAPERS
by F. H. Beinroth

This section of the report summarizes the highlights of papers presented at the workshop (Appendix B). These papers are referred to in the text and will be published along with transcripts of discussions of the papers at a later date.

### Economic Considerations

Heady (1974) emphasized that "there can be numerous models of farmer decision environments ranging from (a) complete allocative models with investment alternatives in the farm which compete for scarce resources and thus suggest how scarce capital should be distributed among fertilizer outlays, new seeds, water systems, etc., to (b) extreme micro-analyses which assumes each farmer has unlimited capital and perfect knowledge". The first situation clearly characterizes the mass of low income farmers in the developing countries. The experimental design and the levels of treatments selected should, therefore, conform to the situation indicated in model (a) above.

Highly refined fertilizer recommendations would require continuous mathematical models of the fertilizer response surface in its relation to soils and environmental variables for individual farms. As this would require unreasonable efforts, fertilizer response data are needed which allow "rule of thumb" approximations for optimum use of fertilizer under different situations of capital restraint. Therefore, the design of experiments should be such that it provides response predictions over the range of the surface to which different "rules of thumb" might apply, varying with different economic decision environments. Considering the decision environments for the majority of LDC farmers, it would seem more appropriate to use a configuration of treatments in the design which places emphasis on the positively sloped portion of the response surface with high elasticity rather than on the high levels of the surface with low elasticity.

Production Functions

In their paper, Laird and Turrent (1974) state that "the science of crop production is presently at a very elementary level in evolving a research methodology for determining production technologies for rainfed agriculture". It would seem that our knowledge is not yet sufficiently wide to proclaim with certainty that crop production surfaces conform to one specific algebraic form. There also appears to be no theoretical basis for deciding *a priori* which mathematical model would represent best a particular production situation. As the underlying response model is not well-defined, the experimental design must, therefore, provide information to evaluate the model itself.

According to Heady (1974), for the majority of cases, the best function seems to be a conventional quadratic with linear and squared terms and first-order interactions for the fertilizer variables. However, Nelson and Anderson (1974) alluded to the difficulty of estimating residual nutrient levels when quadratic, square root or exponential response functions are used for experimental situations which have yield plateaus. Capo (1974) also emphasized that production functions must take into consideration the existing levels of nutrients which the soil is capable of supplying. He felt that response surfaces are best described by a multiplicative equation.

Completely different from these curvilinear models are the Liebig-type linear-response-and-plateau models discussed by Nelson and Anderson (1974). In this model there are two linear segments, one with high and one with zero slope. A system of sub-models belonging to the "linear-plateau family" was also presented. These models have desirable attributes for use in LDCs, such as the ease of computation, and the economic implications are said to be quite simple and straightforward. North Carolina State University also favored the linear-plateau type response function for developing countries and Sanchez et al. (1974) reported satisfactory experience with this model in Latin America. Laird and

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Turrent (1974) questioned the accuracy of economic optima as estimated from prediction equations and indicated that graphic analysis may be employed with advantage.

The discussion at the workshop manifested a considerable divergence of opinion regarding the nature of the production functions to be fitted to the data. Most participants seemed to favor the use of additive production functions; i.e., functions in which the influences of the various yield-controlling factors are added. One participant presented data on the usefulness of a multiplicative function, in which the magnitude of the influence of a factor depends on the levels of the other yield-controlling factors.

The general disagreement on this subject stressed the need to test the usefulness of different kinds of production functions. The project should, therefore, scrutinize the various kinds of functions to test their adequacy for the particular production situation at the experiment sites and for LDCs in general. This should contribute to the overall knowledge of production functions and might provide information of value for improving approaches and procedures now employed in soil fertility programs.

Experimental Design

Sanchez et al. (1974) expressed the view that the experimental design, i.e., the choice of treatments to be applied and the manner in which these treatments are to be assigned to the experimental units, is no longer a significant issue. They felt that the central composite and fractional factorial designs, assigned via some type of randomized blocks, are appropriate for both agronomic and economic interpretation, provided a sufficient range of levels of each nutrient is included.

Laird and Turrent (1974) presented a comparison of nine treatment designs and discussed the considerable differences in bias and variance error, number

of treatment combinations, and flexibility. Their conclusion was that the $5^2$ partial factorial modification by Escobar has several desirable qualities and should be considered for use in research on crop production practices. Also considered a good design is the augmented $2^2$. Cady (1974) indicated that the experimental design should be a randomized complete block design. The additional cost of having blocks instead of a completely randomized design is minimal, whereas the experimental error reduction could be considerable.

The treatment levels, according to Nelson and Anderson (1974), should be spaced so that there is a concentration of treatment points in the region of the expected optimum rate. Preliminary information should be used to control the size of the experiments by not varying factors which are known to be at adequate levels. Capo (1974) felt that at least four and preferably six or seven levels of each of the variables under study should be included.

## Uncontrolled Variables

Uncontrolled variables, such as certain soil conditions, and uncontrollable factors, such as weather, should be carefully measured and monitored for later analysis. Cady (1974) stressed that soil fertility experimentation has a history of collecting plot data, but that experience in measuring site variables is much less extensive. These site variables are factors believed to affect crop yield but cannot be controlled at a constant level across the experiments. Therefore, they may affect fertilizer response at each location differently. Consequently, a major objective in the interpretation of the data from the series of experiments should be the development of a yield model or equation which includes the uncontrolled variables. Culot (1974) also emphasized the need to define and to quantify the "boundaries of the ecological environments" characterizing the experiment locations.

Other Considerations

Heady (1974) pointed out that the demonstration of transferability of agricultural experience on the basis of soil classification could be better and more cheaply accomplished at two or more points in the U.S. However, the projects set out to demonstrate transferability for families of tropical soils for the benefit of less developed countries. This purpose could not be achieved if the projects were confined to the U.S.

## SUMMARY OF DISCUSSIONS
by J. A. Silva

This section was prepared from the taped discussions of the experimental approach of the project during the last two days of the workshop. The details of field experimentation being proposed in the project are described in the position paper for Hawaii presented by Silva (1974) (Appendix D). Recommendations made by workshop participants for modification and elaboration of various aspects of the proposed experimental methodology are presented in the following paragraphs.

Sites

The recommendation which will probably have the greatest effect on the projects is that several sites, or locations of the same soil family be selected in each country rather than just one major site. It was pointed out by several participants that it was essential to the statistical evaluation of the hypothesis of transferability that a large enough number of sites per country be obtained to give a wide range of variability in soil properties, climate and management. The minimum number of sites per country suggested was from 4 to 8, depending on the nature of the variability encountered, and especially on the project associate in the country--his ability to handle many sites, the distance between sites, crops planted and measurements required. A large number of sites provides better estimates of the uncontrolled variables which, it is

believed, will have a pronounced effect on the test of transferability. It is quite likely that the controlled variables alone will not allow direct transfer of management practices from a soil family in one location to the same soil family in another location without taking into account the modifying influences of the uncontrolled variables within a soil family, as well as of initial soil fertility, climate, etc. Therefore, several sites per soil family in a country were recommended. The concept was developed of a primary site on which the fertility experiment and all the other supplementary experiments would be installed and on which a complete set of meteorological instruments would be housed and the farm shed built. Secondary sites in the same country would have only the fertility experiment and the minimum number of meteorological instruments. The distances between sites would depend on the variation in the soil family in the country and the associated climatic and past management variation.

The increase in number of sites per country to 4 to 8 will result in increased time, effort and analyses in the soils investigations to locate several appropriate sites in each country. It will also require more installations of the fertility experiment for testing transferability with accompanying increased fertilizer, seed, labor, and other requirements. As discussed elsewhere, only minimal weather data will be collected from the secondary sites which will minimize the additional cost of meteorological instruments. Other items which will be affected by this change are transportation requirements, number of soil and plant analyses, and data collection and analysis. This increased cost and effort should result in better attainment of the main objective of the project, a test of the hypothesis of transferability.

## Fertility Experiment

The fertility experiment for testing the hypothesis of transferability should be kept very simple with only 2 variables. It was recommended that these

variables be related to characteristics of the soil family such as mineralogy, pH, etc. and may include P, K, pH, Ca or Al, depending on the soil family Phosphorus x pH, and N x P were two suggested treatment combinations. The same treatment combination will be used in sites of the same family, but treatment combinations may differ between families. If possible, these variables should also be those which are expensive to control so that recommendations from the experiments may have greater economic value. In order to keep the experiment manageable, and yet obtain sufficient information to develop production functions, 5 levels of the factors were suggested. It is more important to have a wide range of these factors than to have many levels of these factors. It is also essential that the anticipated optimum level be near the middle of the range of levels selected. This experiment will be maintained with high management inputs, i.e., optimum irrigation, nutrients, plant protection and plant density.

It was recommended that 3 replicates of the fertility experiment be set out to insure that good information is obtained at every site. With the cost of selecting and establishing the site, the cost of the added replicate is small by comparison when it is realized that many things can affect the survival of plots in foreign countries. Therefore, 3 replicates were suggested over 2 replicates.

Experimental design: The experimental design finally recommended by the participants was the $5^2$ partial factorial modification by Escobar described in the paper by Laird and Turrent (1974) presented at the workshop. It was found to be one of the outstanding designs on the basis of (a) appropriateness for use in a graphic estimation of economic optima, (b) magnitude of bias error, (c) number of treatment combinations, (d) flexibility in number of factors and number of levels of each factor, and (e) magnitude of variance error. It also has good coverage of the factor space with its 13 treatments. A diagram of this

design is shown in Figure 1 and coded values for the treatments are given in Table 1.

## Crop Selection

Discussion by the participants of various test crops led to the recommendation that maize be used as the test crop at all sites for the test of transferability. This crop has the advantage of being a short-term crop which is relatively easy to manage, has good disease resistance, is not too photoperiod sensitive, and can be readily harvested for reliable yields. Other crops may also be grown on the sites, depending on the interests of the host country. Some other crops suggested by participants were *Cassava*, *Panicum maximum* (Guinea grass), *Glycine max. (L.) Merr.* (soybeans), *Leucaena leucocephala* (Koa Haole), and various pasture grasses.

The problem of whether to use one variety of maize at all sites in all countries or to use the "best adapted" variety for each country was discussed at length. The final recommendation was to use the "best adapted" variety for each country because it was felt that it would be virtually impossible to find one variety that was well adapted to all countries. Therefore, the true yield potential of the soil family in that country could not be properly assessed by the poorly adapted variety. However, with a variety that was well adapted to the country, the true yield potential will be measured and a better comparison of soil families will result. The "best adapted" variety will be that recommended by local research institutions in the country.

## Variety Experiment

With the decision to use the "best adapted" maize variety as the test crop in the fertility experiment, it becomes necessary to install a variety experiment in each country to evaluate the recommended "best adapted" variety against other well adapted varieties to assure that the "best adapted" variety is in

**Table 1.** Coded values for the treatments in the $5^2$ partial factorial modification by Escobar

| Treatment Number | Factor A | Factor B |
|---|---|---|
| 1 | -0.85 | -0.85 |
| 2 | -0.85 | +0.85 |
| 3 | +0.85 | -0.85 |
| 4 | +0.85 | +0.85 |
| 5 | -0.40 | -0.40 |
| 6 | -0.40 | +0.40 |
| 7 | +0.40 | -0.40 |
| 8 | +0.40 | +0.40 |
| 9 | 0 | 0 |
| 10 | -0.85 | 0 |
| 11 | +0.85 | 0 |
| 12 | 0 | -0.85 |
| 13 | 0 | +0.85 |

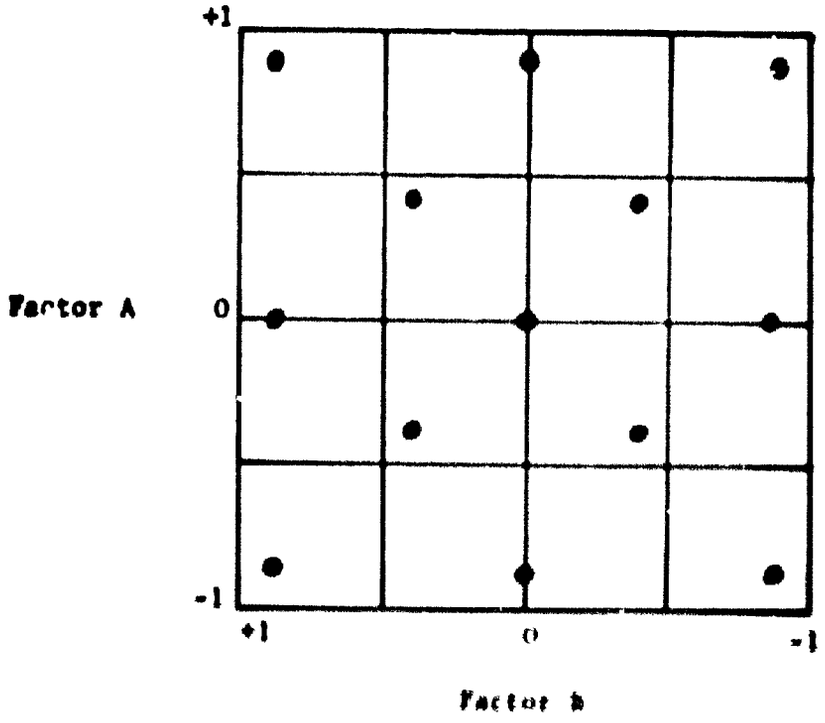


Figure 1. Treatment design for $5^2$ partial factorial modification by Escobar.

fact used in the experiment. Therefore, a variety experiment should be installed at the primary site to evaluate several leading varieties in that particular country. Varieties used in experiments in other countries may also be evaluated at each primary site to compare their yield potential under a range of conditions. The number of varieties should be kept small and a randomized block design used in the experiment.

Management Experiment

As suggested in the original project proposal to AID, a management experiment will also be installed at the primary site in each country. The objectives of this experiment will be (1) to provide information to local governments on ways to increase production by improved availability and utilization of resources; and (2) to provide basic information to the local farmer with limited resources to indicate what he can do to increase his yields. The participants recommended that 7 management variables be considered although only some of these would be included in any particular country, depending on the state of knowledge about these variables in the country. The management variables suggested at two levels (with and without) are listed below.

± Irrigation

± Lime

± Weed Control

± Insect & Disease Control

± N

± P

± K

It was suggested that two varieties of Maize also be included in this experiment. One would be the "best adapted" variety and the other would be the "second best adapted" variety. These would be included to evaluate the varieties' ability to

respond to the factors being investigated. It was mentioned that a danger in using different varieties in different countries was that a particular variety may have been intentionally or unintentionally selected for lack of response to lime, P or some other variable being tested in the fertility experiment. This would result in nonsense data on response to this variable. The experimental design used in the management experiment would be a fraction of a $2^n$ factorial that would give information on main effects and 2-factor interactions.

Plant Density Experiment

No specific recommendations were made by the participants regarding the plant density experiment, although it was agreed that it was important to obtain this information for the crops tested.

Measurement of Parameters

It was agreed that certain soil parameters should be measured for the entire site to characterize the soil, i.e., physical and mineralogical parameters. Other parameters should be determined for each experimental plot prior to application of treatments, i.e., chemical parameters associated with fertility. The parameters listed on page 40 of the paper by Silva (1974) were accepted by the participants and certain additional parameters and modifications were suggested. It is not expected that all these parameters will be determined at all sites, but as many of them as possible will be measured to provide supplementary information for interpretation of results.

In addition to the chemical parameters listed on page 40 of the paper by Silva (1974) the following parameters were suggested for determination.

1. Electrical Conductivity (for extrapolating Al saturation)
2. CEC determination by three methods
   a. neutral salt
   b. $BaCl_2$-triethanol amine, pH 8.2

c. N ammonium acetate, pH 7.0

3. Lime requirement by titration curves

4. KCl extractable Al (add it to cations and call it exchange capacity)

5. Extractable P by North Carolina Method (replaces Olsen method)

6. Mineralizable $NH_4$- and $NO_3$-N

7. Woodruff's energy of exchange

The following additional soil physical parameters were recommended.

1. Soil Strength (measured with a penetrometer)

2. Field Capacity (determined in the field)

3. Hydraulic Conductivity

Measurement of climatic parameters was discussed and it was recommended that a fairly complete set of meteorological instruments be installed at the primary sites to measure the parameters described on page 42 of the paper by Silva (1974). At the secondary sites, only the minimum number of meteorological instruments should be installed. These would be for measurement of daily rainfall, and maximum, minimum, and average air temperature. Other measurements which may be useful, if possible, are relative humidity and pan evaporation. At the primary site, it was suggested that sunlight be recorded on a daily basis rather than hourly as initially suggested. The drought-day index should also be calculated to aid in scheduling irrigation. Soil moisture was generally considered to be an optional measurement, but it was suggested that it be measured periodically to check on water balance calculations. A suggestion was also made that some measure of runoff or amount of water infiltrated be obtained, if possible. The use of a drought index which is based on visual symptoms of wilting was recommended for use in unirrigated plots which may very likely be located at the secondary sites. This can be quantified and included in the yield equation.

It was pointed out that since the experiments will be carried out on similar soil families this will preclude encountering a wide range of environmental conditions. This is due to the fact that the soil moisture regime and the soil temperature regime are criteria of classification at the family and higher taxonomic levels, therefore, only a limited range in climatic conditions is permitted for a given soil family of a certain subgroup. The overall climatic pattern is therefore not a variable in a population of identical soil families, but local weather conditions are. Therefore, it is necessary to obtain good measurements of these local weather conditions which affect crop yield in a particular period.

Discussion of the management variables listed on page 43 of Silva's paper (1974) resulted in the recommendation that "previous history" be recorded rather than "crop rotation" since it was decided that each of the main fertility experiments should be installed on virgin land rather than on the previous experimental site. Thus, past treatments such as manuring or burning should be identified. However, it was strongly recommended that every effort be made to install these experiments on virgin land, if possible, to minimize complicating influences of past history.

Planting date will be very important and it was suggested that crops be planted in relation to some local climatic event to which the local farmers relate their planting. If no such event occurred, then planting could be done according to the calendar date taking into account season of the year. If two locations with the same soil family have two different planting dates according to local climatic events, then these local dates should be adhered to at each site, since experience has shown this to be the best planting time at each site. Information from local institutions will be of assistance here.

It was generally agreed that plant samples should be taken at some critical time during the crop for analysis of important nutrients. This information would

be of assistance in interpreting results of the experiments.

Analysis of Data

There was general agreement that standard multiple regression analysis will be used on the data from each site and for each country to develop yield equations which will include the controlled and uncontrolled factors affecting yield. The statisticians present concluded that there was no statistically correct method for testing the hypothesis of transferability of information between sites or countries because of certain problems. One of the problems is that the statistic derived for testing transfer is not really an F test which is supposed to be the ratio of two chi-squares. There was no obvious statistical test of this hypothesis which met this requirement. Another problem resulted from the inclusion of the uncontrolled variables in the regression equations. In order to include the effects of the uncontrolled variables, some adjustment must be made. This may be done by calculating a predicted Y in the middle of the treatment design or by solving for the economic optimum in some way. However, it was not known how this could be done. It was suggested that AID may make a real contribution to the solution of this problem, which can have far-reaching effects, by providing a grant to a statistician to work on this problem and derive a solution.

## IMPLICATIONS OF THE RECOMMENDATIONS

The recommendations for modification and elaboration of the proposed experimental methodology which resulted from this Workshop, if accepted, would necessitate reevaluation of the costs and work plans of the Hawaii and Puerto Rico projects. In the original project proposals fewer sites per country were planned than the 4 to 8 sites per country presently recommended. Therefore, more time, labor and analyses will be required to locate the additional sites in each country. In

addition, this will necessitate a departure from the original work plans in that more time will have to be allotted to the soils investigations and also to the establishment of sites and installation of experiments. The additional installations of the fertility experiment for testing transferability will result in increased fertilizer, seed, labor and instrument requirements. The Workshop participants also recommended that a variety experiment be made an integral part of the program to allow continual evaluation of maize varieties so that the "best adapted" variety for each country can be identified and used in the fertility experiment. This variety experiment is in addition to the three experiments planned in the original project proposals, therefore, this will result in additional time, labor and supply requirements. The added sites and experiments will naturally result in more soil and plant samples to be analyzed as well as more data to be processed and statistically analyzed.

The Workshop which is the result of the suggestion of AID's Research Advisory Committee has allowed a very valuable exchange of ideas among scientists in this area and produced a series of recommendations which should allow better attainment of the main objective of the projects, a test of the hypothesis of transferability. It should also greatly increase the benefits of these projects to the LDC's.

## SUMMARY

A. Recommendations

1. One primary and three to seven secondary sites should be installed per country.
2. The primary site should have fertility, variety, management and plant density experiments, with complete weather instrumentation, and buildings.
3. Secondary sites should have only the fertility experiment and minimum weather instrumentation.
4. Fertility experiments to test transferability should have 2 variables at 5 levels each.
5. Variables should be related to the soil family and may include P, pH, K, Ca, Al, etc.
6. The experimental design should be a $5^2$ partial factorial modification by Escobar with three replicates.
7. Maize is to be the test crop at all sites.
8. The "best adapted" variety of maize for each country should be used.
9. A variety experiment should be installed in each country to compare the top varieties of maize in a country and to test varieties from other countries.
10. The management experiments should have two levels (with and without) of the following factors: irrigation, lime, weed control, insect and disease control, N, P, and K.
11. Two maize varieties should be included in the management experiment which should be the two top varieties in the country.
12. The experimental design for the management experiment should be a fraction of a $2^n$ factorial that would give main effects and two-factor interactions.

13. Additional soil chemical and physical parameters should be measured.

14. Additional measurements of climatic parameters and the use of a drought index for unirrigated conditions should be utilized.

15. At secondary sites, daily rainfall, and maximum, minimum and average temperature should be recorded.

16. Fertility experiments should be installed on virgin sites, if possible, and should not be planted on previous experimental sites because of complications due to residual treatment effects.

17. Planting date should be related to some local climatic event, if one exists, which local farmers follow. If not, calendar date is satisfactory, provided season is considered.

18. Data should be analyzed by standard multiple regression techniques including controlled and uncontrolled variables.

19. There is no statistically correct method for testing the hypothesis of transferability of information between sites or countries.

20. AID should be approached to provide a grant to allow a statistician to develop a proper test for transferability.

B. Implications

1. More time and effort than originally planned will be needed in soil selection.

2. Increased costs.

# APPENDIX A

## PARTICIPANTS IN EXPERIMENTAL DESIGN WORKSHOP

Out-of-State Participants

| | |
|---|---|
| R. L. Anderson* | University of Kentucky, Ky. |
| L. J. Bartelli | Soil Conservation Service, Washington, D.C. |
| F. H. Beinroth* | University of Puerto Rico, P.R. |
| E. Brams* | Prairie View A & M College, Texas |
| S. W. Buol* | North Carolina State University, N.C. |
| F. B. Cady* | Cornell University, N.Y. |
| B. G. Capo* | University of Puerto Rico, P.R. |
| J. B. Collins | Prairie View A & M College, Texas |
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| E. O. Heady* | Iowa State University, Iowa |
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| J. Kirkwood | Prairie View A & M College, Texas |
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| C. B. McCants* | North Carolina State University, N.C. |
| J. K. McDermott | AID, Washington, D.C. |
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| D. L. Plucknett | AID, Washington, D.C. |
| H. B. Peterson | Utah State University, Utah |

Hawaii Participants

| | |
|---|---|
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| J. L. Brewbaker | Horticulture, U.H. |
| R. M. Bullock | HAES, U.H. |
| R. de la Pena | Office of Economic Development, Kauai |
| P. Garrod | Agricultural and Resource Economics, U.H. |
| R. E. Green | Agronomy and Soil Science, U.H. |
| W. T. Harada | HAES, U.H. |
| E. B. Hundtoft | Agricultural Engineering, U.H. |
| H. Ikawa | Agronomy and Soil Science, U.H. |
| N. Luyks | East-West Food Institute, Honolulu |
| K. Ozgaki | International Agr. Training Program, U.H. |
| P. P. Rotar | Agronomy and Soil Science, U.H. |
| J. A. Silva* | Agronomy and Soil Science, U.H. |
| L. D. Swindale* | HAES, U.H. |
| G. Tsuji | Agronomy and Soil Science, U.H. |
| G. Uehara | Agronomy and Soil Science, U.H. |
| G. Vieth | Agricultural and Resource Economics, U.H. |
| H. Yamauchi | Agricultural and Resource Economics, U.H. |

*Speakers

## APPENDIX B

### Papers Presented at the Workshop on

### EXPERIMENTAL DESIGNS FOR PREDICTING CROP PRODUCTIVITY WITH ENVIRONMENTAL AND ECONOMIC INPUTS

Beinroth, F. H. Some considerations on soil classification in general, and "Soil Taxonomy" in particular.

Brams, E., J. Collins, and J. Kirkwood. Experimental Design for predicting crop productivity with environmental and economic inputs.

Cady, F. B. Design of soil fertility research for the tropics II. Rationale for design of subsequent studies.

Capo, B. G. Considerations on experiment design and production functions-Position paper, UPR.

Culot, J. Ph. Some examples of the use of production functions to quantify environmental influences on crop productivity.

Drosdoff, M. Design of soil fertility research for the tropics I. Some Cornell University experiences.

Heady, E. O. Some considerations in the design and analysis of fertility experiments for developing country use.

Laird, R. J. and Antonio Turrent. Key elements in field experimentation for generating crop production technology.

Nelson, L. A. and R. L. Anderson. A family of models and experimental designs for evaluating response to fertilizer nutrients when the true model is not known.

Okuno, T. An application of fractional factorial design to a fertilizer experiment in Japan.

Pringle, G. E. Economic aspects of production functions for soils-Position paper, UPR.

Sanchez, P. A., R. K. Perrin, and S. W. Buol. Concepts of program design for soils research and information transferal in developing countries.

Silva, J. A. Field experimentation to allow economic evaluation of management and environmental effects on soil productivity-Position paper, UH.

Swindale, L. D. Crop production and land capabilities of a network of tropical soil families--A description of the UH/UPR/AID Benchmark Soils Research Projects.

APPENDIX C

Program for Workshop on

EXPERIMENTAL DESIGNS FOR PREDICTING CROP PRODUCTIVITY
WITH ENVIRONMENTAL AND ECONOMIC INPUTS

Sponsored by

The Agency for International Development
The University of Hawaii
The University of Puerto Rico

May 20 - 24, 1974

University of Hawaii
Honolulu, Hawaii

Monday, May 20, 1974

St. John 011 8:30 a.m. Welcome

a) Host Institution - L. D. Swindale, UH
b) AID - J. K. McDermot, AID

Charge to the Workshop - E. O. Heady, Iowa State Univ.

Description of Projects

a) Crop Production and Land Capabilities of A Network of Tropical Soil Families--A Description of the UH/UPR/AID Benchmark Soils Research Projects - L. D. Swindale, UH

b) Puerto Rico Project - F. H. Beinroth, UPR

Some Considerations on Soil Classification in General, and "Soil Taxonomy" in Particular - F. H. Beinroth, UPR

St. John 011 1:30 p.m. Expert Papers on Experimental Design

Some Considerations in the Design and Analysis of Fertility Experiments for Developing Country Use - E. O. Heady, Iowa State University

An Application of Fractional Factorial Design to a Fertilizer Experiment in Japan - T. Okuno, National Institute of Agricultural Sciences, Japan

Discussion

Tuesday, May 21, 1974

St. John 011 8:30 a.m. Continuation of Expert Papers on Experimental Design

A Family of Models and Experimental Designs for Evaluating Response to Fertilizer Nutrients When the True Model is Not Known - L. A. Nelson - North Carolina State University and R. L. Anderson - University of Kentucky

Some Examples of the Use of Production Functions to Quantify Environmental Influences on Crop Productivity - J. Ph. Culot, FAO/UNDP, Argentina

Discussion

St. John 106 1:30 p.m. Key Elements in Field Experimentation for Generating Crop Production Technology - R. J. Laird and Antonio Turrent, CIMMYT, Mexico

Design of Soil Fertility Research for the Tropics

I. Some Cornell University Experiences - M. Drosdoff, Cornell University, N.Y.

II. Rationale for Design of Subsequent Studies - F. B. Cady, Cornell University, N.Y.

Discussion

Wednesday, May 22, 1974

St. John 011 8:30 a.m. Experimental Design for Predicting Crop Productivity with Environmental and Economic Inputs - E. Brams, J. Collins, and J. Kirkwood, Prairie View A&M University, Texas

Concepts of Program Design for Soils Research and Information Transferal in Developing Countries - P. A. Sanchez, R. K. Perrin, and S. W. Buol - North Carolina State University

Jefferson Hall 1:00 p.m. Bus leaves) Field Trip - Hawaii Soils and Crops at Waimanalo Farm, HAES

Thursday, May 23, 1974

| | | |
|---|---|---|
| St. John 106 | 8:30 a.m. | Considerations on Experiment Design and Production Functions - Position Paper, UPR - B. G. Capo, UPR |
| | | Economic Aspects of Production Functions for Soils - Position Paper, UPR - G. E. Pringle, UPR |
| | | Field Experimentation to Allow Economic Evaluation of Management and Environmental Effects on Soil Productivity - Position Paper, UH - J. A. Silva, UH |
| | | Discussion |
| St. John 106 | 1:30 p.m. | Discussion and Development of Generalized Experimental Designs for Predicting Crop Productivity with Environmental and Economic Inputs |

Friday, May 24, 1974

| | | |
|---|---|---|
| St. John 106 | 8:30 a.m. | Continuation on Development of Experimental Designs |
| St. John 106 | 1:30 p.m. | Recommendations for Specific Designs for UPR and UH Projects |
| | | ALOHA |

# APPENDIX D

## FIELD EXPERIMENTATION TO ALLOW ECONOMIC EVALUATION OF MANAGEMENT AND ENVIRONMENTAL EFFECTS ON SOIL PRODUCTIVITY

Position Paper for Hawaii

J. A. Silva

Department of Agronomy and Soil Science
College of Tropical Agriculture
University of Hawaii
Honolulu, Hawaii

This project was undertaken to correlate food crop yields on a network of benchmark tropical soils and determine scientifically the transferability of agroproduction technology among tropical countries. Crop production experiments will be carried out on selected soils belonging to related soil families in several countries and the hypothesis that agrotechnology developed on a particular soil family in one location will produce comparable yields on the same soil family in another location will be tested. These soils will belong to soil families of related subgroups as defined by the new U. S. Soil Taxonomy since the family level in this classification is the level at which transference of agrotechnology is proving possible in the temperate zones and within Hawaii. Results of these experiments will have maximum usefulness if production functions are developed to relate crop yield to management, soil, climatic and plant factors which permit economic evaluation. These production equations will also allow yield prediction in other areas with similar soils. It is the purpose of this paper to present a preliminary proposal of methodology to attain the objectives of this project.

Objectives:

The major objectives of the project are presented below.

1. Test the hypothesis that agrotechnology developed for a soil family in Hawaii will produce comparable yields on the same soil family elsewhere, i.e.,

Africa, Asia, Puerto Rico.

2. Develop yield response equations for each site and determine the important management, soil, climatic, and plant variables.

3. Develop yield response equations for the same soil family at all sites combined to determine which factors are required to allow a single equation to adequately describe yield response for various members of a soil family.

4. Develop, if possible, a universal yield equation which will adequately describe the yield response for any soil, given the appropriate variables.

5. Determine economically feasible inputs for the different production functions at various levels of national resources.

In order to attain these objectives, a series of experiments will be installed at each of the major sites so that the response to the major nutrients, N, P, and K, as well as to other management variables can be measured. These experiments must be relatively uniform at all sites of the same soil family so that proper evaluation can be made. In addition, the experiments should be comparable over all soil families if comparisons between soil families are to be made as well.

Site Selection:

The soils studied will be limited to upland tropical soils of the Oxisol and Andept Great Groups. Families which occur in Hawaii will be sought in one country in Africa and two countries in Asia. It is anticipated that the exact soil family may not always occur in a suitable location in every country. Therefore, it may become necessary to utilize closely related soil families which differ only in relatively minor characteristics and for practical purposes are the same as the family occurring in Hawaii. Among the criteria considered in selecting a site for the experiments, the most important will be the presence of the appropriate soil family. The existence of a research institute in the country (Government

research station or University) which is interested in cooperating on the experiment, the attitude of the local government to the project and the presence of an AID mission in the country are other considerations which must be met before a site is selected. The location of the site to a nearby population center with adequate facilities such as electricity, telephones and water will also be desirable. The ability to irrigate the experiment is considered an important requirement of the site since variations in rainfall can cause reduced yields or complete failure of crops with loss of information. It is not considered necessary that there be a large, continuous water source on the site proper, but a source from which water can be hauled should be within a reasonable distance of the site. It is planned to use drip irrigation which has relatively low water requirements. However, it may be found in the field that this requirement is impractical and it may have to be dropped, but it will be a goal to seek, if possible.

Crop Selection:

It is necessary that at least one crop be grown at all sites so that appropriate yield comparisons can be made. The crop selected should be an important food crop in the countries concerned, responsive to fertility differentials, and reasonably simple to manage. Maize or corn is a crop being considered as it generally meets the criteria mentioned above. Cassava is another possible crop which has world-wide importance, although it has a reputation of being rather unresponsive to fertilizers. Some studies have shown fairly large yield increases from fertilizer applications by cassava, so it may be suitable. Upland rice is also being considered because it is of world-wide importance and meets the criteria mentioned. Sorghum has been suggested as an indicator crop, but there is concern that its susceptibility to bird damage may make it impractical to use with confidence that reliable grain yields will be obtained. It does have

appeal because of its drought resistance and ability to ratoon, but its vulnerability to birds, especially in small plantings, makes its usefulness to the small farmer questionable. Pigeon peas have also been suggested because of their versatility as a food for man as well as animals. However, recent information from Puerto Rico indicates that it is an important food crop in very few South American countries. Soybeans are being considered, but their sensitivity to photoperiod is a concern. It may be difficult, if not impossible, to find a single variety that will produce well at all sites. Although it is necessary to have at least one crop grown on all sites, several other crops of interest to the host country can also be grown so that information of particular interest to them can be obtained. Because varieties of the same crop can differ in their yield potential, it is necessary that the same variety of the indicator crop be grown at all sites. This may cause problems due to lack of adaptability to the environment, insects and diseases at all sites. However, it is proposed that two varieties which are reasonably well adapted to the major locations be grown at all sites so that information will be obtained not only on the same variety at all sites, but also on the best adapted variety at each site. This has an added advantage in that it allows evaluation of the management parameter, variety.

Treatment Selection:

The treatments selected must allow evaluation of crop response to major nutrients, as well as evaluation of interactions between major nutrients and other variables, controlled and uncontrolled, and also allow development of production functions from which economic interpretations can be made. Productivity or yield which is a function of management, soil, climate and plant factors may be expressed by the equation

$$y = f(x_m, y_s, z_c, w_p)$$

where y is yield, $x_m$ are management variables, $y_s$ are soil variables, $z_c$ are climatic variables, and $w_p$ are plant variables. Soil and climatic variables are characteristic of the sites and generally not subject to man's control. However, these variables can have marked effects on the prodactivity of an area and thus must be measured, if possible. This will be discussed in more detail later, but the controllable variables will be considered in the present section as these can be manipulated to provide a series of treatments which allow evaluation of soil productivity.

Management variables include fertilization (amount and timing), irrigation, pH, plant population, weed, disease and insect control, time of planting, crop, variety, etc. Of these fertilization (quantity of fertilize.) is one of the most important in controlling productivity of a soil. Therefore, levels of N, P, and K will be employed to give a range of yields to allow evaluation of site productivity. Other nutrients may also be considered, but it is felt that these three major nutrients generally are the most limiting in tropical soils and measureable improvement in yield should be obtained with increasing quantities of these elements. Possible deficiencies of other nutrients may be discovered from soil or plant analysis and can be incorporated into the experiment, if considered necessary.

Nitrogen is usually the most limiting element in tropical soils so three or more levels of nitrogen ranging from zero to an amount considered more than adequate for the crop will be used at each site in combination with amounts of P and K. Soil analysis will be used to evaluate the status of P and K at each site and levels of each nutrient will be established on the basis of this analysis. Soil P will be evaluated by the P sorption isotherm method of Fox and Kamprath (1970) and soil levels will be adjusted to provide comparable ranges of P in solution with a maximum of about 0.20 ppm P in solution. Therefore, the P differential

in a particular experiment will depend on the soil P level and the crop. Similarly, soil K will be assessed with N $NH_4OAc$, pH 7.0 and the range of K applications adjusted accordingly. Since it is desired to develop a production function including these nutrients, three or more levels of each nutrient will be included, if found to be inadequate. Where P or K are adequate, only 2 levels of the element will be required for verifying the soil analysis. A control plot which receives no fertilizer will be included to allow evaluation of the natural fertility of the soil. A blanket application of micronutrients, including B, Cu, Mg, Mn, Mo, Zn and possibly others considered essential for the soils and crops used will also be applied to all fertilized plots to prevent yield reductions from inadequate levels of these nutrients. A preliminary assessment of micronutrient deficiencies will be obtained from selected plots which receive near optimum amounts of N, P, and K, but are not given the blanket application of micronutrients.

Irrigation is another management factor which can have marked effects on yields, especially when normal rains do not occur, or when a crop is to be grown during the normally dry season of the year. Productivity of a soil can be greatly influenced by the presence or absence of adequate irrigation. Therefore, it is essential to include an irrigation differential to properly evaluate soil productivity. If soil productivity with irrigation is high enough, it may be sufficient incentive for a government to develop facilities to irrigate the area and thus increase productivity in the country. Furthermore, there are large areas of arable land in the tropics that are idle during the normal dry season when sunlight energy is at its highest and could be used by plants for production of food for man and his livestock. A supply of irrigation water during this period would increase and help stabilize food production in the country. Therefore, it is proposed that at least two irrigation levels, with and without irrigation, be included as treatments in each experiment and possibly several levels of irrigation

be included where supplies of irrigation water are readily available. Experience with drip irrigation in Hawaii suggests that its reduced water requirements would make it suitable for these experiments. Where several levels of irrigation are to be included, a differential consisting of three intervals, zero irrigation, medium frequency, and high frequency may be used or moisture sensing equipment such as Bouyoucos blocks or tensiometers may be employed to establish an irrigation differential.

Adjustment of soil pH or application of lime is a management factor that can produce large yield increases in tropical soils not only because it increases availability of nutrients, but it also reduces Al toxicity and supplies Ca. It is proposed that at least 3 pH levels which range from the original soil pH to a pH considered adequate for crop production be included in the experiment. There are several opinions regarding the definition of an adequate pH level. Kamprath (1970) recommends liming to neutralize KCl extractable Al, Puerto Rico recommends liming to 75% of base saturation, results in Hawaii have suggested that pH 5.5 to 6.0 is adequate. A decision will have to be made on which criterion should be used and then a series of treatments can be established.

Plant population, or stand is a management variable which affects productivity of a crop, and can be included in the experiments. However, in the original project proposal, a series of plant population experiments was planned independently of the main fertility experiment. In light of the number of variables being considered, it might be wise to use only one plant population in the main fertility experiment which is that considered best in Hawaii, or in the country where the experiment is located. More detailed evaluation of stand can be obtained in a separate study at the site.

The crop and variety grown (also management variables) can be kept constant at all sites, but as was mentioned earlier, there is the possibility that one

variety will not be adapted for all sites and the evaluation of soil productivity will be biased by a poorly adapted variety. Therefore, it is proposed that two varieties which are ada d to several sites be grown at all sites so that soil productivity at each site can be evaluated by an adapted variety and yet variety continuity throughout the sites be maintained. An alternative procedure is to have one standard variety at all sites and a second variety which is well adapted to each individual site. Thus there may be as many as 4 or 5 different varieties in all sites combined, but only 2 varieties at any one site.

Experimental Design: 1/

The design selected should be one that provides sufficient points to allow development of production functions, permit evaluation of interactions and result in an experiment of manageable size. Because several factors are being considered, and interactions are desired, two general classes of designs which should be considered, according to Justesen (1971), are the classical factorial and the central composite designs. If the experiment is on 2 factors each at 3 equidistant levels, the two types coincide.

In the present experiment the factors to be tested are applied N, P, K, and pH, and variety and irrigation with a minimum of 3 levels of the first 4 variables required to allow development of production functions. A complete factorial combination of these 4 factors at $3^4$, $4^4$, or $5^4$ would have 81, 256 or 625 treatment combinations, respectively. This does not include the 4 irrigation x variety treatment combinations which would increase these values 4-fold making the experiments too large for proper management.

The size of the experiment can be reduced by taking a fraction of the fertility combinations and imposing the 4 irrigation x variety treatments on them. Such a design for 1/3 replicate of a $3^4$ factorial is given by Cochran and Cox (1957)

1/ The original experiments described in the project proposal submitted to AID are shown in Appendix 1.

(see Table 1) and would reduce the total number of treatment combinations to 27 for the fertility variables. The treatments are in blocks of 9 and the defining contrast is ABCD. Three additional treatment combinations were added to the original design for the purposes of this experiment (Table 1). A 0000 plot was added to blocks II and III to provide estimates of indigenous soil fertility for each block and a 2222 plot without micronutrients was added to block I for a preliminary assessment of micronutrient deficiencies. This gives a total of 30 treatment combinations and combining them with the 4 irrigation x variety treatments brings the total number of plots to 120. However, there are only 3 levels of each fertility variable to permit linear and quadratic surfaces to be developed for determining optimum nutrient levels.

Irrigation treatments generally require relatively large plots, therefore, it is proposed that the plot arrangement be such that irrigation treatments are set up in large blocks, one without irrigation and the other with adequate irrigation. The fertility treatment combinations would be allocated at random throughout an irrigation block and each fertility plot would be split into 2 subplots on which the 2 varieties would be assigned at random.

Colwell (1971) proposed a fractional factorial design with 4N x 4P x 2K x 3S variables with 48 plots which was considered suitable for soils likely to give little or no response to K. This design has some merit for the present experiment, especially in situations where P or K are considered adequate. However, when the 4 irrigation x variety treatment combinations are included in this design, the total number of treatment combinations is 192.

The second degree composite designs proposed by Box and Wilson (1951) offer additional possibilities for obtaining sufficient precision in a manageable experiment. Justesen (1971) lists three advantages of the central composite designs over the factorial designs when there are three or more variables. They

Table 1. Coded fertility treatments for an extended 1/3 replicate of a $3^4$ factorial with 30 units in incomplete blocks of 10 units each.

| Block I | | | | Block II | | | | Block III | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| N $X_1$ | P $X_2$ | K $X_3$ | pH $X_4$ | N $X_1$ | P $X_2$ | K $X_3$ | pH $X_4$ | N $X_1$ | P $X_2$ | K $X_3$ | pH $X_4$ |
| 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 1 | 2 |
| 0 | 1 | 2 | 2 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 |
| 0 | 2 | 1 | 1 | 0 | 2 | 0 | 2 | 0 | 2 | 2 | 0 |
| 1 | 0 | 2 | 2 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 1 | 1 | 1 | 0 | 2 | 1 | 1 | 2 | 0 |
| 1 | 2 | 0 | 0 | 1 | 2 | 2 | 1 | 1 | 2 | 1 | 2 |
| 2 | 0 | 1 | 1 | 2 | 0 | 0 | 2 | 2 | 0 | 2 | 0 |
| 2 | 1 | 0 | 0 | 2 | 1 | 2 | 1 | 2 | 1 | 1 | 2 |
| 2 | 2 | 2 | 2 | 2 | 2 | 1 | 0 | 2 | 2 | 0 | 1 |
| 2 | 2 | 2 | 2*-Micro nutr. | 0 | 0 | 0 | 0* | 0 | 0 | 0 | 0* |

*Added treatments

Defining contrasts: 2 df. from $x_1x_2x_3x_4$, equivalent to putting $x_4 = x_1x_2x_3$ (Y).

Analysis of variance*

1.

| Effects | df |
|---|---|
| Block | 2 |
| Main | 8 |
| 2-factor | 16 |
| Total | 26 |

*added plots deleted

2.

| Effects | df |
|---|---|
| Block | 2 |
| Main | 8 |
| $x_1x_2$, $x_1x_3$, $x_2x_3$ | 12 |
| Error ($x_4$ Interactions) | 4 |
| Total | 26 |

If all interactions of $x_4$ are negligible.

are (a) regression coefficients can be tested directly for their importance because of orthogonality; (b) fewer observational points are required and degrees of freedom for testing the fitness of the model are still adequate; and (c) the number of levels is increased by two for each factor which will provide for a better test of the lack of fit.

Baird and Pitts (1957) described a central composite design which consisted of 5 rates each of N, $P_2O_5$ and $K_2O$ selected to furnish maximum information on main effects and interactions. The total number of plots was 18 and increments of all nutrients were equally spaced. Hurst and Mason (1957) presented a graphical display of the 15 treatment combinations of this experiment which originate from the central composite design and explained that the remaining 3 treatments were included to provide supplemental information for calibration of soil tests. Voss, Hanway and Fuller (1970) used a one and one-half cube with star points replicated design to study the yield response to N, P and K. It had 25 treatment combinations.

The 4 fertility variables in the present experiment may be arranged in a central composite design and then combined with the 4 irrigation x variety treatments. A central composite rotatable second order design for 4 x-variables with N = 31 is presented by Cochran and Cox (1957). It is basically a $2^4$ factorial + star design + 7 points in the center. When the 4 irrigation x variety treatments are combined with these 31 treatments, the total number of plots is 124. However, variation within the 31 fertility plots could be quite large and it would be advantageous to break these treatments into smaller blocks with less intra-block variation. Therefore, a central composite second order design in incomplete blocks presented by Cochran and Cox (1957) was investigated. With 4 x-variables, N = 30 and there were 3 incomplete blocks of 10 plots each. The treatment combinations are shown in Table 2. As described in the section on treatments, a measure of productivity of the soil without fertilizer is desired, therefore an

Table 2. Fertility treatments for a central composite second order design in incomplete blocks of 12 units. N = 30 original treatment combinations + 6 added treatment combinations.

Coded Levels

| Block I | | | | Block II | | | | Block III | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| N $X_1$ | P $X_2$ | K $X_3$ | pH $X_4$ | N $X_1$ | P $X_2$ | K $X_3$ | pH $X_4$ | N $X_1$ | P $X_2$ | K $X_3$ | pH $X_4$ |
| -1 | -1 | -1 | -1 | -1 | -1 | -1 | 1 | -2 | 0 | 0 | 0 |
| 1 | -1 | -1 | 1 | 1 | -1 | -1 | -1 | 2 | 0 | 0 | 0 |
| -1 | 1 | -1 | 1 | -1 | 1 | -1 | -1 | 0 | -2 | 0 | 0 |
| 1 | 1 | -1 | -1 | 1 | 1 | -1 | 1 | 0 | 2 | 0 | 0 |
| -1 | -1 | 1 | 1 | -1 | -1 | 1 | -1 | 0 | 0 | -2 | 0 |
| 1 | -1 | 1 | -1 | 1 | -1 | 1 | 1 | 0 | 0 | 2 | 0 |
| -1 | 1 | 1 | -1 | -1 | 1 | 1 | 1 | 0 | 0 | 0 | -2 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | -1 | 0 | 0 | 0 | 2 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| -2 | -2 | -2 | -2* | -2 | -2 | -2 | -2* | -2 | -2 | -2 | -2* |
| 1 | 1 | 1 | 1*-Micro nutr. | 0 | 0 | 0 | 0*-Micro nutr. | 2 | 2 | 2 | 2* |

*Added treatments

Treatment Levels

kg/ha

| Code | N $x_1$ | P $x_2$ | K $x_3$ | pH $x_4$ | |
|---|---|---|---|---|---|
| -2 | 0 | 0 | 0 | 0 | |
| -1 | 50 | 150 | 50 | + .5 | pH unit |
| 0 | 100 | 300 | 100 | +1.0 | " |
| 1 | 150 | 450 | 150 | +1.5 | " |
| 2 | 200 | 600 | 200 | +2.0 | " |

unfertilized plot, -2-2-2-2, was added to each incomplete block to assess this. In order to maintain balance in the design, as suggested by Tramel (1957), an offsetting treatment combination of 2222 was added to one block. This treatment completes one diagonal of the design and is also of agronomic interest in that it has the highest rates of all 4 variables. Theoretically it should have the highest yield, barring excessive rates. Also an assessment of possible deficiencies of micronutrients is desired so additional 0000 and 1111 plots were added which would not receive the micronutrient applications. These plots bring the total number of plots per block to 12 and the total number of plots for the fertility variables to 36. Combination with the 4 irrigation x variety treatments brings the total number of plots in the experiment to 144. This is a fairly large experiment, but in light of the variables being evaluated and the type of response curves to be developed, it does not appear likely that very great reduction in total number of plots is possible without sacrificing information on certain variables. There are 5 levels for each fertility variable which allows development of fairly precise yield response curves for determination of optimum rates for each variable and for tests of lack of fit.

Nalimov, Golikova, and Mikeshina (1970) presented 2 designs for four variables which have the property of D-optimality. Both had 3 levels of each variable. One of them had 24 treatment combinations and the other which was basically Kono's design (1962) modified to satisfy the condition of non-singularity for Hartley's (1959) second-order designs had 18 treatment combinations. These designs would reduce the total number of plots to 96 and 72, respectively, but offer only 3 levels of each variable which provides rather low precision for estimates of optimum rates, and tests for lack of fit.

Analysis of Imposed Management Factors:

Data obtained from the series of treatments described above will allow calculation of relationships between yield and the 6 management factors studied. The selected quadratic equation for which 26 parameters must be estimated is given below.

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_6x_6 + b_7x_1x_2 + b_8x_1x_3 + b_9x_1x_4 + b_{10}x_1x_5 + b_{11}x_1x_6 + b_{12}x_2x_3 + b_{13}x_2x_4 + b_{14}x_2x_5 + b_{15}x_2x_6 + b_{16}x_3x_4 + b_{17}x_3x_5 + b_{18}x_3x_6 + b_{19}x_4x_5 + b_{20}x_4x_6 + b_{21}x_5x_6 + b_{22}x_1^2 + b_{23}x_2^2 + b_{24}x_3^2 + b_{25}x_4^2$$

Where $x_1$ = applied N
$x_2$ = applied P
$x_3$ = applied K
$x_4$ = applied lime (pH)
$x_5$ = irrigation
$x_6$ = variety

An alternative approach is to calculate a yield equation for each variety under each of the two irrigation conditions giving a total of 4 equations for each site. The quadratic equation is given below for one variety at one irrigation level.

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_1x_2 + b_6x_1x_3 + b_7x_1x_4 + b_8x_2x_3 + b_9x_2x_4 + b_{10}x_3x_4 + b_{11}x_1^2 + b_{12}x_2^2 + b_{13}x_3^2 + b_{14}x_4^2$$

where the symbols are the same as described above. This approach appears somewhat more logical as there would be interest in the performance of each variety separately and also under the two irrigation conditions.

The production surface equation selected here is the quadratic which is generally considered adequate for describing fertility responses. However, Heady, et al. (1971) compared four production surface equations, i.e., Cobb-Douglas,

square root, 1.5 power, and quadratic or square equation and found the square root equation to be the most efficient in predicting the corn production surface. The experiment was an N x P experiment with 9 levels of each element in an incomplete factorial design. Therefore, it would be wise to evaluate several possible production models in this study to find the most efficient.

Several regression procedures are available for developing regression equations with a computer. Laird and Cady (1969) evaluated three of these, i.e., stepwise, backward elimination, and an agronomic approach. They found that based on residual sum of squares, the backward elimination model was slightly better than the stepwise, which in turn was better than the agronomic. However, if the criterion used was the ability of the equation to predict yields for new sets of data, measured by the predictive mean squares, the agronomic and stepwise models were the best. Since the aim of the present study is to predict yields on similar soil families in other areas, it would be wise to use predictive mean squares as the criterion for selecting the best regression model.

Economic Analysis:[1]

The production functions estimated by the regression analysis will be what economists refer to as production frontiers (frontier functions as opposed to production functions in as much as the equations represent the yields determined under well controlled situations and will generally be greater than a producer would be expected to obtain under the same conditions). These production surfaces can be solved to determine derived demand equations for each of the agronomic variables. Derived demand equations will determine the optimal input combinations for any specified market condition. The set of derived demand equations combined with the production frontier determine a profit frontier (function) allowing the

[1]By Dr. P. Garrod, Department of Agricultural Economics, University of Hawaii.

potential profitability of the crop for a given region and a specified set of market conditions to be determined.

Other possible economic applications could be the determination of the social rate of return on such production related investments as irrigation or the subsidization of fertility inputs. It is also possible to estimate the potential internal rate of return to the economic actor of investments in irrigation facilities or in inputs which improve the long run (more than one growing season) fertility of the soil.

Soil Factors:

One of the objectives of this project is to develop yield response equations for the same soil family over all sites where it occurs so that appropriate inputs of fertilizers, etc., can be made to obtain economically optimum yields. However, it is realized that local soil and climatic conditions existing at each site, even of the same soil family, can have measureable effects on productivity of the soil. Therefore, it is imperative that appropriate soil and climatic parameters be included in the yield equations to allow adjustment for local variations. Soil properties can be divided into three broad categories, chemical, physical, and mineralogical. Within each category a range of parameters exists which may be measured. The task is to identify those parameters that are likely to be important in plant growth and productivity. Several workers have investigated this problem and arrived at various conclusions. Voss, et al. (1970) considered soil N, P, K, pH, subsoil N, P, K, pH, and soil yield potential which was based on soil type, slope, and erosion. Soil N and P had the largest effects on yield response. Elgabaly (1971) suggested the physical properties of texture, structure, bulk density, and available water range (1/3 atm to 15 atm); the chemical properties of pH, $CaCO_3$, organic matter, (C,N), total N,P, K; available N, P,K, CEC, Exch Al,

Mn, and Ca; mineralogical information on the semiquantitative estimation of clay minerals; morphological information on depth of solum, depth of humus horizon, depth of carbonate horizon; and slope characteristics of aspect, degree and length. He also suggested collecting soil samples at 25 cm intervals to a depth of 100 cm. Okuno (1972) investigated the variables to be included to predict crop yields for the main crops grown in Bulgaria and included soil, climatic and management factors. He considered the soil factors, content of physical clay, content of humus, and pH in water all at two depths (0-30 and 30-50 cm.), texture coefficient, and thickness of humus horizon. Three of these variables appeared in the final yield equation. They were pH in subsoil, texture coefficient, and humus in top soil. Sopher and McCracken (1973) studied the correlations between soil properties, management practices and corn grain yields on selected North Carolina Coastal Plain soils and considered the following soil variables: 1/3 bar moisture (%), 15 bar moisture (%), 1/3 bar - 15 bar moisture, sand (%), silt (%), clay (%), pH water, pH in N KCl, total exchange acidity (me/100 g), exchangeable Al (me/100 g), acid extractable P and K (kg/ha), organic matter (%), exchangeable Ca, Mg, K, Na (me/100 g), CEC, base saturation (%), and CEC/clay * organic matter (me/100 g). They found the soil factors that affected yields most were soil moisture holding capacity, certain combinations of clay and sand, extractable P, percent base saturation and properties which control soil acidity, and the amount of charge on the cation exchange complex.

Buol, et al. (1974) developed a somewhat different approach in that they used a technical soil classification system for grouping soils with similar fertility limitations. Soils were grouped at the highest level according to topsoil and substrate textures and the 13 modifiers were selected to evaluate specific fertility-related parameters. These modifiers included low CEC, Al toxic, acid, Fe-P fixation, x-ray amorphous, vertisol, K deficient, carbonate, saline, sodic

and cat clay indices as well as two climatic parameters designated as gley (saturated with water for more than 60 days per year) and dry (dry more than 60 consecutive days per year). They found a considerable improvement in fertilizer rate recommendations when the fertility capability groupings as well as soil test results were used.

Based on the above literature and experience in Hawaii and Puerto Rico, it is proposed that the soil parameters listed below be measured at each site in the surface and subsoil.

Chemical parameters

1. CEC
2. Lime requirement
3. pH $H_2O$
4. pH N KCl
5. Δ pH
6. Exch. cations=Ca, K, Mg, Mn, Na
7. Base saturation
8. Al saturation
9. P sorption
10. Extractable P (0.5 M $NaHCO_3$)
11. Total N
12. Total organic C
13. C:N ratio
14. Micronutrients=Cu, Zn, Fe, Mo, S
15. Iron (Free iron / clay)
16. Free $CaCO_3$
17. K in silt fraction
18. Electrical conductivity

Mineralogical parameters

1. Relative mineral composition

Physical parameters

1. Particlesize (texture)
2. Structure
3. Bulk density
4. 1/10 bar moisture
5. 1/3 bar moisture
6. 15 bar moisture
7. Moisture release curve
8. COLE value (Coefficient of Linear Extensibility) Swell-Shrink
9. Atterberg limits
10. Aggregate stability
11. Horizon depth
12. Mottling
13. Slope

These parameters include criteria used in the soil family classification as well as others closely related to soil fertility. Thus it should be possible to identify important parameters affecting soil productivity for each family.

Climatic Factors:

Several researchers have studied the relationships between climatic factors and yield of various crops. Laird and Cady (1969) included excess moisture, drought, and hail in their equation for corn yield. Voss, et al. (1970) considered relative photosynthesis which was based on daily precipitation, evapotranspiration, and on available soil moisture to a depth of 150 cm at 15 cm increments at the beginning of the growing season. This variable was highly correlated with corn yield. Elgabaly (1971) suggested pre-sowing rain, temperature units during the growing season, moisture balance (total precipitation + moisture supply - evapotranspiration) and rainfall during a given critical period of growth, for yields in Bulgaria. Trashliev, et al. (1971) suggested some of the same variables in their studies of yields of wheat and maize in Bulgaria, as did Okuno (1972) who also included number of days above 5°C in winter. Oldeman (1971), working with sugarcane in Hawaii, considered rainfall in the summer, winter, at month of harvest, and one month before harvest; pan evaporation per month; radiation per month; maximum and minimum temperature and diurnal temperature difference at harvest. Buol, et al. (1974) included two climatic parameters in their condition modifiers for the fertility-capability classification system they developed. These were gley (saturated with water for more than 60 days in most years) and dry (dry for more than 60 consecutive days per year within 20-60 cm depth).

The climatic parameters listed below have been selected in discussions with Dr. Paul Ekern, University of Hawaii, and are being proposed for the present experiment.

1. Rainfall - quantity and intensity (hourly recording)
2. Air temperature - maximum, minimum, and average (continuous recording)
3. Solar radiation (hourly recording)
4. Relative humidity (continuous recording)
5. Wind - velocity and direction (continuous recording)
6. Daylength (from sunlight record or latitude)
7. Pan evaporation (daily)
8. Soil moisture
9. Soil temperature 3-6 inch depth - maximum and minimum (daily)

Parameters 7, 8, and 9 are considered to be optional if facilities are not available to obtain them. However, a measure of soil moisture, especially at the beginning of a crop would be helpful in assessing crop growth. Also pan evaporation measurements would be useful in determining the rate of moisture loss from the area and assist in scheduling irrigations and assessing moisture balance.

Management Factors:

In addition to management variables being intentionally varied as treatments in these experiments there are others which can vary from site to site or crop to crop that can have pronounced effects on yield levels obtained. Laird and Cady (1969) considered three of these, i.e., previous crop, leaf blight, and weeds, and all were included in the agronomic model which was found to have the highest predictive ability of the equations developed. Voss, et al. (1970) included past cropping, planting date, weeds, and plant population in their regression equation and found a considerable improvement in $R^2$ resulted. Elgabaly (1971) suggested date of sowing, land preparation, plant population, pest control, weed control, crop rotation, moisture levels and genotype as the important management variables

to be included in production equations. Oldeman (1971) included month of harvest, age, crop cycle, irrigation water per month, applied N, $P_2O_5$, and $K_2O$, and days after last irrigation. Sopher and McCracken (1973) considered the management variables plant population and planting date.

In the present experiment it is proposed that the management parameters listed below be recorded in addition to the imposed management variables.

1. Plant population
2. Crop rotation
3. Insect damage
4. Disease severity
5. Weed population
6. Planting date
7. Harvest date
8. Tillage

Plant Factors:

The ability of plants to take up nutrients is not always directly proportional to the levels of these nutrients in the soil due to conditions, chemical or physical, which may restrict absorption of certain nutrients. This has been shown in Hawaii by Thiagalingam (1971) and Khalid (1974). Therefore it is suggested that appropriate tissue samples be taken from each plot at the appropriate time and analyzed for moisture, N, P, K, Ca, Mg, Mn, Al and possible micronutrients. This will provide information on the content of these nutrients in the plant and allow better understanding of nutrient interactions and effects on yield. Other plant parameters may also be required for various crops, i.e., barrenness in corn, tillering in rice or sorghum, etc.

Development of Yield Response Equations with all Factors:

The yield response equations developed for the imposed variables in the experiment should be expanded to include the various management, soil, climatic, and plant factors in order to identify factors of importance in predicting yields for other soil and climatic conditions. The yield function is given by the formula:

$$y = f(x_1, x_2, \ldots x_m; y_1, y_2, \ldots y_s; z_1, z_2, \ldots z_c; w_1, w_2, \ldots w_p)$$

where y = yield of crop

$x_1, x_2, \ldots x_m$ = management factors

$y_1, y_2, \ldots y_s$ = soil factors

$z_1, z_2, \ldots z_c$ = climatic factors

$w_1, w_2, \ldots w_p$ = plant factors

These factors will be included in a regression equation which will be of the general model given below.

$$y = \beta_o + \beta_1 x_1 + \ldots + \beta_m x_m + \gamma_1 y_1 + \ldots + \gamma_s y_s + \delta_1 z_1 + \ldots + \delta_c z_c + \eta_1 w_1 + \ldots + \eta_p w_p + \varepsilon$$

This is a linear function of the unknown parameters $\beta_o$, $\beta_1 \ldots \beta_m$, $\gamma_1 \ldots \gamma_s$, $\delta_1 \ldots \delta_c$, and $\eta_1 \ldots \eta_p$ where the independent variables $(x_i;\ i=1,..m)$, $(y_j;\ j=1,\ldots s)$, $(z_k;\ k=1,\ldots c)$ and $(w_u;\ u=1,..p)$ can be the original measurements and variables derived from them, such as squares, products, square roots, logarithms, etc. Regression equations will be developed for each site to determine the important management, soil, climatic and plant factors. Then data from soils of the same family at different sites will be included in a regression analysis to produce a single equation which contains the important parameters which will allow prediction

of yields on the same family in different locations. Finally, an attempt will be made to include data from all sites in the study and develop a generalized or universal yield response equation which will adequately describe the yield response for any soil family, given the appropriate variables.

Economic evaluation of the derived demand equations for combined data should prove informative since effects of uncontrolled variables on yield levels will modify the economically optimum rates of fertilizer use. Also, Dr. P. Garrod suggested that if it is possible to approximate the probability distribution associated with climatic variables, then it would be possible to determine the production frontier, derived demand equations, social rate of return, and internal rate of return subject to risk criteria, i.e., what can the economic actor be 95% sure of occurring. Information derived from these analyses will be extended to the local governments as described earlier.

One test of the hypothesis of transferability of agrotechnology can be made by testing the response equations developed for two sites of the same soil family to determine if the response surfaces described are actually similar. This testing procedure is described by Pesek and Heady (1961). Analysis of variance of the combined data with a test of site effects would provide another evaluation of this hypothesis. Laird and Cady (1969) describe such a procedure which may have to be modified somewhat depending on the experimental design finally adopted.

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# APPENDIX 1

## ORIGINAL EXPERIMENTS DESCRIBED IN PROJECT PROPOSAL SUBMITTED TO AID

### Crop and Soil Management Experiments

Experiments with the following objectives will be installed at each major site.

1. To determine the potential productivity of soils under high management input.
2. To develop optimum management systems for multiple cropping.
3. To determine optimum plant population for various crops under local soil and climatic conditions.

The potential productivity of soils at each location will be determined with an N x P x K experiment to allow correlation with soil parameters and evaluation of transferability of agricultural technology. The aim is to attain maximum or near-maximum production with appropriate levels of these nutrients under optimum management conditions, i.e., adequate irrigation, calcium (pH), plant protection (weed, disease and insect control), and plant population.

Under these conditions, the soil-potential as well as local climate become the limiting factors and can thus be evaluated. Since N is often the most limiting nutrient in tropical soils, a minimum of three and possibly more N levels will be included at each location depending on the crop. Soil analyses will be used to guide the levels of P, K, and Mg at each site so that comparable soils will be evaluated at essentially the same levels of these nutrients. Soil pH values will be adjusted to approximately 6.0. Soil P will be evaluated with the P sorption isotherm method of Fox and Kamprath (1970) and soil levels will be adjusted to about 0.10 ppm P in solution, if they are not at this level.

Therefore, the presence of a P differential and the number of P rates in a particular experiment will depend on the soil P level and crop. The 0.1 ppm levels are required to produce maximum yields in many crops. Similarly, levels of K and Mg for maximum growth will be determined by methods suitable for tropical soils developed at the University of Hawaii and will serve as guides for differential rates of these nutrients. All fertilized plots except those mentioned below will receive a blanket application of micronutrients including Zn, B, Cu, Mn, Mo and others considered essential for the soils and crops used.

The experimental design will be an augmented block with the basic 2 x 2 x 2 factorial replicated three times and the other treatment combinations unreplicated. This will allow data for regression analysis as well as provide information on interactions between the variables tested. There will also be a complete control plot which receives no fertilizer at all, but is irrigated and otherwise treated as the fertilized plots. This treatment will serve as an indication of the "natural potential" for the soil without fertilizer and will be compared with similar plots in other soils. In addition, a plot will be given the highest fertilizer combination but will not be given the blanket micronutrient fertilization to allow a preliminary evaluation of possible micronutrient problems in the soil. These two plots will be incorporated at random in the experiment.

A second set of experiments testing various levels of management will be installed at the major sites. The objective of these experiments will be to demonstrate the increase in yield potential with improved management practices. Practices to be compared are irrigated vs non-irrigated, limed vs unlimed, and plant protection vs no plant protection (this will be separated into weed control, insect control and disease control). These practices will be maintained at two fertility levels, no additional fertilizer vs the highest level of fertility used at that site. All treatments will be replicated three times and the

design is a split-plot with irrigation level as the whole plots. Local farmer practice will be included as a comparison.

A third set of experiments designed to determine the optimum population for various crops will be installed at the major sites. These will have several population levels at the highest level of fertility and will be replicated three times.

A series of crops as mentioned above is to be gorwn at each of the major locations. The cropping cycles will be arranged so that a particular crop will be grown in the same season at all locations, i.e., because locations are north and south of the equator, a particular crop grown in the spring in the North will be grown in the comparable spring in the South which may be 4-6 months later. Crops will be planted in succession, with as much overlap as possible to capitalize on the principle of multiple cropping and to provide the farmer with a number of alternative crops in a year so that should one fail, he will not be without some crop production for the year. The continued rotation of crops with seasons will also provide information on the optimum cropping period for various species, as well as species adaptability to several seasons of cropping.

In order to test information obtained at the major sites, experiments will be installed at "satellite" locations. These are rural locations of similar soils on which simple experiments would be installed for farmer benefit.

Through the use of modern methods of data processing, correlations between crop yields and soil properties and production functions for crops in relation to many soil and management factors will be developed, using methods similar to those developed by Voss and Hanway (1970) and similar workers. The results of the experiments, when combined with the soil family data, will provide the information required to establish the extent to which agricultural technology is transferrable and to develop the land potential and capability units for phases of soil families in different tropical and subtropical regions.