RESEARCH ON THE TRANSFER OF AGROTECHNOLOGY

FINAL REPORT of the PUERTO RICO BENCHMARK SOILS PROJECT 1975-1981

Funded by the
US Agency for International Development
under contract AID/ta-C-1158

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COLLEGE OF AGRICULTURAL SCIENCES
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FOREWORD

The Benchmark Soils Project was established in 1974 to demonstrate the viability of a soil classification based approach to the transfer of agroproduction technology in the tropics as a means to increase the efficiency of agronomic research through its wide geographical diffusion and thus to accelerate the pace of agricultural development in the developing countries.

This report summarizes the work performed and the accomplishments achieved by the Benchmark Soils Project of the University of Puerto Rico under contract AID/ta-C-1158 with the US Agency for International Development (AID). It should not be construed as being the final report of the entire Benchmark Soils Project, which is the collective title of two parallel research contracts awarded by AID to the Universities of Hawaii and Puerto Rico. The University of Hawaii project is still in progress and its final report will be available in 1983.

The report has been structured to present the project and its results at various levels of generalization and brevity. A one-page narrative statement highlights the project accomplishments and their implications. A comprehensive but condensed sypnopsis is contained in the Executive Summary. A detailed account of the project is given in the body of the report and the results are placed into perspective in a concluding section. Most of the research data are presented in the Appendix.

First and foremost, we want to thank AID for providing the financial resources for the project and at the same time we wish to commend AID for the perceptive apprehension and farsightedness it demonstrated in funding this kind of research. We owe special thanks to Dr. Tejpal S. Gill of AID who served as Project Monitor and whose skillful management of the project assured its smooth functioning at all times. Moreover, Dr. Gill's encouragement and technical and administrative guidance gave the project direction, style and substance.

Project work in Brazil depended heavily on the outstanding collaboration of the Empresa de Pesquisa Agropecuaria de Minas Gerais (EPAMIG). We express our thanks to all EPAMIG staff involved in the project and especially to its first president, Dr. Helvecio Mattana Saturnino, who was an enthusiastic supporter of the Benchmark Soils Project, and to its subsequent president, Dr. Flamarion Ferreira, under whose tenure the project operations in Minas Gerais were completed. EPAMIG provided the field facilities and a multitude of administrative and technical services without which the project could not have operated.

The project was fortunate in being able to enlist Dr. Larry A. Nelson of the Statistics Department of North Carolina State University as a statistical consultant. Dr. Nelson, assisted by Ms. Teresa Gastardo and Dr. Jeffrey L. Paschke, handled all statistical aspects of the project and his intellectual and technical contributions were crucial to its success. Dr. Nelson also prepared the statistical section of this report, which was expertly typed by Ms. Margaret A. Rice of NCSU.

The relationship with the companion project of the University of Hawaii was always excellent and characterized by fine camaraderie. The association with the University of Hawaii in this endeavor proved very beneficial to the University of Puerto Rico project.

F. H. Beinroth
Principal Investigator
Benchmark Soils Project
University of Puerto Rico

HIGHLIGHTS OF ACCOMPLISHMENTS AND IMPLICATIONS

The basic premise of the Benchmark Soils Project of the Universities of Hawaii and Puerto Rico is that agrotechnology--particularly soil and crop management experience--can be transferred among and within tropical countries on the basis of the soil family as defined in the US system of soil classification, Soil Taxonomy. The successful completion of the University of Puerto Rico project provides the first concrete results of a scientific test of this hypothesis.

The findings of the project quantitatively substantiate the general validity of the stated transfer hypothesis. This conclusion is based on the results of the statistical analysis of a multitude of crop, soil and weather data accumulated over seven years of research at six experiment sites in Brazil and Puerto Rico using three different state-of-the-art techniques developed under the auspices of the Benchmark Soils Project. By implication, the project results also validate the soil family concept as postulated in Soil Taxonomy and the principle of benchmark soils.

Numerous soil and crop management experiments conducted in Brazil and Puerto Rico established the high crop production potential of the soil family studied with only moderate inputs of fertilizers and resulted in valuable agronomic information of immediate applicability to local farm situations. These studies were designed to conform to the economic decision environment of resource-poor farmers in agrarian LDCs.

The demonstrated scientific feasibility to employ the benchmark soils and the soil family concepts in the process of agrotechnology transfer in the tropics has far-reaching implications of consequence to the agricultural development in LDCs. As the project results indicate, the stratification of the agroenvironment into distinct niches of agroproduction as provided by Soil Taxonomy, in conjunction with the transferability of soil-specific experience with fertilization, cropping systems, erosion control measures, water management, etc., can be utilized to effectively reduce the cost and magnitude of agricultural research in LDCs. This constitutes a viable mechanism and framework for expediting the wide diffusion of agroproduction technology which will help to minimize duplicity of effort and result in economy of thought and economy of action.

The rational utilization of the benchmark soils concept in the process of agrotechnology transfer, in combination with a minimum of site-specific research for local adaptation, can make a significant contribution to ameliorating the depressing prospects of food deficits in the LDCs by accelerating the pace of their agricultural development. The principles and findings of the Benchmark Soils Project should therefore be put to use in a pragmatic program designed to demonstrate, in a operational network, the steady flow of agricultural technology from research sites to farmer fields in the tropics and subtropics.

BSP experiments at Isabela, Puerto Rico

I. EXECUTIVE SUMMARY

A. REFERENCE BACKGROUND

The Benchmark Soils Project (BSP) of the University of Puerto Rico (UPR) was established in January 1975 under contract AID/ta-C-1158 with the US Agency for International Development as a companion project to a similar AID contract of the University of Hawaii. While the UPR/BSP had a duration of seven years and terminated in December 1981, the contract of the University of Hawaii became effective in 1974 and will be operational through May 1983. Both projects were closely coordinated and constituted an integrated joint endeavor of both universities.

In the first comprehensive study of its kind, the BSP ventured to scientifically establish the transferability of agrotechnology, particularly soil and crop management experience. Central to this effort was the benchmark soils concept and the soil family as defined in the US system of soil classification, Soil Taxonomy. The intent of the soil family is to group together soils that are relatively homogeneous in properties important to plant growth. Consequently, comparable phases of all soils of a family should have a common and predictable response to management practices, correlative input-output characteristics, and similar crop production potential. The transfer hypothesis underlying the BSP is derived from these principles and is that empirical agroproduction experience gained with a soil of a particular family can be transferred and extrapolated to all other comparable members of that family, irrespective of their geographic occurrence.

The general aim of the UPR/BSP was to experimentally and statistically validate this hypothesis. The primary research objectives were:

1. To demonstrate that soil management and crop production knowledge can be transferred among tropical countries on the basis of soil families as defined in Soil Taxonomy, and

2. To establish that the behavior of tropical soils and their potential for food production under various levels of management inputs can be predicted from soil taxonomic units.

A secondary objective was to expand the knowledge base for the management of a family of tropical soils (Tropeptic Eutrustox) in particular consideration of the economic decision environment of small farmers in LDCs.

The basic research strategy of the project was to conduct a series of identical experiments in a network of soils belonging to the same family, monitor crop performance and weather conditions, and statistically compare response to management and yields.

The soils selected for experimentation by UPR were highly weathered, but moderately fertile red upland soils of savanna ecosystems of the subhumid tropics defined as Eutrustox in Soil Taxonomy. The particular soil family under study was the clayey, kaolinitic, isohyperthermic family of Tropeptic Eutrustox. This family was chosen because it occurs in both Puerto Rico and Hawaii and thus provided the required link between the two projects.

Six experiments sites were established and operated in such soils; three at Isabela in Puerto Rico and three at Jaiba in northern Minas Gerais, Brazil, in cooperation with the Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG). The University of Hawaii project installed two research sites in soils of the same family in Hawaii.

A total of 136 field experiments were conducted at the six research sites in Puerto Rico and Brazil. Eighty-one of these were so-called transfer experiments which were specifically designed to generate the data base for the statistical transfer test. They were highly controlled, drip-irrigated fertility experiments with phosphorus and nitrogen as variables and maize as the testcrop. The other 55 experiments included 22 variety trials with maize and soybeans, and 33 soil and crop management experiments that emphasized efficiency of cultural practices.

B. TEST OF THE TRANSFER HYPOTHESIS

The field data of the transfer experiments were statistically evaluated with three different techniques developed under the auspices of the BSP. They were the P-statistic, the confidence interval procedure, and a graphical method. The results with the confidence interval procedure and the graphical method provided strong positive evidence for transferability. The results with the P-statistic were less conclusive but not negative. Attention is drawn to Fig. 6 in the text which allows an instant visual appraisal of the transferability of management practices. The graphs show that, if certain site variables are considered, fertilizer response at a new site can be predicted on the basis of experiments conducted at other sites with the same soil family essentially as well as by an experiment conducted at the new site.

On balance, the statistical studies yielded a qualified validation of the postulated transfer hypothesis and, by implication, of the concepts of benchmark soils and the soil family. In view of the complexity of the conjecture under study and considering the difficulties encountered in its experimental and mathematical corroboration, these results are very reassuring.

C. AGRONOMIC ACCOMPLISHMENTS

The results of the agronomic research demonstrate the high productivity of Eutrustox with moderate fertilizer inputs. Highest mean maize yields of over 9,000 kg/ha were obtained in Puerto Rico and Brazil with about 40 kg/ha of phosphorus and 175 kg/ha of nitrogen. Soybean yields were as high as 5,000 kg/ha. These are excellent yields for the tropics and underline the high crop production potential of Eutrustox, particularly if one considers that with irrigation at least two crops can be grown in the same year.

Pioneer brand hybrid X304C was experimentally identified as a maize variety well adapted to the agroenvironment of Eutrustox. A maize composite population improvement study conducted with 88 varieties from all over the world, initiated by the UPR/BSP and now continued by EPAMIG, has produced promising changes in plant height, disease resistance, susceptibility to lodging, and prolificacy. It is expected that after further cycles a new maize variety for the Jaiba region can be released. Several soybean varieties adapted to this area have also been identified.

A maize plant population of 55,000 to 60,000 plants/ha can be recommended for Eutrustox on the basis of studies in Puerto Rico and Brazil. For unirrigated maize production in the Jaiba area, mid-November was determined as the optimal time for planting. With planting dates later in the wet season yields dropped off sharply from 6,300 to 2,000 kg/ha.

Irrigation trials with maize and sorghum employing a continuous variable line-source irrigation technique were conducted in Brazil in collaboration with the Centro Nacional de Pesquisa de Milho e Sorgo (CNPMS). The data are now processed by CNPMS for the development of a moisture utilization model for maize and sorghum in Brazil. Other irrigation studies confirmed that the time around flowering is the period when maize is most susceptible to moisture stress.

Tillage experiments indicated that for maize production in Eutrustox complete tillage is not necessary for each planting, and that plowing when the soil was almost dry resulted in the best seedbed preparation. Maize stover as a crop mulch can be effectively used to conserve soil moisture and increase yields under rainfed conditions.

An intensive multicropping experiment using a 20 x 20-m area of Eutrustox yielded produce valued at US$ 1,160 over a 27-month period. The study showed how small plots of land can be intensively utilized with modest inputs to effectively improve the quantity and quality of the diet of resource-poor farm families.

D. DISSEMINATION AND IMPACT

The Benchmark Soils Project was prominently exposed and discussed at many international conferences and workshops. Project rationales and findings were further disseminated through a sizeable and effective public relations and publication program implemented and sustained by the University of Hawaii BSP. More than 1,200 individuals and institutions in 89 countries are routinely informed about BSP developments.

International soil classification workshops organized by UPR and held in Brazil, Malaysia and Thailand, Syria and Lebanon, and Rwanda made a significant contribution to the utilization of the benchmark soils concept. The success of these workshops was instrumental in the establishment of a new AID-sponsored program, the Soil Management Support Services (SMSS) of the USDA Soil Conservation Service. The goal of this program is to assist LDCs in producing the quality resource inventories that are the prerequisite for soil-based transfers of agrotechnology, to refine Soil Taxonomy, and to promote its application in the Third World. The SMSS is thus closely related to the BSP and facilitates possible follow-up activities.

Planning meetings held at ICRISAT and FAO developed strategies for the implementation of the benchmark soils concept and BSP principles in a program of more comprehensive scope and wider geographical extent.

The main impact of the BSP to date has been the creating of wide awareness and familiarity with the project and its philosophy, instigating support activities, and generating considerable momentum for the use of the benchmark concept for agrotechnology transfer.

E. CONCLUSIONS

With the overall success of the University of Puerto Rico project, the BSP has begun to scientifically establish the validity of a soil family-based model for agrotechnology transfer. The encouraging results of the present project are expected to be reinforced by the findings of the ongoing project of the University of Hawaii which will be based on larger data sets from three different soil families.

It is proposed that these results be utilized in a follow-up program and a model for the anologue transfer of agrotechnology is presented in the report. A logical culmination of the current BSP effort should be the establishment of a prototype network of national and international agricultural research centers designed to demonstrate the steady flow of agroproduction technology from research centers to farmer fields in the tropics and subtropics.

II. THE PUERTO RICO BENCHMARK SOILS PROJECT

A. PROJECT RATIONALE

1. GENERAL PERSPECTIVE

Projections by FAO (1979) indicate that worldwide agricultural production will have to increase by 60 percent in the next 20 years to meet food requirements of future populations. About 70 percent of this increase will need to come from intensification of agriculture and the other 30 percent from an expansion of arable land--as much as 200 million ha, mostly in the tropics. If the less developed countries (LDCs) are to increase per capita food availability by at least 1 percent per year, they need to expand their food production over the next 25 years by an average rate of about 3 to 4 percent per year and increases in yield need to average about 2.5 percent per year (US National Research Council, 1977).

There are no fundamental reasons for these targets not to be met or for Malthusian scenarios. The world can feed its people and conceivably many more if Revelle's (1976) conjecture of a carrying capacity of the world of 40 billion people is not too optimistic. Distressingly, however, the performance so far has been less than reassuring. Dudal (1978) estimates that during the 20-year period ending in 1977 the area of cultivated land in the world increased by 135 million hectares which corresponds to about 10 percent of the land resources still available for cultivation and to only about 9 percent of the land currently in agricultural use. Yet, in the same period the world's population increased by 40 percent. The expansion of cultivated lands in the LDCs in particular is far lagging behind that required by the increase in population there.

Rapid improvement of agricultural productivity in LDCs, consistent with the required growth rates, implies a transition from a natural resource-based agriculture to a science-based agriculture. To bring about this transition within a short period of time requires massive inputs of capital and research personnel. Many of the LDCs are small in size and population, however, and in view of their limited experiment station capacity, an inelastic supply of scientific and technical manpower, and a general lack of capital, such nations cannot expect to generate by themselves the full range of scientific knowledge and expertise needed to develop and sustain a viable agriculture. They rely on assistance from external sources.

Transferring food production technology from the temperate climatic zone to the tropics seemed a natural solution but has been largely ineffective and discouraging. Principal among the reasons for the lack of success is the failure to recognize the location specificity of agricultural technology which is controlled mainly by differences in soil and climate. It is becoming increasingly obvious that the technology for tropical agriculture must be developed primarily in the tropics (Beinroth et al., 1980).

The knowledge base for a modern tropical agriculture is now gradually being generated through the work of national and international agricultural research centers. But the results of this research must also be disseminated. The transfer of this knowledge and its adaption to local conditions is of crucial importance to the agricultural and economic development is agrarian LDCs.

In the context of this perspective and on the basis of the rationales elaborated below, the Benchmark Soils Project contends that soil classification is a suitable vehicle for and an essential element of the process of agrotechnology transfer.

2. SIGNIFICANCE OF SOIL SURVEY AND CLASSIFICATION TO AGROTECHNOLOGY TRANSFER

Soil classification provides pragmatic groupings of soils for precise predictions about soil behavior, and its most important application is in soil survey. Historically, soil surveys have been geared to the improvement of agriculture, and most LDC governments presently support soil survey activities because they believe soil surveys supply reliable and accurate information for agricultural development and soil-resource management. Soil surveys, however, are only useful if they follow reasonable scientific standards and if they are interpreted for practical purposes. Such interpretations are predictions of soil behavior under stated conditions, which require the careful synthesis of many data in relation to soil qualities that are the result of the interaction between soil characteristics, crop requirements, and management practices (Kellogg, 1961). Soil survey interpretation makes possible the most intensive use of soil science by integrating knowledge from many other disciplines (Smith, 1965).

Many authoritative statements can be found in the literature that allude to the fact that soil classification, in conjunction with soil surveys, affords an effective basis for knowledge transfers. Smith (1965), for example, wrote:

> "We make the basic assumption that experience with a particular kind of soil in one place can be applied to that particular kind of soil wherever it exists if consideration is taken of any climatic differences. The soil survey acts as a bridge that lets us transfer the knowledge gained by research or by the experience of cultivators from one place to all other places where it is applicable."

Of the various systems of soil classification in use, Soil Taxonomy (Soil Survey Staff, 1975) has the greatest potential for land use appraisals because it " ..was created to support soil surveys and the interpretations of surveys that are required by both developing agriculture and advanced farming" (Johnson, 1980). A unique feature of Soil Taxonomy is that it incorporates climate in the definition of soil taxa and thus not only stratifies soils and climate but implicitely also the agroenvironment. The lower categories of Soil Taxonomy therefore conform more nearly to distinct agroproduction niches (Beinroth, 1980).

Soil Taxonomy was published by the USDA Soil Conservation Service in 1975 after 20 years of preparation. It is an attempt at a comprehensive taxonomic classification of soils and constitutes the most elaborate and most quantitative system developed to date. Although basically an American system, Soil Taxonomy is gradually becoming the internationally accepted classification for scientific communication, and more and more pedologists, particularly in the Third World, are talking to each other in terms of this system. It is also used, either in lieu of or parallel to, national systems of soil classification, notably in Southeast Asia and in Latin America.

Like most taxonomic systems, Soil Taxonomy is a multicategoric system. Each category is an aggregate of taxa, defined at about the same level of abstraction, with the smallest number of classes in the highest category and the largest number in the lowest category. In order of decreasing rank, these categories are order, suborder, great group, subgroup, family, and series. As is true with all multicategoric systems, the properties associated with classes accumulate from the higher and more abstract categories down to the lower categories.

The soil family constitutes a condensed scientific statement that integrates the knowledge about a narrowly defined group of soils and their environment. Soil families are, within a given subgroup, differentiated primarily on the basis of soil characteristics that provide classes having relative homogeneity in properties important to plant growth and that are indicative of soil-water-root relationships. Soils classified in the same family should, therefore, have nearly the same management requirements, a common response to cultural practices, and a similar potential for crop production.

B. PROJECT HYPOTHESIS, OBJECTIVES AND SCOPE

1. TRANSFER HYPOTHESIS

Soil Taxonomy (p. 80) states that "the responses of comparable phases of all soils in a family are nearly enough the same to meet most of our needs for practical interpretations of such responses." The basic hypothesis underlying the Benchmark Soils Project is derived from this statement and is that comparable phases of all soils of a family have a common and predictable response to management practices, correlative input-output characteristics, and similar crop production potential. As a consequence, empirical agroproduction experience gained with a soil of a particular family can be transferred and extrapolated to all other comparable members of that family, irrespective of their geographic occurrence.

This thesis is clearly based on a model of analogous reasoning. In analogue transfers an attempt is made to stratify the agroenvironment with sufficient precision to ensure successful transfer of technology (Swindale, 1980). Analogous areas are determined and identified by taxa of Soil Taxonomy which stratify both soils and climate. Basic to this model is the benchmark soils concept developed by Kellogg (1961). More recently Miller and Nichols (1980) defined a benchmark soil as a soil occupying a key interpretative position in a soil classification framework and/or covering a large area. It is considered a representative reference site from which research results can be transferred or extrapolated to other sites with similar properties.

2. OBJECTIVES

The basic objective of the Benchmark Soils Project of the University of Puerto Rico was to experimentally validate the stated project hypothesis and the benchmark soils concept. No such effort has previously been undertaken in the tropics. The primary research objectives of the project therefore were:

1. To demonstrate that soil management and crop production knowledge can be transferred among tropical countries on the basis of soil families as defined in Soil Taxonomy, and
2. To establish that the behavior of tropical soils and their potential for food production under various levels of management inputs can be predicted from soil taxonomic units.

Implicit in these objectives are the substantiation of the value of soil survey and classification for land use planning and the testing of the validity of established taxonomic criteria. A secondary objective was to expand the knowledge base for the management of a family of tropical soils (Tropeptic Eutrustox) in particular consideration of the economic decision environment of small farmers in LDCs.

3. PROJECT SCOPE

The scope of the project was to test an approach to agrotechnology transfer that can be used in "horizontal transfers," i.e., knowledge transfers among researchers at a scientific level. Such knowledge and experience has been referred to as "upstream" technology which involves prototype solutions generated by commodity or discipline oriented research at national and international agricultural research centers (Gilbert et al., 1980). The process of adapting this knowledge to specific local farm situations and its integration into existing farming systems may be termed "vertical transfers" and involves "downstream" research and diffusion.

It is realized that both elements are of equally critical importance to the ultimate success of agrotechnology transfer. The project, however, was concerned primarily with and focused on a methodology for horizontal transfers. Research in the area of vertical transfer as well as the actual transfer of agrotechnology were by design beyond the terms of reference of the present project.

Dr. F. H. Beinroth, Professor of Soil Science, served as Principal Investigator. Over the years, 18 professionals, 8 nonprofessionals and a varying number of field laborers were engaged in project activities (see Project Personnel in the Appendix). Dr. T. S. Gill monitored the project on behalf of AID with competence and efficacy.

UPR's work in Brazil depended heavily on the superb cooperation of the Empresa de Pesquisa Agropecuária de Minas Gerais, EPAMIG. This agency is a dependency of the Ministry of Agriculture of the State of Minas Gerais and is in charge of all agricultural research in the state. It is also affiliated with EMBRAPA, the national research organization for agriculture. EPAMIG's first president, Dr. Helvecio Mattana Saturnino, was an enthusiastic supporter of the BSP. Since 1980 Dr. Flamarion Ferreira has presided over EPAMIG and continued the excellent collaboration. A memorandum of agreement between UPR and EPAMIG which detailed UPR's involvement and responsibilities in Brazil and specified EPAMIG's technical and administrative contributions became effective in January 1976.

Major milestone events of the UPR/BSP were:

Mar 1973	Project proposal submitted to AID
May 1974	Workshop on experimental design in Honolulu, Hawaii
Jan 1975	UPR contract becomes effective
Jul 1975	Field work started in Puerto Rico
Aug 1976	First joint BSP coordination meeting in Puerto Rico
Oct 1976	Field work started in Minas Gerais, Brazil
Feb 1977	Project review
Aug 1977	Second joint BSP coordination meeting in the Philippines
Jan 1978	Three-year extension of UPR contract becomes effective
Oct 1978	Workshop on implications of agrotechnology transference research at ICRISAT, Hyderabad, India
Mar 1980	BSP panel consultation on strategy for land evaluation and agrotechnology transfer at FAO, Rome, Italy
Dec 1980	Field work concluded
Jan 1981	One-year extension of UPR contract becomes effective
Feb 1981	BSP Symposium at ISSS conference on soils with variable charge at Palmerston North, New Zealand
Dec 1981	UPR contract terminates
Feb 1982	UPR's final report published and disseminated

2. RELATION TO THE BENCHMARK SOILS PROJECT OF THE UNIVERSITY OF HAWAII

The UPR/BSP was a companion project to the BSP of UH which will be active until 1983. The UH/BSP has essentially the same objectives but a broader scope and a wider geographic sphere of operations. Whereas the field work of the UPR/BSP was confined to one soil family in Puerto Rico and Brazil, UH is conducting research on three soil families in Hawaii, Cameroon, Indonesia, and the Philippines.

The Puerto Rico project operated in close technical coordination with the Hawaii project. This was achieved through joint BSP Coordination Meetings, held in Puerto Rico in 1976 and in the Philippines in 1977, and through frequent visits and consultations. The Hawaii BSP handled the public relation aspects of the projects and the printing of joint progress reports. UH/BSP also assumed the responsibility for the overall, network-wide analysis of experiment results which will be presented in UH's final report.

Although the UPR/BSP had its own administrative and some institutional identity, it really was part of one larger and fully integrated endeavor jointly undertaken by the Universities of Hawaii and Puerto Rico.

University of Hawaii (UH), University of Puerto Rico (UPR) and AID participants at the first BSP coordination meeting in Puerto Rico. From left: A.R. Hurdus (UH), J. Badillo (UPR), J.A. Silva (UH), T.S. Gill (AID), C. Sarmiento (UPR), L.D. Swindale (then UH, now ICRISAT), I. P. Gedjer (UH), G.L. Spain (UPR), C.E. Seubert (UPR), F.H. Beinroth (UPR), L. Calduch (UPR), and G.Y. Tsuji (UH).

D. RESEARCH NETWORK

1. GENERAL

Three families of tropical soils were selected by the BSP for the test of the transfer hypothesis. They comprise soils derived from volcanic ash (Hydric Dystrandepts), acid clay soils of humid regions (Typic Paleudults) and strongly weathered but moderately base-saturated soils of savanna ecosystems (Tropeptic Eutrustox). The UPR/BSP worked only with the clayey, kaolinitic, isohyperthermic family of the Tropeptic Eutrustox which are described in more detail below. This soil family was chosen because it occurs both in Puerto Rico and Hawaii and thus provided the required link between the two projects.

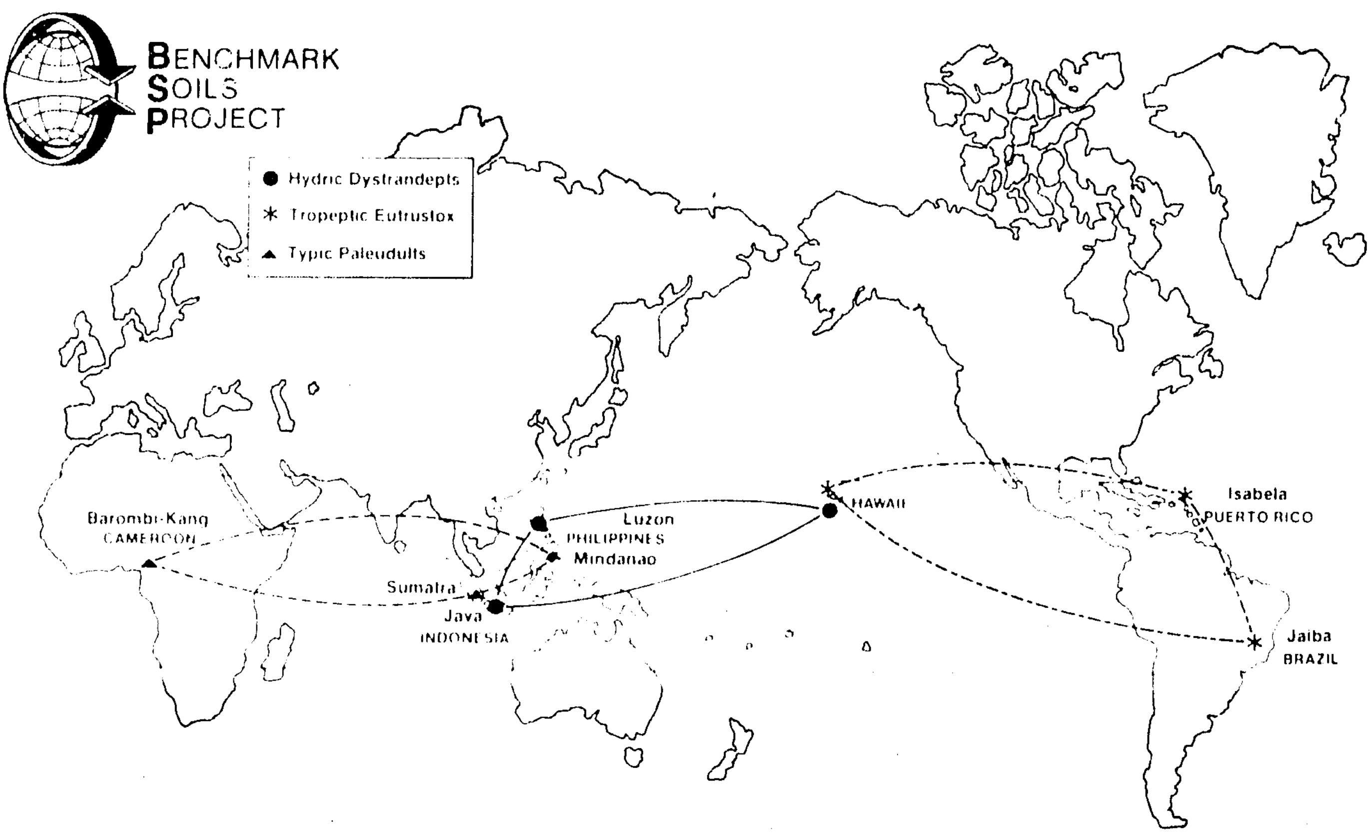


Fig. 1. The three soil family networks in the Benchmark Soils Project.

In theory, locations for field experimentation should be randomly selected from all the units of the population of soils comprised in the stated soil family. In the project, however, random sampling was not feasible, primarily because only a limited number of countries could be involved and because of political and logistic considerations. On the basis of preliminary investigations involving literature surveys and consultations, the search was concentrated on Brazil, Colombia, the Dominican Republic, Jamaica and Venezuela.

In spite of extensive field and laboratory studies, the desired family of Eutrustox could only be identified in the northern part of the state of Minas Gerais in Brazil.[1] Other potential locations had to be eliminated because the soils failed to meet the specific family criteria or because of adverse logistic conditions. Experiment sites were, therefore, established in Puerto Rico and in Brazil.

2. RESEARCH SITES

Statistical considerations evinced the need to have a minimum of eight research sites per soil family. For the family of Tropeptic Eutrustox, three sites each were established in Puerto Rico and Brazil; two sites are operated by UH on Oahu and Molokai in Hawaii.

In Puerto Rico, one primary site ("Ramal") of 3 ha and one secondary site[2] ("Cerro") of 2 ha were installed in 1975 on the grounds of the Isabela Agricultural Experiment Station of UPR. This 120-hectare research station is located in the northwestern corner of Puerto Rico and was founded in 1928 to serve the Isabela Irrigation District. An additional secondary site ("Calero") of 2 ha was established on a private farm about 8 km west of the other sites. The Puerto Rico sites were clustered around latitude 18° 28'N and longitude 67° 03'W at an elevation of about 130 m above sea level.

In Brazil, one primary site ("Paranã") and two secondary sites ("Bahia" and "Ceara") were established in 1976 and 1977 in an area djacent to the Sao Francisco River in northern Minas Gerais known as the "Distrito Agro-Industrial de Jaiba." This 300,000-hectare scheme was recently developed and is now being

[1] We are grateful to Mr. M. Camargo of SNLCS/EMBRAPA for his excellent cooperation in identifying this site.

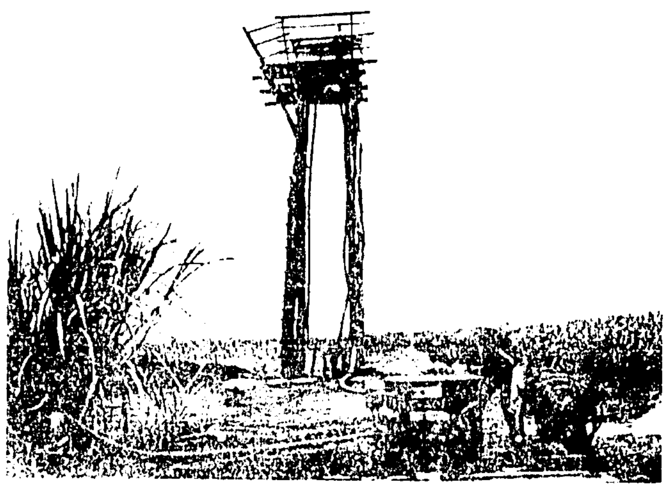
[2] For the distinction between primary and secondary sites, see Section III.

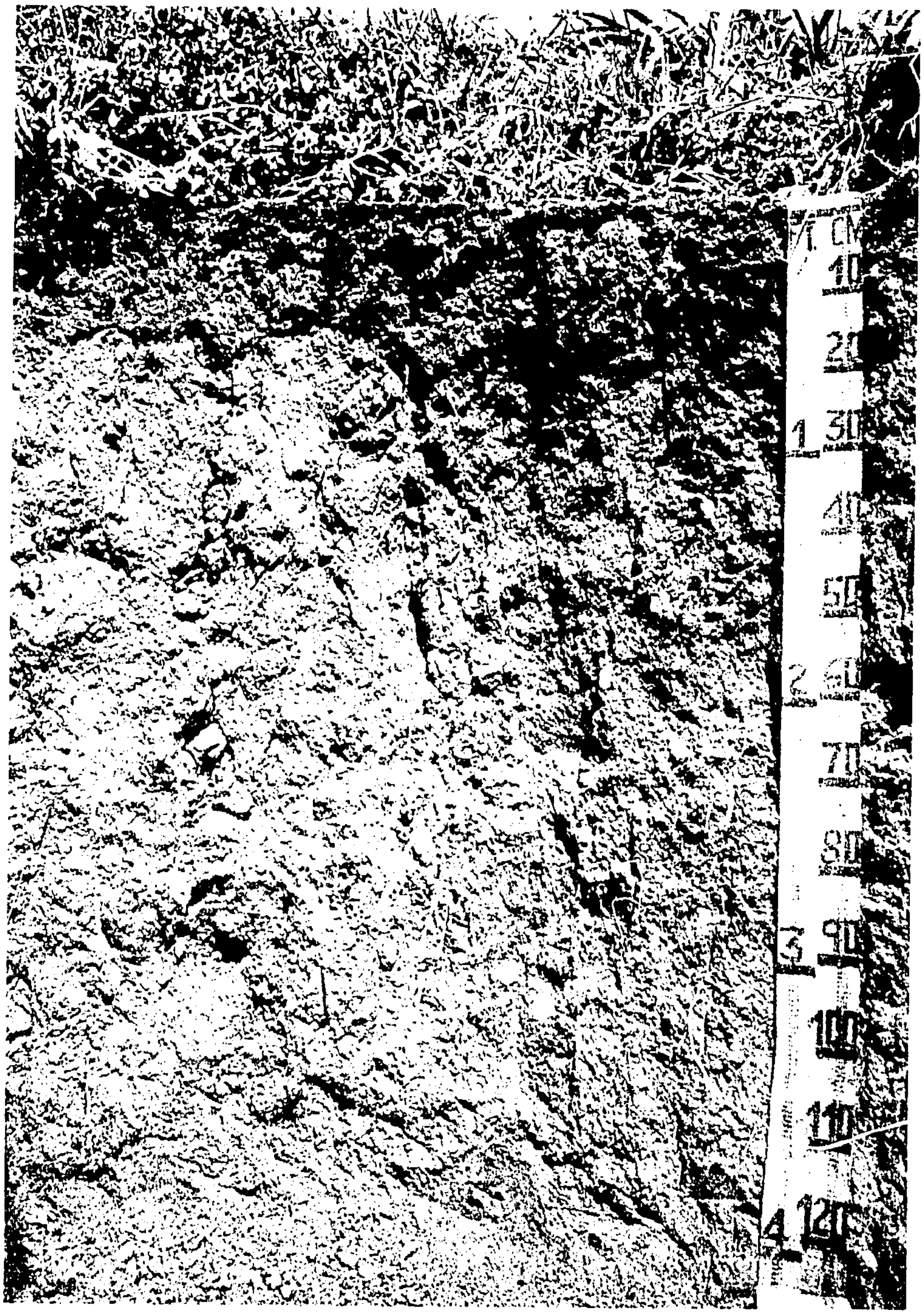
opened for colonization by small farmers. The BSP sites were thus well located from the point of view of local impact and utilization. The primary site near Jaiba comprised 6 ha and was on a new experiment farm of the project's cooperating agency, EPAMIG. The two secondary sites of 3 ha each were set up on private land at distances of 3.5 and 5 km northwest of the primary site. The Brazil sites were located at or near latitude 15° 23' S and longitude 43° 46' W at an levation of approximately 500 m above sea level.

At all three locations the infrastructure for experimentation had to be developed by the project, including the drilling of three 60-m-deep water wells. Upon project termination, the BSP field, laboratory and office facilities were turned over to EPAMIG and are now used and maintained by that agency.

The Puerto Rico project thus operated six sites. Together with the two sites of the Hawaii project, the BSP Eutrustox network includes eight sites in three widely separated regions -- Oceania, South America and the Caribbean.

BSP office, laboratory and irrigation facilities at Jaiba, Brazil





Profile of the Coto soil, a Tropeptic Eutrustox from Isabela, Puerto Rico

3. SOILS

The clayey, kaolinitic, isohyperthermic family of Tropeptic Eutrustox belong to the group of soils that has been called Laterites, Sols Ferrallitiques and Latosols in recent years and is now referred to as Oxisols in Soil Taxonomy. Eutrustox are well-drained and usually red clay soils occurring under savanna or deciduous forest vegetation in subhumid tropical regions, normally on basic parent materials. They are strongly weathered soils that are slightly acid to neutral, have an appreciable supply of bases, and moderate to high base saturation in the subsoil. Among their adverse properties are a limited water holding capacity, a tendency to compact when cultivated with heavy equipment, and moderate ph .phorus deficiency. Their main constraint for crop production is insufficient soil moisture in more than three months per year. Although not the most common kind of Oxisols, Eutrustox are extensive in tropical South America and Africa. They represent important soil resources preferred for immediate development over other Oxisols on account of their inherent productivity.

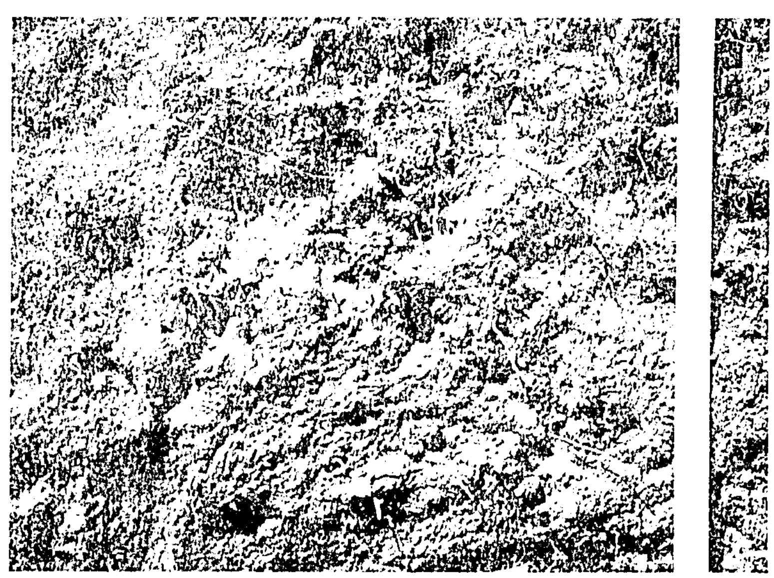
The main diagnostic features of Eutrustox are the oxic horizon and the ustic soil mositure regime as defined in Soil Taxonomy. The oxic horizon is a highly weathered subsoil horizon that consists mostly of a fine-textured mixture of oxides of iron and aluminum and low activity clays resulting in a cation exchange capacity of less than 16 meq per 100 g of clay. There are no or only traces of minerals that could weather to release bases. The ustic soil moisture regime implies that the moisture control section of these soils is dry in some or all parts for 90 or more cumulative days in most years, but it is moist in some part for 180 cumulative days or continuously moist in some part for 90 consecutive days. The concept of the ustic soil moisture regime thus is one of limited moisture that, for the tropics, is typified in a monsoon climate which has at least one rainy season of three months or more.

Further properties which clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox by definition must have include: less than 16 kg of organic carbon in the surface cubic meter; a base saturation of more than 50 percent in the major part of the oxic horizon; a moderate degree of soil structure in the oxic horizon or a depth of less than 125 cm, or both; more than 35 percent clay; more than 50 percent kaolinite and less than 10 percent montmorillonite in the clay fraction; a mean annual soil temperature of 22°C or more with less than 5°C difference between mean summer and mean winter temperature; and a depth of more than 1 m. The covariant and accessory properties associated with the defined characteristics have been discussed by Beinroth (1981).

Profile descriptions and analytical data for one representative pedon each from the BSP experiment sites in Isabela, Puerto Rico, and Jaiba, Brazil, are presented in the Appendix. As the data show, these particular Eutrustox have high clay contents throughout (53-81%), a low cation exchange capacity of 7.5 to 14.9 meq per 100 g of clay in the subsoil, a base saturation of up to 86 percent, pH values ranging from 4.5 to 6.5, small amounts of extractable bases in the subsoil (1.8-6.9 meq/100 g soil), and rather high amounts of organic carbon (1.1-3.1%) in the surface soil.

Within the limits permitted by the definition of clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox, there is obviously some diversity among the soils of the BSP sites in Puerto Rico and Brazil. They vary, for example, in percentage base saturation, clay content, color, degree of soil structure, organic matter content in the surface horizon, and in other non-classificational parameters. These differences and variability notwithstanding, the soils at all of the six UPR/BSP experiment sites belong to the same soil family and all have the same slope class.

Moreover, in a detailed soil survey by the USDA Soil Conservation Service (1975) the three Puerto Rico sites are included in the same mapping unit. Similarly, the soil survey of the Jaiba area in Brazil (EMBRAPA/EPAMIG/RURALMINAS, 1976) does not differentiate the soils at BSP sites. If the Puerto Rico and Brazil sites occurred in juxtaposition, however, the soils would be mapped as two different soil series of the same family on the basis of differences in color, structure and solum depth. In addition to the two references above, further information on the soils of the BSP network has been provided by Ikawa (1979) and Beinroth (1979).



Close-up view of the oxic horizon of a Eutrustox at Jaiba, Brazil

4. CLIMATE

The climate at Isabela, Puerto Rico is of the Thornthwaite type B/CA'r--subhumid transitional to humid, tropical. At Jaiba, Brazil the type is C/B'w--subhumid transitional to humid, tropical, dry winters. According to 42-year records mean annual precipitation at Isabela is 1,657 mm, the mean annual air temperature 24.8°C and the mean annual evaporation 1,735 mm. During the time of BSP work at Isabela the weather was somewhat drier and cooler, however, with annual precipitation averaging 1,530 mm and a mean annual temperature of 24.0°C. Thirty-year records available for Januaria, located about 40 km west of Jaiba, indicate a mean annual rainfall of 875 mm, a mean annual air temperature of 24.4°C and a mean annual evaporation of 1,354 mm. At the BSP sites at Jaiba corresponding values of 1,010 mm and 23.5°C were recorded over a 4-year period.

Mean monthly precipitation and air temperatures for Isabela and Jaiba are shown in the graphs in Fig. 2. (More detailed weather data are presented in the Appendix.) It is obvious that the two locations have different rainfall patterns. Whereas in Jaiba there occurs a pronounced dry season in the winter months of June, July and August, seasonality at Isabela is less distinct and the amount of rainfall in any given year is subject to much greater variability. This reflects a maritime climate in Puerto Rico versus a continental climate in Brazil.

Mean monthly air temperatures are rather uniform throughout the year at both Isabela and Jaiba. The range between mean monthly minimum and maximum temperature, however, is considerable. At Jaiba a mean minimum temperature of 10°C was recorded for the months of June and July and mean maximum temperatures of 33°C for the months of March, September and October. At Isabela, December, January and February had the lowest mean temperature (17°C) and August and September the highest (31°C).

Mean solar radiation at Jaiba was 157,800 langleys/year and ranged from 366 langleys/day in June to 505 langleys/day in March. At Isabela a yearly mean of 151,200 langleys was registered with the lowest radiation in January (329 langleys/day) and the highest (473 langleys/day) in June.

From a soil taxonomic point of view, the BSP sites in Puerto Rico and Brazil have an isohyperthermic soil temperature regime. (Under a proposed revision of the soil temperature regimes, both locations would have an "isomegathermic" regime.) The soil moisture regime is typically ustic at Jaiba and marginally ustic at Isabela. A computer analysis of the weather data for Isabela revealed the presence of a udic soil moisture in some years but it was ustic in the majority of years. It appears that the present definition of the ustic soil moisture regime is too broad to allow meaningful agricultural interpretations. The introduction of a "udi-ustic" regime has therefore been considered. The evidence accrued by the BSP strongly supports this proposal.

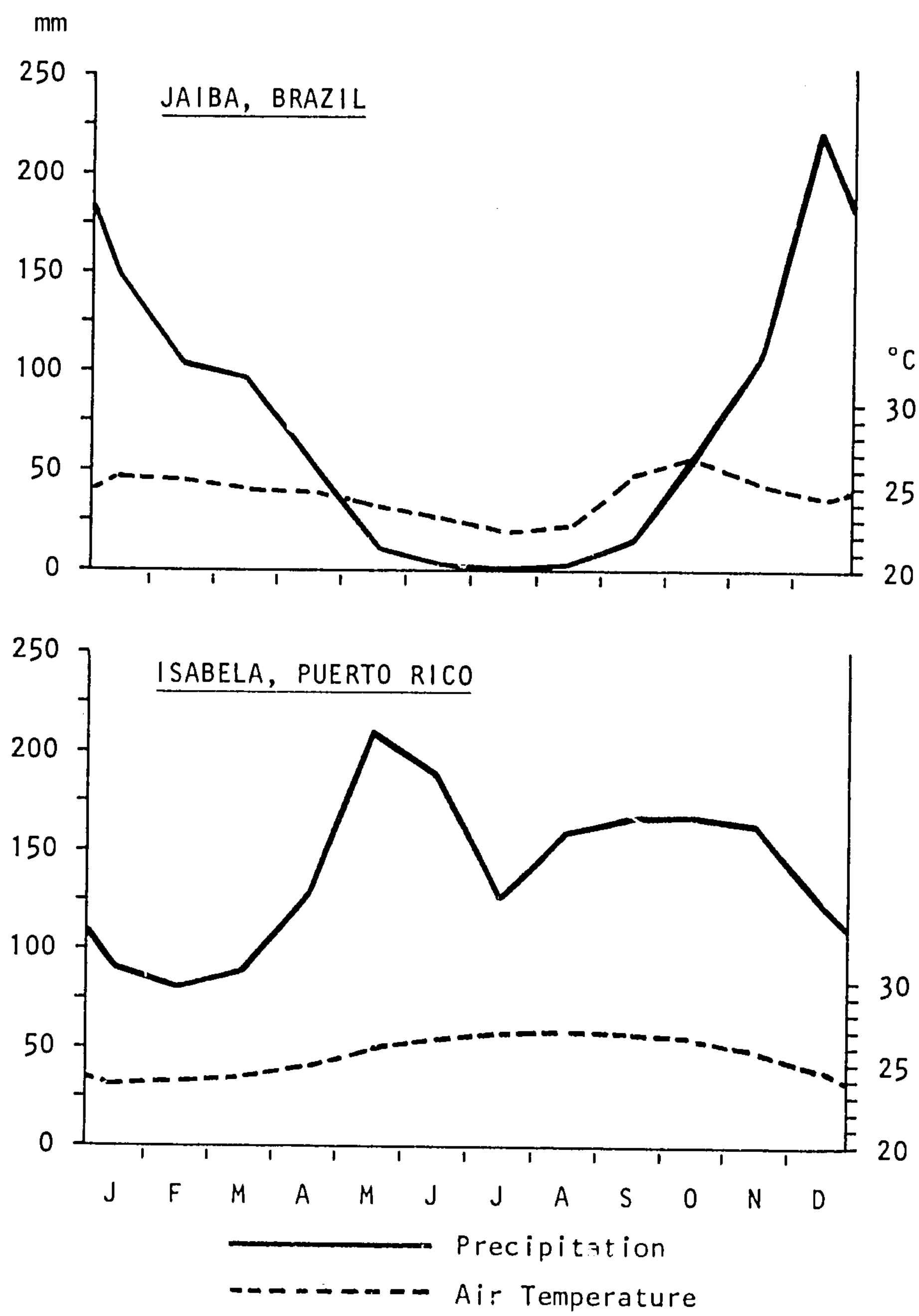


Fig. 2. Mean monthly precipitation and air temperature for Januaria near Jaiba, Brazil (1931-1960) and Isabela, Puerto Rico (1930-1971)

III. THE TEST OF THE TRANSFER HYPOTHESIS

A. AGRONOMIC DATA BASE

1. GENERAL

In the project design distinctions were made between two types of experiment sites, designated primary and secondary sites, and three kinds of experiments referred to as transfer experiments, variety trials and management experiments.

Primary sites were experiment locations where all three kinds of experiments were conducted and which were completely instrumented for the collection of pertinent weather data. Secondary sites were locations where mainly transfer experiments were conducted and which had fewer weather instruments.

Transfer experiments were soil fertility trials specifically designed to generate the data base required for the statistical evaluation of the transfer hypothesis. A total of 81 such experiments, 44 in Puerto Rico and 37 in Brazil, were conducted according to the schedule contained in the Appendix. (Variety trials and management experiments are discussed in Section IV.)

Originally maize and soybeans were selected as testcrops with phosphorus and potassium as the two treatment variables. When early transfer experiments showed little or no response to added potassium, nitrogen was substituted for potassium and logically soybeans, being a legume, were eliminated. Since 1977 maize was the only testcrop and phosphorus and nitrogen the standard treatment variables in all transfer experiments.

Maize is particularly well suited as an indicator crop as it is highly responsive to phosphorus and nitrogen. It is, moreover, the most important food crop in Latin America where 25.6 million ha are cultivated to maize. This area represents 47.4 percent of the maize-producing areas in the LDCs and about 17 percent of the world area (Wortman and Cummings, 1978).

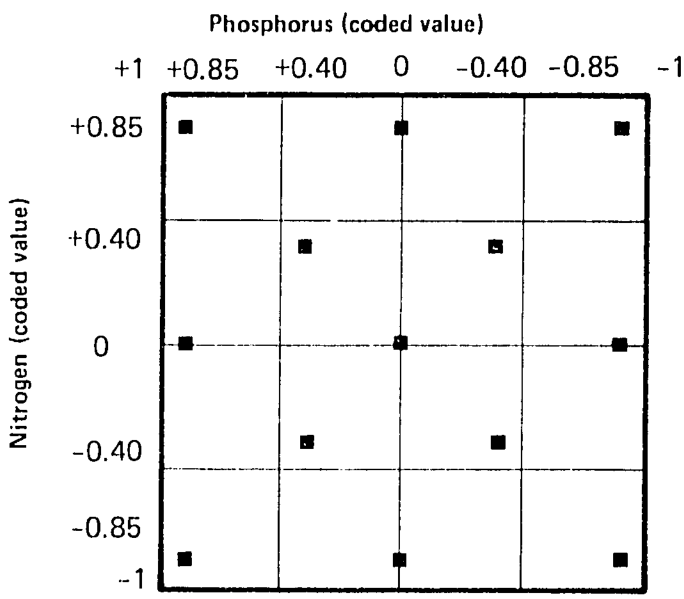
2. EXPERIMENT DESIGN

The strategy for testing the project hypothesis consisted basically of conducting a series of well-controlled and identical experiments in soils belonging to the same soil family, monitoring weather and crop performance, and statistically analyzing the yield data.

To guide and assist the BSP in the development of an appropriate research design and methodology, a Workshop on Experimental Designs for Predicting Crop Productivity with Environmental and Economic Inputs was organized by the University of Hawaii and held in Honolulu in May 1974 with financial support from AID. The recommendations of the workshop were summarized by Silva and Beinroth (1975) and the papers presented have been published (Silva, 1981).

In concurrence with the workshop recommendations, the experimental design used for transfer experiments was a randomized complete block with 16 treatments randomized within each block. There were three blocks in all transfer experiments except for B-19, B-20 and B-21 which had four. The first 13 treatments were according to Escobar's modified 5^2 partial factorial described by Laird and Turrent (1981). As shown in Fig. 3, this design has 13 of the 25 possible combinations of the five levels of each of the two factors. It covers the design space well, thus allowing the fitting of a second order response surface from a limited number of treatments. Cady and Laird (1973) reported that this particular design appeared to be superior to some other designs which they studied in terms of bias error and spatial characteristics.

Fig. 3. Treatment design for the 5^2 partial factorial modification by Escobar used for the two-factor transfer experiments



Transfer experiment treatment variables were levels of phosphorus (P) and nitrogen (N). Coded values of the two factors for the 13 treatment combinations are shown in Table 1. These were the vectors used to obtain the linear coefficients when fitting response surfaces by individual experiments. Three other treatments, which were controls, were also randomized in with these 13 treatments. As the example values in Table 1 illustrate, both P and N levels were calculated from a midpoint value to 40% and 85% higher and lower than this value. The actual amounts of P applied for an experiment were based on phosphate sorption curves determined from soil samples taken from each experiment. The amounts of N applied were determined from earlier field trials and were the same for all experiments.

Table 1. Example of treatments used for transfer experiments

Phosphorus		Nitrogen	
Coded Level 1/	Applied P (kg/ha) 2/	Coded Level 1/	Applied N (kg/ha) 2/
-.85	3.2	-.85	29
-.85	3.2	+.85	186
+.85	38.9	-.85	29
+.85	38.9	+.85	186
-.40	12.6	-.40	71
-.40	12.6	+.40	144
+.40	29.4	-.40	71
+.40	29.4	+.40	144
0	21.0	0	108
-.85	3.2	0	108
+.85	38.9	0	108
0	21.0	-.85	29
0	21.0	+.85	186
partial control	0.0	----	0.0
N control	28.8	----	0.0
P control	0.0	0	108

1/ Coded levels are the midpoint (0) for each nutrient, and ± .40 and .85 x midpoint values.

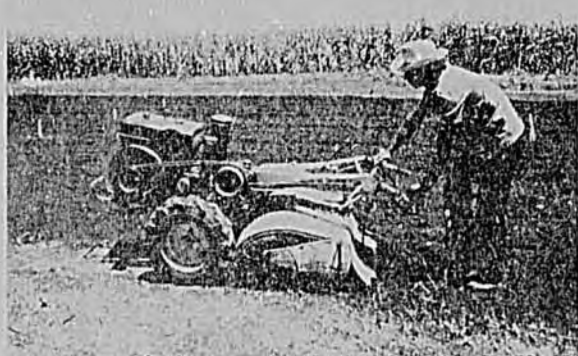
2/ Example values for applied P were for a specific experiment, B-56, and based on phosphate sorption isotherms. Treatment levels of N, based on earlier field trials, were uniform for all experiments.

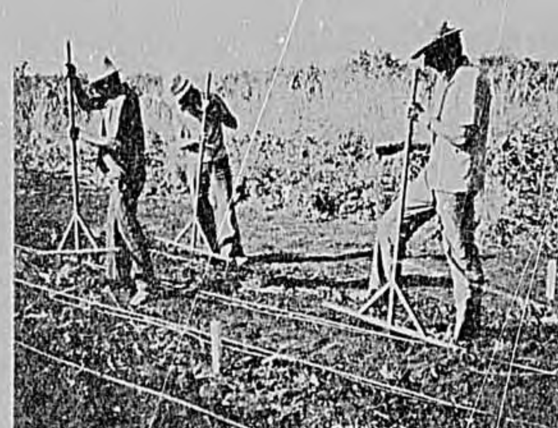
3. PROCEDURES

Early in the project a set of guidelines was developed together with the UH/BSP that detailed all facets of field operations, such as land preparation, planting and harvesting, disease and insect control, cultivation, irrigation, and data collection, as well as field plot design, data processing and laboratory methods. These guidelines, which were revised as necessary, were sufficiently specific to ensure comparability of the data recorded at all network sites.

The transfer experiments were conducted twice on the same plots. Initial transfer experiments were fertilized at the rates discussed above. The follow-up studies on the same plots, called residual transfer experiments, received the same amounts of fertilizer as the initial experiments but no phosphorous.

For initial experiments the land was cleared and plowed to a depth of 25 cm. Before applying treatments blocks were selected for uniformity and 3 x 8 m plots were staked out. Treatment P (triple or simple superphosphate, TSP or SSP) and N (urea) were carefully applied to each plot together with blanket applications of 100 kg K (KCl), 100 kg Mg ($MgSO_4$), 15 kg Zn ($ZnSO_4$), and 2 kg B (borax) per hectare. Where SSP was used for P treatments, sulphur was applied at 50 kg/ha. One third of the N-fertilizer was incorporated by rototilling the soil to a depth of 20 cm, two thirds were applied as a side-dressing 30 days after seedling emergence.





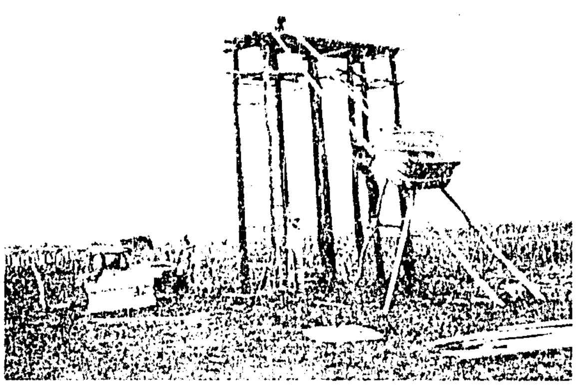
Land preparation with a rototiller (left) and planting a transfer experiment at Jaiba, Brazil

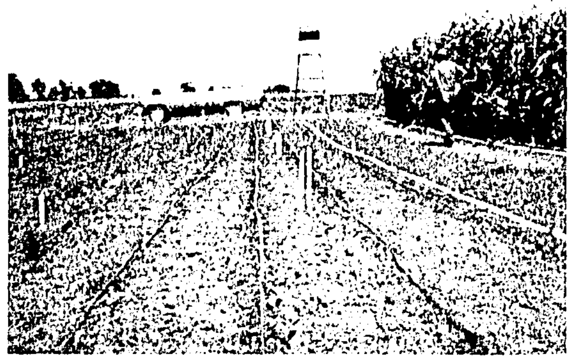
A trickle irrigation system was installed for each experiment using Chap 3 mil bi-wall tubing with outlets spaced at 20 cm. Tensiometers were install in plots with intermediate treatment levels at depths of 15, 20 and 30 cm as guides for scheduling irrigations. Soil moisture was maintained at or near optimum levels until the maize reached maturity (black layer formation).

Two seeds were sown about 3 cm deep in holes uniformly spaced at 23 cm within rows 75 cm apart. The maize stand was subsequently thinned to one plant per hill or approximately 58,000 plants/ha. During the growth of the maize, insects and diseases were controlled using appropriate pesticides. Weeds were controlled both manually and with herbicides.

A six meter portion (1 meter in from each end) of the two center rows of maize was harvested from each plot. Yield components measured for each plot included ear weight, ear lengths, percent seed moisture, 100-seed weight, grain weight and dry stover weight. Plant counts, lodging percentage, and ear counts were also made. During the experiment, 30-day and mature plant heights, days to 50 percent tasseling, 50 percent silking, and black layer formation were recorded.

An integral part of all transfer experimentation was the collecting and processing of weather data. These data were of importance to the statistical analyses and for the daily monitoring and management of each experiment. The climatological instrumentation of the BSP field sites was according to the standards and procedures outlined by the US National Weather Service. Primary sites were accorded a full complement of weather





Installation of water tanks for drip irrigation at Jaiba, Brazil (left) and a functioning drip irrigation system at Isabela, Puerto Rico instruments. Each of these sites contained a fenced climatological station with a standard instrument shelter and instrumentation for recording continuous ambient air temperature and relative humidity, cumulative daily solar radiation, maximum and minimum soil temperatures at 5 and 50 cm depth, wind run, precipitation, and pan evaporation on a daily basis. The secondary sites contained somewhat less extensive weather instrumentation, generally an instrument shelter with equipment for measuring maximum and minimum air temperatures, cumulative solar radiation, and precipitation.

Pre-plant soil samples for each initial transfer experiment consisted of 1 to 3 composite samples derived from many random subsamples taken from the blocks at 0-15 cm depth. These pre-plant samples were air-dried and sent to the laboratory. After crop harvest, but before preparations for conducting a residual transfer study on the same site, post-harvest soil samples were collected. Four soil subsamples from each plot were composited to form a plot sample, thus 48 post-harvest plot samples were submitted for analysis for each experiment. These post-harvest initial transfer experiment soil samples also served as pre-plant samples for the residual studies immediately following them.

The pre-plant and post-harvest samples were analyzed for P following a modified Truog method and P-isotherms were determined. In addition these and other soil samples were analyzed for nitrogen, bases, cation exchange capacity, and pH.

A complete record of all weather and soil data, crop phenology measurements, plot by plot yield data, and other field observations is on file at UPR. These data are expected to be used and scrutinized in the preparation of relevant technical papers.

Marcos Torres records weather data at Jaiba, Brazil

4. RESULTS OF TRANSFER EXPERIMENTS

Yield data, amounts of phosphorus and nitrogen applied and an analysis of variance for each transfer experiment are reported in the Appendix Tables 2, 3 and 4.

These data show that from an agronomic and soil fertility point of view the soils at the BSP sites at Jaiba, Brazil, and Isabela, Puerto Rico, differed in that the Jaiba soils responded primarily to phosphorus and the Isabela soils to nitrogen. This difference in behavior is attributed to the past history of the experiment sites. Whereas the Isabela sites, located on an experiment station, had been cultivated and fertilized for more than 50 years, the Jaiba sites were cultivated for the first time.

Consequently, applied P was more effective in Brazil than in Puerto Rico and resulted in significant yield increases in 31 out of 34 transfer experiments, with significance at the 0.01 level in 30 trials. By contrast, only 4 out of 32 transfer experiments in Puerto Rico had significant positive yield responses to P. Nine trials in Brazil and one in Puerto Rico showed significant quadratic response to P, but most P response curves were linear. This suggests that the highest P treatment level may not have been sufficient to obtain maximum yield.

For the highest level of P (+.85) applied, the mean actual rate over all P x N transfer experiments was 36.1 kg/ha in Brazil. The mean yields of the P-control and +.85 P plots are reported in Table 2 and show a gain of 3,384 kg/ha of maize grain in initial transfer trials with the higher rates of applied P. The subsequent residual trials, in which no further P was applied, produced another 1,683 kg/ha gain. Combining the initial and residual experiment values results in a total mean yield increase of 5,067 kg/ha for two crops of maize with a mean rate of 36.1 kg P/ha applied to the first planting only. If a linear relation is assumed, this would represent a return of 140 kg of grain per kg of P applied. On the other hand, in Puerto Rico there was essentially no grain yield return for the phosphate investment.

Available soil nitrogen at the Brazil sites was generally sufficient; only 7 out of 34 experiments showed significant yield gains with applied N. Over all P x N transfer trials in Brazil there was no mean yield increase with N applied at the highest coded level (+.85) or a rate of 175 kg/ha.

Table 2. Mean maize grain yields for selected treatments of 66 initial and residual transfer experiments at Jaiba, Brazil and Isabela, Puerto Rico

	Partial Control	N Optimum		P Optimum	
		P-control	P+.85	N-control	N+.85
	kg/ha				
Brazil					
Initial	3296	3597	6981	6257	6209
Residual	3031	3325	5008	4548	4251
Puerto Rico					
Initial	5084	6197	6388	5031	6436
Residual	2468	5660	5532	2247	6521

Partial control = no applied P and no applied N
P-control = no applied P
N-control = no applied N

In Puerto Rico, response to applied N was significant in 20 out of 32 transfer trials. At optimum P levels the +.85 coded level of N, equivalent to a rate of 175 kg/ha, produced mean yield gains over all experiments of 1,405 and 4,274 kg/ha for initial and residual experiments, respectively. Nitrogen was applied at the same treatment levels to both plantings of maize; but the plots receiving no N produced even less in the second planting, hence the greater return for N applied to the residual trials. Assuming a linear relation, a mean increase of 8.0 and 24.4 kg/ha of grain was produced per kg of N applied to initial and residual experiments. P x N interaction was significant in only 3 of the 66 transfer experiments conducted in Brazil and Puerto Rico. Only one of these (B-57) showed significance at the 0.01 level of probability.

Residual experiments generally produced lower mean grain yields than did the initial trials; an exception to this occurred with the N +.85 treatment in Puerto Rico (Table 2). For residual trials in Puerto Rico partial control and N-control treatment mean yields were only half of those for initial experiments, suggesting a very rapid depletion of nitrogen with cropping at Isabela. This also occurred in Brazil but apparently did not result in the same low soil levels as in Puerto Rico.

Mean yields over all initial transfer experiments, however, were similar fo the Brazil and Puerto Rico sites when optimal or higher levels of both nutrients were applied. In Brazil the mean yields for the optimal or higher P and N treat ments ranged from 6,209 to 6,981 kg/ha with corresponding Puerto Rico mean yield falling within this range.

The highest maize grain yield of all transfer trials in Puerto Rico was 11,515 kg/ha with the Pioneer brand hybrid X306B in experiment PR-3. For that experiment the overall mean was also high, 10,223 kg/ha. Subsequent high yields in Puerto Rico have been 9,391 and 9,020 kg/ha with X304C in experiments PR-21 and 59. These maize yields compare favorably with those previously recorded at Isabela by Cornell University, the USDA Agricultural Research Service and the UPR Experiment Station. Researchers from these institutions obtained maximum yields of 5,100 kg/ha (Fox et al., 1974), 5,975 kg/ha (Sotomayor-Rios, 1979) and 8,237 kg/ha (Badillo Feliciano et al., 1979). The highest mean yield in Brazil was 9,192 kg/ha with X304C in experiment B43.

These are excellent yields for the tropics. They were achieved with relatively low fertilizer inputs which clearly demonstrates the high potential of Eutrustox for maize production, particularly if one considers that with irrigation at least two crops can be grown in the same year.

The difference in maize growth in a plot with a high P application (D) and in a plot with a low P application (A) is striking in this transfer experiment conducted at Jaiba, Brazil

Transfer experiments at Isabela, Puerto Rico

B. STATISTICAL EVALUATION

1. INTRODUCTION

The general aim of the Benchmark Soils Project was to study agrotechnology transfer. For statistical purposes, however, it was necessary to delimit the problem to one important aspect of agrotechnology. Fertilization, particularly with phosphorus, was chosen as the technology and its transferability was studied. Statistical techniques were developed to evaluate the conjecture that experimental fertilizer response results are transferable from one site to another site within the same soil family.

Under a subcontract from the UPR/BSP, the Department of Statistics of the University of Kentucky conducted theoretical studies that were useful in developing statistical techniques for the evaluation of agrotechnology transfer.[1]

The quantitative relationships evaluated in the evaluation of transfer are shown in Fig. 4. The soil and long-term climate are assumed to be constant within a soil family. But nutrient levels may vary, in part due to past soil fertilization, and can affect P and N response considerably. Also, weather in a given season can deviate from long-term climatic expectations. These variables cannot be controlled but they have been measured.

2. DATA USED IN TRANSFER ANALYSES

a. Yield Data

Careful study of the yield response data obtained from the initial and residual transfer experiments was made experiment by experiment. These studies were carried out together with the project agronomists who conducted the field operations. In general, experiments which had coefficients of variation greater than 20 percent were eliminated from the set used for the transfer analysis. If there was some question in the mind of the agronomists about the validity of the data from an experiment, it was also eliminated. Experiments in which no response to either P or N was obtained were omitted.

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[1] Allen, David M. and David C. Jordan, 1980. The use of prior information for prediction. Unpublished mimeo. University of Kentucky.

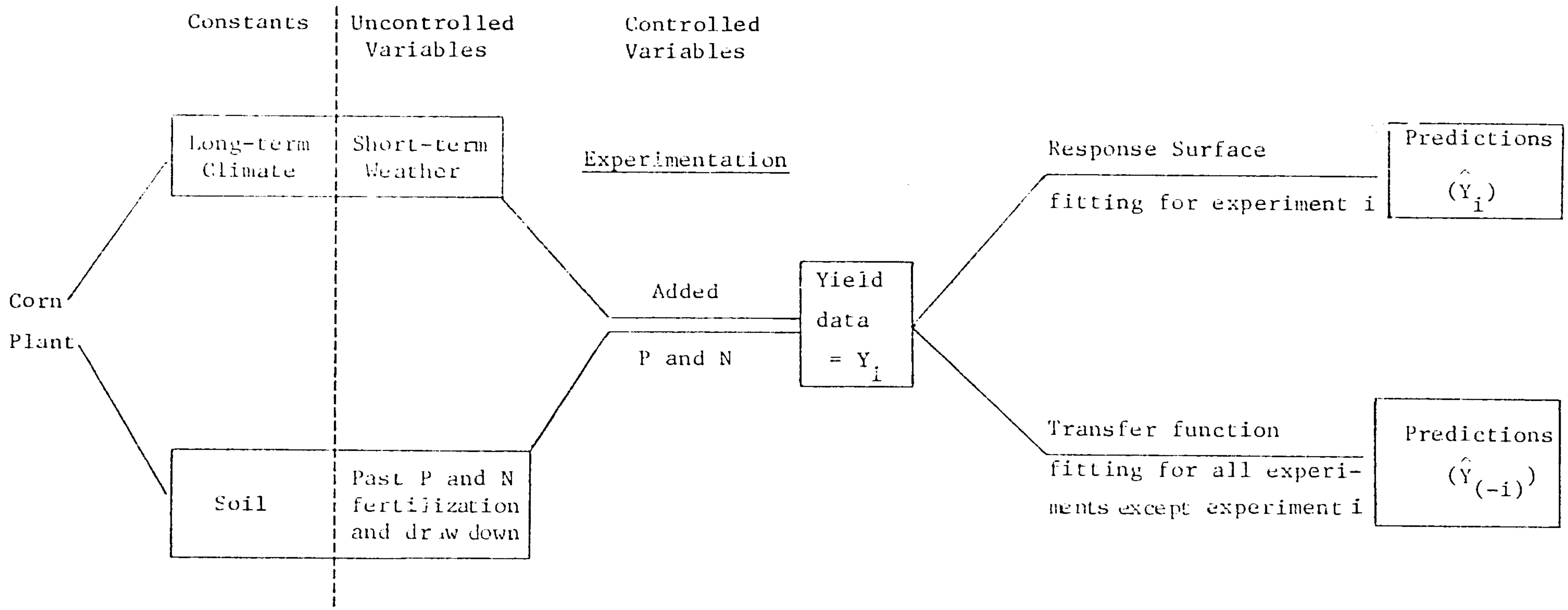


Fig. 4. Diagram showing experimental scheme as well as predictive model aspects of the statistical approach.

After the careful study of the field data and elimination of questionable experiments, a set of 31 experiments remained for the transfer analysis. These experiments, listed in Table 3, include 18 from Brazil and 13 from Puerto Rico. They span the period from 1977 to 1980. Once this transfer set was established, experiments were not deleted from the set even after initial results from transfer analyses were available.

No attempt was made to include transfer and residual transfer experiments in the same analysis because the levels of the yields were so different and the coefficients of variation were also higher for the residual transfer experiments. Consequently, interest centered primarily on the transfer experiments.

Raw yield data arranged by treatment for selected treatments of the maize transfer experiments are reported in Appendix Tables 2a and 2b. Treatment means, P main effect means, and N main effect means, are reported in Appendix Tables 3a, 3b, 3c, and 3d. P main effect means summarize most of the response information for Brazil experiments whereas N main effect means summarize the Puerto Rico information. There was no interaction between country and season.

Summary statistics from the fitting of a second order response surface for each experiment are reported in Appendix Table 4. In general, this surface fits data from transfer experiments for both Brazil and Puerto Rico well.

The Brazil experiment means ranged from 1,721 to 7,115 kg/ha. The coefficients of variation for these experiments ranged from 10.8 to 43.9 percent. For Puerto Rico, the experiment means ranged from 1,952 to 8,330 kg/ha. The coefficients of variation for these experiments ranged from 5.6 to 35.9 percent.

b. Weather Data

Since it was not possible to know definitely which weather variables would account for variation among experiments, a number of variables which theoretically might explain among experiment variation were measured as described in a previous section. Only air temperature and solar radiation, however, proved useful for the transfer analysis, in addition to the number of days to 50 percent tasseling.

Derived weather and related variables and their abbreviated designations are as follows:

Variable	Abbreviation
-Average daily maximum daily temperature for 60-day period with 50% tasseling as the midpoint	MAXTEMP
-Average daily minimum daily temperature for 60-day period with 50% tasseling as the midpoint	MINTMP
-Average daily solar radiation during 60-day period with 50% tasseling as the midpoint	Langleys
-Average number of days to 50% tasseling	TASSM

Based on the maximum temperature variable a linear-plateau variable was developed because N-linear response appeared to level off at about 31^{o}C. This variable was the vector for a model III of the linear-plateau family of Anderson and Nelson (1975). The new variable was entered into the transfer regressions in the form of an interaction with the N-linear variable. Values of the new maximum temperature variable called MXTMP were assigned 31^{o}C if the readings of maximum temperature were $\geq$ 31^{o}C. Otherwise the new variable had the value of the original maximum temperature variable. Average values of weather variables by experiment are reported in Appendix Tables 1a and 1b.

c. Soil Data

Soil Truog P values in ppm for samples from Treatment 15 (partial control) were averaged over the replications for that experiment. This variable was used to give an evaluation of the initial P status of each experiment. Truog P means, as well as those for other uncontrolled variables are reported in Table 3.

A derived soil variable was developed from the Truog test data. Fig. 5 shows a plot of the relationship between the P linear response coefficient and the Truog soil P. The shape of the plot led us to believe that a plateau in P response was being reached at about 14 ppm soil P. A model III linear-plateau model (Anderson and Nelson, 1975) was then fitted which accommodated a declining linear P yield response in the lowest range of soil test and then broke into a plateau at 14 ppm soil P. The single vector required for fitting this variable was called X_1 and it took on the values of the actual Truog P reading if soil P was less than 14 and 14 otherwise. The variable X_1 facilitated the transfer of soil Pxadded P information from Brazil to Puerto Rico experiments.

Table 3. Means of the site variables used in the transfer analysis

SITE	SEASON	PLANTING DATE	CONTROL TROUG (PPM)	DAYS TO 50% TASSELING	SOLAR RADIATION (LANGLEYS/DAYS)	TEMPERATURE (C) MAX.	MIN.	YIELD (KG/HA)
BRAZIL								
B09	DRY	06/08/77	7.68	83	445	31.32	14.87	5692
B19	WET	11/10/77	7.68	70	465	30.97	18.85	3955
B20	WET	11/20/77	13.21	66	480	34.94	22.40	6958
B21	WET	11/20/77	9.57	73	498	31.71	.	4031
B22	DRY	06/20/78	8.64	89	435	32.03	12.91	4142
B24	DRY	06/20/78	12.93	80	440	33.60	13.13	5968
B26	DRY	06/19/78	9.70	81	423	34.33	13.02	6783
B36	WET	01/09/79	8.00	63	488	31.08	18.29	4836
B38	WET	01/12/79	7.45	59	472	31.90	18.28	6604
B43	DRY	05/06/79	9.78	85	474	32.13	12.99	6932
B45	DRY	06/09/79	13.32	82	428	32.86	12.97	7115
B47	DRY	06/08/79	9.78	88	475	33.81	13.25	6590
B52	WET	11/26/79	9.40	60	411	29.59	19.24	5766
B54	WET	11/28/79	12.74	57	372	30.56	19.06	6796
B56	WET	11/26/79	9.31	59	428	30.03	19.18	6049
B64	DRY	04/26/80	6.37	76	374	30.00	10.98	4895
B66	DRY	04/26/80	16.67	69	325	31.78	11.48	6234
B68	DRY	04/26/80	6.73	74	374	32.02	10.72	6140
PUERTO RICO								
P19	WET	06/23/77	19.38	48	460	30.04	21.20	4782
P20	DRY	11/15/77	14.80	56	334	27.94	18.28	6415
P21	DRY	12/12/77	15.06	56	322	27.60	17.97	8330
P27	WET	04/25/78	20.82	51	487	29.55	20.75	4956
P30	WET	05/08/78	44.48	50	484	29.78	20.92	7290
P33	WET	06/08/78	40.00	49	454	30.13	21.40	4575
P37	DRY	12/06/78	18.32	62	372	27.67	17.96	6319
P45	WET	05/16/79	31.58	55	467	29.77	21.45	6452
P53	DRY	12/01/79	41.43	78	533	27.28	17.38	6340
P54	DRY	12/01/79	75.33	62	468	26.91	17.55	7373
P55	DRY	12/05/79	48.57	60	474	26.95	17.55	6262
P62	WET	04/29/80	23.27	56	527	30.43	21.19	7195
P63	WET	04/30/80	81.30	58	529	30.49	21.29	6629

Means of the weather variables are computed for a 60-day period starting 30 days before and ending 30 days after mean date of 50% tasseling

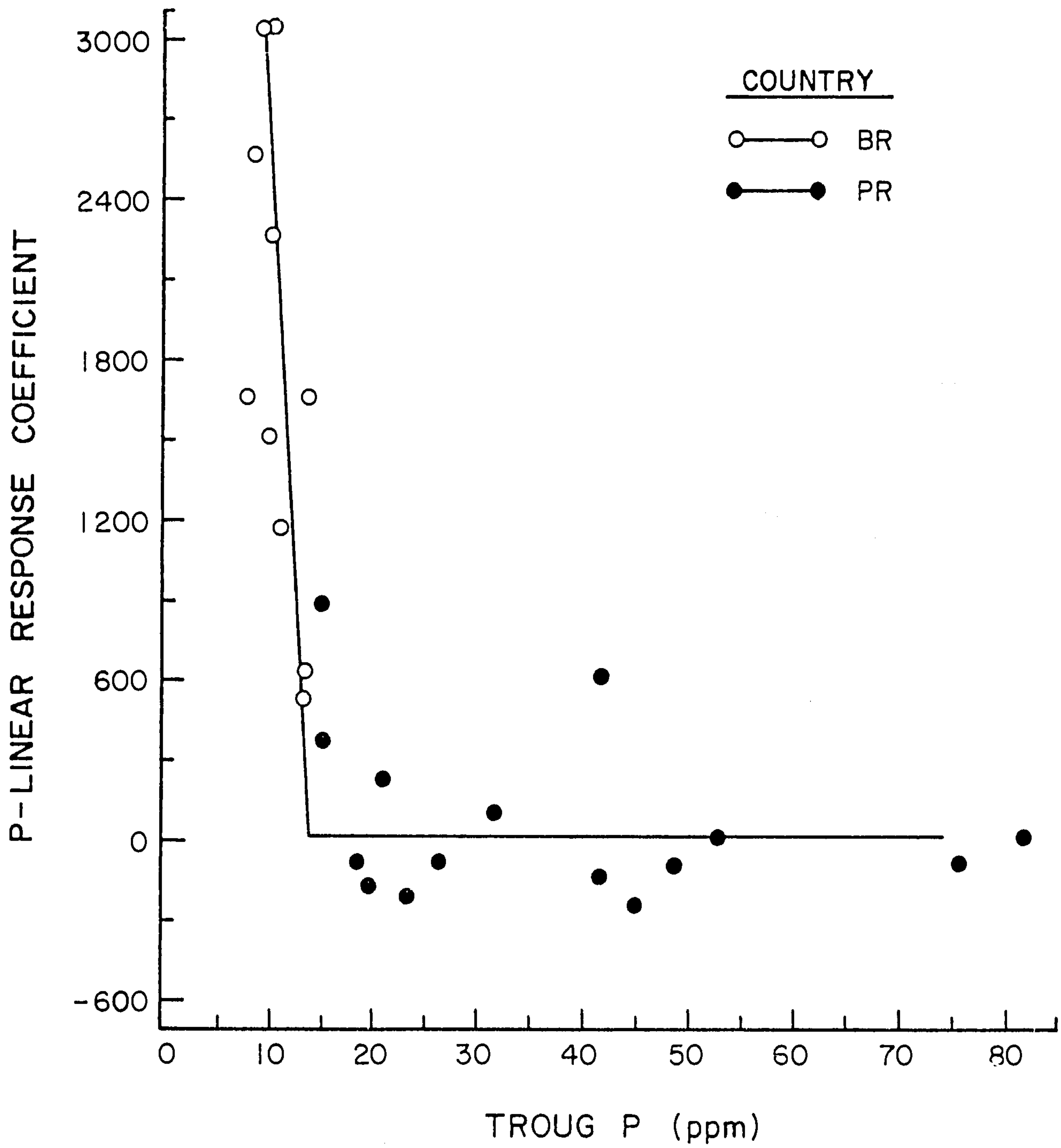


Fig. 5. Plot of relationship between the P-linear response coefficient and the Truog soil test P

3. STATISTICAL PROCEDURES FOR TRANSFER EVALUATION

a. General

Two statistical procedures were used to evaluate the adequacy of transfer. The first was a confidence interval procedure. The second was the P-statistic procedure developed by Wood and Cady (1981). Both involved use of a transfer function which included uncontrolled variables as predictors in the model. A third graphical method for transfer evaluation will be described in a subsequent section.

It became evident fairly early in the analysis of the data that it would not be possible to adequately explain the variation in yield levels among experiments with the uncontrolled variables measured. This variability was sizeable, accounting for approximately 40 percent of the variation in all of the numbers of the transfer data set. Workers such as Nelson and McCracken (1962) have reported being able to explain only 60 to 80 percent of the among site variability in a data set for a given soil but we are dealing here more with weather variability at two sites which is expected to be less readily explained. It did become apparent, however, that the uncontrolled variables do contribute to changes in the shape of the response surfaces (i.e., there is an interaction between the controlled and uncontrolled variables). Being realistic about not being able to explain well among-experiment variation per se, we subtracted out the experimental mean from each treatment before performing the confidence limit and P-statistic calculations for evaluating transfer of fertilizer response information. Using these deviations we were able to account for much of the interaction between the controlled and uncontrolled variables with our transfer models.

b. Confidence Interval Procedure

A method was devised whereby confidence limits were developed from experiment-specific data and then evaluation consisted of counting the number of predictions based upon data from all of the other experiments which occurred within the confidence interval. More specifically, data from an individual experiment, i, from one of k experiments were used to judge if predicted treatment mean yields, $\hat{\bar{Y}}_{(-i)}$ (expressed as deviations from the experimental mean, $\bar{\bar{Y}}_{(-i)}$ using data from the other k-1 experiments) would be reasonably close to the values predicted by individual site data only, $\hat{\bar{Y}}_{i}$. This prediction and confidence interval estimation procedure was repeated for the k sites. For a given model, if most of the $\hat{\bar{Y}}_{(-i)}$ fall within the confidence interval which was centered on $\hat{\bar{Y}}_i$ deviations, we would say that transfer of fertilizer response information is feasible. On the other hand, if a large proportion falls outside of the confidence interval we would say that transfer of fertilizer response information depends upon additional factors beyond the scope of the present study.

Schematic Description of Confidence Interval Procedure

$$\text{Probability}\ \{\underbrace{\hat{\bar{Y}}_i - t_{.025}\, s_{\hat{\bar{Y}}_i}}_{\text{Lower Limit}} < \mu_i < \underbrace{\hat{\bar{Y}}_i + t_{.025}\, s_{\hat{\bar{Y}}_i}}_{\text{Upper Limit}}\} = .95$$

95 percent confidence interval based upon predictions ($\hat{\bar{Y}}_i$) from experiment i only. The $\hat{\bar{Y}}_i$ term is estimated from all experiments

$\hat{\bar{Y}}_{(-i)}$ = Predictions based upon information from other k-1 sites

Question: Do these predictions based upon other k-1 sites fall within the confidence interval?

The confidence limits for individual experiment response surfaces were obtained by adding or subtracting an uncertainty value from $\hat{\bar{Y}}_i$ deviations for each treatment. As suggested above, we pooled lack of fit sum of squares and experimental error sum of squares. In general the uncertainty values consisted of $t_\alpha s_{(\hat{\bar{Y}}_i)}$ where t_α is Student's tabular t based upon 997 degrees of freedom and a significance level of α and $s_{(\hat{\bar{Y}}_i)}$ is the standard error of the deviation of the predicted mean from the general mean. We used an α level of .05. The reason for using 997 degrees of freedom in looking up tabular t will be explained later. The predictions, $\hat{\bar{Y}}_i$, to which the uncertainty values were added or subtracted were obtained by fitting a quadratic response surface to the deviations of the 13 treatment means from the overall mean for the experiment. The mathematical form for the response surface within a site was

$$\hat{\bar{Y}}_i = b_1 P + b_2 N + b_3 P^2 + b_4 N^2 + b_5 PN$$

where $\hat{\bar{Y}}_i$ is the predicted deviation of a treatment mean from the experiment mean, P is the controlled level of P and N is the controlled level of N. The P^2 and N^2 variables have been centered so that they are orthogonal with the linear terms

c. P-Statistic Procedure of Wood and Cady

Wood and Cady (1981) developed a procedure for evaluating the transferability of fertilizer response statistically via a ratio similar to the F ratio which is familiar to most researchers. This ratio is indicative of how much "noise" is introduced into the predictions of fertilizer response if they are developed from data which are not experiment-specific. They predicted the yields, known as $\hat{Y}_{(-i)}$ for one of k experiments using a transfer function estimated from the other k-1 experiments (including site variables). This process was repeated for each of the k sites. If the transfer residuals $Y_i - \hat{Y}_{(-i)}$ are approximately of the same magnitude as the ordinary residuals $Y_i - \hat{Y}_i$ (obtained from an equation developed from within site data only), we have evidence for agrotechnology transfer. To measure the relative size of these residuals Wood and Cady used the sum of squares of $(Y_i - \hat{Y}_{(-i)})$ divided by the sum of squares of $(Y_i - \hat{Y}_i)$ over all of the experiments, i.e., P = prediction statistic = $\frac{\text{Transfer SS}}{\text{Residual SS}}$. They called this ratio the P-statistic which is a specific criterion for evaluating the conjecture of transferability of fertilizer response information.

Schematic Description of Wood-Cady P-Statistic Procedure

$$P = \sum_{i=1}^{k} (Y_i - \hat{Y}_{(-i)})^2 / \sum (Y_i - \hat{Y}_i)^2$$

where P is P-statistic, Y_i is yield for a particular rep-treatment for experiment i, $\hat{Y}_i$ is the predicted rep-treatment yield for experiment i using data from experiment i, and $\hat{Y}_{(-i)}$ is predicted yield using data from other k-1 sites.

The P-statistic represents a relative measure of the dilution of predictability of fertilizer response at site A which occurs when we transfer to site A results of fertilizer experiments conducted during another season at site A and/or at other sites having soils of the same family as site A. A P-statistic of 1.4 implies that there is a 40 percent increase in "noise" in the prediction sum of squares by conducting experiments during another season and/or at another location. Depending upon the number of experiments being studied, an increase in "noise" of this magnitude represents a considerable decrease in predictability. Wood and Cady (1981) described the mathematical aspects of P including its distribution (in P-1 form) and methods of assessing its significance level. A brief introduction to these will be given below but other particulars will be given and with PN. The N^2 vector has been orthogonalized so that the P^2 and N^2 terms are mutually orthogonal. The coded and orthogonized vectors which were used in the P-N regression for transfer are shown in Table 4. Thus with all terms orthogonal and deviations from the experiment mean being used, an intercept is not included. The vectors used in fitting individual experiment response surfaces are shown in Table 4.

Table 4. Coded and orthogonalized vectors used in fitting the response surfaces by experiment

Tmt. No.	P	N	P^2	N^2	PN
1	-.85	-.85	.3398077	.2666304	.7225
2	-.85	.85	"	"	- "
3	.85	-.85	"	"	- "
4	.85	.85	"	"	"
5	-.40	-.40	-.2226923	-.1747357	.16
6	-.40	.40	- "	"	-.16
7	.40	-.40	- "	"	-.16
8	.40	.40	- "	"	.16
9	0	0	-.3826923	-.3002799	0
10	-.85	0	.3398077	-.4558696	0
11	.85	0	"	- "	0
12	0	-.85	-.3826923	.4222201	0
13	0	.85	- "	"	0

Rather than estimating variance from only the 39 observations within an experiment in calculating these uncertainty values, a more stable estimate of variance obtained from all experiments was used. This was obtained by pooling all lack of fit and experimental error sums of squares for the 31 experiments and then dividing by the pooled degrees of freedom for these pooled quantities (997).

Following the calculation of the confidence limits for the 961 treatment means over the 31 sites, an evaluation was made to see how many predicted treatment mean deviations $\bar{Y}_{(-i)}$ occurred assuming a given transfer model within the 95 percent confidence interval determined by adding to and subtracting from the $\hat{\bar{Y}}_i$ an uncertainty value. The transfer models used to predict the $\hat{\bar{Y}}_{(-i)}$ involved data from the k-1 experiments other than the i^{th} experiment and included interactions between controlled and uncontrolled variables.

in the RESULTS AND DISCUSSION section as they pertain to a specific P-statistic. Using their methodology we see that $P-1 = \frac{k^2}{(k-1)^2} \cdot \frac{Y'B_1Y}{Y'BY}$ where P is the prediction statistic, k is the number of sites, B_1 and B are (kn x kn) symmetric matrices with $B_1B = 0$, $BB = B$ and $Y' = [Y_1' \vdots Y_2' \vdots --- \vdots Y_k']$. The quadratic form of the numerator can be represented as $\sigma^2 \sum_{\ell=1}^{kn} \theta_\ell \chi_\ell^2$ (1 d.f.) where the χ_ℓ^2 (1 d.f.) are independent χ^2 random variables and θ_ℓ, $\ell=1,---, L$ are the eigenvalues of B_1. The denominator is distributed as $\sigma^2\chi^2$ {pooled residual d.f.} since yields were adjusted for block effects.

Thus

$$\frac{(k-1)^2}{k^2}(P-1) \sim \frac{\sigma^2 \sum_{\ell=1}^{L} \theta_\ell \chi_\ell^2 (1 \text{ d.f.})}{\sigma^2\chi^2 \text{ (pooled residual d.f.)}} .$$

With large degrees of freedom for the denominator, a simplification can be made

$$997\{(k-1)^2/k^2\}(P-1) \cong \sum_{\ell=1}^{L} \theta_\ell \chi_\ell^2 \ (1 \text{ d.f.}) .$$

Because no tables exist for the significance level of $\{(k-1)^2/k^2\}(P-1)$ we used Monte Carlo simulation to estimate the significance level by generating 10,000 standard normal deviates $N_\ell, \ell=1,---,152$ using Procedure GGNML subroutine from International Mathematical and Statistical Libraries, Inc. (Houston, Texas, USA). These normal deviates, N_ℓ's, were squared to form χ_ℓ^2's each with 1 d.f. Then each variable was formed as the linear combination of χ_ℓ^2 (1 d.f.) variables.

The significance level of a calculated P will vary depending upon the uncontrolled variables included in a given transfer regression, the values of these variables and the number of experiments. Consequently, a calculated P for a specific transfer model to be tested requires a separate Monte Carlo run. Constant experimental error variances were assumed across sites based upon results of Hartley's test for comparing the 31 error variances which showed that they were not different. Because mean yields were expressed as deviations from the experimental mean it was not considered necessary to include the main effects of the uncontrolled variables in the models. Models used are shown in Table 5. Plots of the type shown in Fig. 5 were used in establishing which uncontrolled variables were most highly related to linear and quadratic P and N response.

Table 5. Models used for the transfer regressions in the P-statistic procedure

Model No.	Terms
1	Yield (deviation)$_{(-i)}$ = P N P^2 N^2 PN;
2	Yield (deviation)$_{(-i)}$ = P N P^2 N^2 PN P*X_1 P*TASSM P*Langleys N*X_1 P*X_1*Langleys P*X_1*TASSM;
3	Yield (deviation)$_{(-i)}$ = P N P^2 N^2 PN P*X_1 P*TASSM P*Langleys N*X_1 N*MINTMP;
4	Yield (deviation)$_{(-i)}$ = P N P^2 N^2 PN P*X_1 P*TASSM P*Langleys N*X_1 N*MXTMP;
5	Yield (deviation)$_{(-i)}$ = P N P^2 N^2 PN P*X_1 P*TASSM P*Langleys N*MXTMP P*TASSM*MXTMP;
6	Yield (deviation)$_{(-i)}$ = P N P^2 N^2 PN P*X_1 P*TASSM P*Langleys N*MXTMP;
7	Yield (deviation)$_{(-i)}$ = P N P^2 N^2 PN P*X_1 P*TASSM P*Langleys N*MXTMP P2*X_1;

Simple correlations of the P and N response coefficients and the uncontrolled variables were also obtained. The transfer models which included certain uncontrolled x controlled variable interactions were then developed. The final model chosen for the transfer in connection with the P-statistic was Model 6.

The P-statistic procedure was also used on a set of 18 residual transfer experiments: B-25, B-27, B-53, B-55, B-57, B-67, B-69 from Brazil, and PR-31, PR-34, PR-35, PR-41 PR-42, PR-43, PR-50, PR-51, PR-58, PR-59, and PR-60 from Puerto Rico. The techniques were much the same as for the transfer experiments except that only two uncontrolled variables interacted with the controlled variables and thus the transfer model was much simpler. Testing of the P-statistic followed procedures used for transfer experiments.

d. Graphical Procedure

The graphical procedure was designed to plot transferred response surfaces and to compare them visually with response surfaces plotted from experiment-specific data only. For each experiment, the 13 predictions $\bar{Y}_i$, obtained by fitting the experiment-specific model (Model I) were plotted to obtain a response surface. Another surface was obtained by plotting the prediction, $\bar{Y}_{(-i)}$, for experiment i from the other 30 experiments assuming a model which included the variables for both of the controlled and uncontrolled factors (i.e., Model 5). Because both of the above types of predictions were obtained in deviation form, the experiment mean was added back to the predictions before plotting.

The two plottings for a given experiment are then compared visually to see if the general shapes are similar and if the ranges in predicted yields are more or less equivalent.

The graphical procedure provides an additional source of information which can be used to reinforce the findings of the confidence interval and P-statistic procedures.

e. Individual Plot Data vs Means for Calculating the Confidence Intervals and the P-statistic

In using the transfer models the question arose whether the transfer analysis should be conducted on a plot per plot basis or on the 13 treatment means per experiment.

For the confidence interval approach it seemed logical to use treatment means in the regressions to obtain confidence limits for predicted means. It is the average response surface which we are trying to transfer rather than the individual plot yields. The error used in calculating the confidence limits was obtained by pooling lack of fit and experimental error sums of squares and then dividing by pooled degrees of freedom (997). The resulting mean square was then divided by the number of replications for each particular location.

For calculating the P-statistic there were other relevant considerations. There are 11 of the 31 experiments occurring in the transfer analysis set in which the block effects are significant at the five percent level or lower. There are several other experiments in which the block mean squares are considerably larger than the experimental error mean squares even though the F-ratio for blocks is not significant at the five percent level. We first considered averaging over the blocks and conducting the transfer regression on treatment means. This would remove the block effects from the numerator of the expression used in calculating the P-statistic. The problem with this approach is that the lack of fit sum of squares pooled over the experiments used in the transfer regression, which would need to be used as the denominator in calculating the P-statistic, underestimates experimental error. This would automatically place an upward bias on the P-statistic. We felt more comfortable with a procedure which involved pooling both the lack of fit sum of squares and the experimental error sum of squares over all sites involved in the transfer regression. The approach used therefore was to subtract block effects in addition to the general mean from each plot observation and then to run the transfer regressions on these per plot data which had been adjusted for blocks.

f. Statistical Computations

All simple statistics, correlations, plots of response surfaces and other data manipulations were made using various procedures of the Statistical Analysis System (SAS).

The confidence limits and predictions were obtained by PROC General Linear Models of SAS, fitting the regressions on treatment means for each experiment. The uncertainty factors obtained by the computer were multiplied by a factor to reflect the fact that both the sum of squares for experimental error and the sum of squares for lack of fit were pooled over the 31 transfer experiments and then divided by 997 degrees of freedom as an estimate of error. This error was then divided by the number of replications (either 3 or 4) to put it on a per mean basis. The number of predictions falling within the confidence limits were then manually counted. An example of the statistical computations for experiment B-22 is given in Appendix Table 6.

The transfer regressions and experiment-specific regressions used in connection with the P-statistic procedure were conducted using Procedure General Linear Models (GLM) of SAS. The numerator required several MACRO statements which caused the prediction sum of squares to be calculated for each of the 31 different experiments. Computing was done using individual plot yields, $Y_{(i)}$, which had been adjusted for block effects.

4. RESULTS AND DISCUSSION

a. General

Analyses of variance for the regressions of the Brazil and Puerto Rico experiments are reported in Appendix Tables 5a and 5b. The results of tests of various model terms and the lack of fit information in this Table correspond to those shown in Appendix Table 4. Blocking appeared to be effective in many of the experiments. In general, P linear was significant at either the 5 percent level or one percent level for all of the Brazil experiments, except for one residual transfer experiment (B-48). In most cases it was significant at the one percent level. The quadratic term was seldom significant. Significant linear nitrogen response was obtained in only seven of the Brazil experiments and these were at the five percent level only except for B-47. Several of these were residual transfer experiments. In only three experiments (B-47, B-65 and B-68) was the quadratic nitrogen term significant. Of these, B-65 was a residual transfer experiment. The P x N interaction term was significant only for three experiments (B-47, B-57 and B-65). Of these, only for B-65 was the significance at the one percent level.

Nitrogen response was the major result in Puerto Rico. Significant N linear response occurred for all but 11 experiments. N-quadratic response was much less frequent. Significance at the five percent level or lower occurred for only five of the Puerto Rico experiments.

Phosphorus response was observed in only three experiments in Puerto Rico. It was strong in two of these (PR-20 and PR-21). All of these experiments were initial transfer experiments.

The R^2 values for the fit of the second order response surface ranged from .13 to .99 for the Brazil experiments. The range is much narrower if only initial transfer experiments are considered. The R^2 values for the fit of the same model for the Puerto Rico experiments ranged from .12 to .99, but again a much narrower range would be obtained if the residual transfer experiments were excluded. In general, the quadratic model tended to fit slightly better in the case of the Brazil than the Puerto Rico experiments as judged by the R^2 values.

The lack of fit did not exceed the experimental error as often as the reverse. There was only one site (PR-21) in which the lack of fit term was significant and then it was only at the five percent level.

A combined analysis of variance for data from the 31 transfer experiments is shown in Table 6. This revealed strong location and treatment effects and a significant experiment x treatment interaction. P-linear is the single most important effect. Reps (Expts) mean square is sizeable.

Table 6. Combined analysis of variance of yield data for the 31 transfer experiments

Source of variation	d.f.	Sum of Squares	Mean Square
Expts	30	1,453,616,642	48,453,888
Reps (Expts)	65	160,767,755	2,473,350
Treatments	12	698,990,338	58,249,195
P	1	583,776,082	583,776,082
N	1	70,785,330	70,785,330
P2	1	38,356,019	38,356,019
N2	1	3,988,727	3,983,727
PN	1	150,599	150,599
Lack of fit	7	1,933,581	276,226
Tmts x Expts	360	827,538,091	2,298,717
Model x Expts	150	708,696,405	4,724,643
Lack of fit x Expts	210	118,841,686	565,912
Pooled Error	780	495,509,020	635,268
TOTAL	1247	3,636,421,846	

b. Results Using the Confidence Interval Procedure

The number of $\hat{\bar{Y}}_{(-i)}$ occurring within the 95 percent confidence intervals obtained from "within experiment" predictions was counted and the tally by experiment is shown in Table 7. The number of $\hat{\bar{Y}}_{(-i)}$ occurring within this confidence interval over all experiments is 296 which is 73.4 percent of the total number of treatment means for the 31 experiments (i.e., 31 x 13 = 403 means).

The percentage occurring within the interval was higher on the average for Puerto Rico experiments (80.5 percent) than for Brazil experiments (68.4 percent). There were three Brazil experiments which had quite low percentages occurring within the interval (B-43, B-66 and B-68). Otherwise those which occurred outside of the interval were not necessarily concentrated in data for specific experiments.

A tabulation of the percentage of $\hat{\hat{Y}}_{(-i)}$ occurring within the confidence interval by individual treatment for Brazil and Puerto Rico is shown in Table 8. For both Brazil and Puerto Rico, the highest proportion of predictions fell outside of the confidence interval for Treatment 7 which is .40 and -.40 for P and N, respectively, and Treatment 10 which is -.85 and 0 for P and N, respectively. For Brazil, the prediction was also poor for Treatment 8.

For situations in which the transfer model is predicting very well, one would still expect about five percent of the predictions, $\hat{\hat{Y}}_{(-i)}$, to occur outside of the 95 percent confidence interval. We have experienced 26.6 percent occurring outside of the interval which is 21.5 percent more than one would expect with very good transfer. Although the transfer is less than perfect, the percentage of the $\hat{\hat{Y}}_{(-i)}$ occurring within the confidence interval is quite respectable and does indicate that transfer is being achieved.

c. Results Using the P-statistic Procedure

The overall P-statistic for a regression among 31 transfer experiments using Model 6 was 1.5075 which was significant at the .0001 level. This implies that unless a one in 10,000 chance error has occurred there has been a real increase in the prediction sum of squares as a result of using experiments conducted in other seasons and sites over the equivalent sum of squares from site-specific data. The calculation was as follows:

$$P = \frac{\text{Transfer SS}}{\text{Residual SS}} = \frac{926,166,242}{614,350,826} = 1.5075$$

The denominator is distributed as $\sigma^2\chi^2$ with $\{k(n-p-1-(r-1))\} = 997$ d.f. where k, n and p have been defined in the Statistical Procedures for Transfer Evaluation section and r is the number of replications per experiment.

Thus

$$\frac{(k-1)^2}{k^2}(P-1) = .9365(P-1) \sim \frac{\sigma^2 \sum_{\ell=1}^{152} \theta_\ell \chi_\ell^2 (1 \text{ d.f.})}{\sigma^2\chi^2(997 \text{ d.f.})}$$

Table 7. Percentage of predictions ($\hat{\hat{Y}}_{(-i)}$) occurring within 95 percent confidence interval (reported by experiment) assuming Model 6

Experiment	% of predictions in 95% confidence interval	Experiment	% of predictions in 95% confidence interval
B-09	38.5	PR-19	92.3
B-19	53.8	PR-20	92.3
B-20	100.0	PR-21	84.6
B-21	92.3	PR-27	61.5
B-22	69.2	PR-30	61.5
B-24	46.2	PR-33	76.9
B-26	53.8	PR-37	53.8
B-36	46.2	PR-45	100.0
B-38	100.0	PR-53	46.2
B-43	38.5	PR-54	92.3
B-45	76.9	PR-55	84.6
B-47	69.2	PR-62	100.0
B-52	76.9	PR-63	100.0
B-54	100.0		
B-56	100.0	Average for Puerto Rico	80.5%
B-64	100.0		
B-66	53.8	Average over all	
B-68	15.4	experiments:	$\frac{296}{403} \times 100 = 73.4\%$
Average for Brazil	68.4%		

Table 8. Percentage of predictions ($\hat{\bar{Y}}_{(-i)}$) occurring within 95 percent confidence interval by treatment for Brazil and Puerto Rico (Model 6)

Treatment	Brazil (18 experiments)	Puerto Rico (13 experiments)	Overall (31 experiments)
	%	%	%
1	50.0	92.3	67.7
2	50.0	76.9	61.3
3	77.8	76.9	77.4
4	94.4	92.3	93.5
5	77.8	92.3	83.9
6	77.8	84.6	80.6
7	38.9	69.6	51.6
8	33.3	61.5	64.5
9	83.3	84.6	83.9
10	33.3	76.9	51.6
11	83.3	84.6	83.9
12	77.8	69.2	74.2
13	77.8	84.6	80.6

Since there are 997 d.f. for error, a simplification can be made

$$997 \{(k-1)^2/k^2\}(P-1) \sim \sum_{\ell=1}^{152} \theta_\ell X_\ell^2 \text{ (1 d.f.)}$$

This implies that we need to compare 997 (.4753) = 473.9 with the quantiles of $\sum_\ell \theta_\ell X_\ell^2$ (1 d.f.).

Because of the large dimensions of B_1 due to $k = 31$ and $n = 39$, its eigenvalues had to be obtained by partitioning B_1 into three sub-matrices each of dimension k and obtaining the eigenvalues for them separately. This partitioning was feasible because the X variables were originally orthogonalized and centered at zero.

The eigenvalues of the first matrix were either zero or one depending upon k, the number of sites, and p-2, the number of X-variables not used to form interactions with site variables. In particular, there were $(k-1)(p-2) = 30(3) = 90$ eigenvalues equal to one in this first matrix.

The eigenvalues of the second matrix resulted from including interactions of the linear effects of P with X_1, TASSM and Langleys. The eigenvalues of the third matrix resulted from including the interaction of the linear effect of N with MXTMP. For a detailed treatment of the computation of the eigenvalues see. 3 and 4 of Wood and Cady (1981).

A separate transfer regression was run for the transfer set of the 31 Puerto Rico and Brazil experiments plus four Eutrustox experiments from Hawaii. The resulting P value was 1.6574 which was significant at the 0.0001 level.

The results of the P calculation for the residual transfer experiments show a P of 1.547 which was only slightly higher than that for the transfer set (but on the other hand, only 18 experiments were involved in comparison with 31 experiments used for the transfer experiments). Only interactions for $P \times X_1$ and N x MINTMP were included in this residual transfer regression because other controlled x uncontrolled variable interactions were not significant.

The following relationship exists:

$$\frac{(k-1)^2}{k^2}(P-1) = .8919(P-1) \sim \frac{\sum_{\ell=1}^{87} \theta_\ell X_\ell (1 \text{ d.f.})}{\sigma^2 X^2 (558 \text{ d.f.})}$$

Since there are 558 d.f. for error, a simplication is made

$$558 \{(k-1)^2/k^2\} (P-1) \doteq \sum_{\ell=1}^{87} \theta_\ell X_\ell^2 \ (1 \text{ d.f.})$$

This implies that we need to compare 558(.4879) = 272.2 with the quantiles of

$\sum_\ell \theta_\ell X_\ell^2$ (1 d.f.).

Using Monte Carlo techniques similar to those used for the transfer experiments the probability calculated to be associated with $P = \frac{792,536,087}{512,331,425} = 1.5469$ was .0001. Thus the inferences to be drawn from the P-statistic evaluation of transfer for the residual transfer experiments are the same as they are for the transfer experiments.

One can see which experiments are apt to be contributing greatly to the numerator of the P-statistic by studying the discrepancies of the phosphorus linear regression coefficients obtained using data from the specific experiment and using data from the other 30 transfer experiments. These P linear coefficients are reported in Table 9. The experiments in which P response was grossly overestimated by the 30 other experiment regressions are B-09 and B-19. For B-36 and B-43 the 30 other experiment regressions grossly underestimated the response.

Table 9. Phosphorus linear regression coefficients estimated by experiment and from fitting a surface to predictions for that experiment from the other 30 transfer experiments (Model 6)

Expt. No.	Other 30 expts.	Specific Expt.	Expt. No.	Other 30 expts.	Specific Expt.
B-09	2590	1482	PR-19	-52	-181
B-19	2554	1779	PR-20	514	882
B-20	560	628	PR-21	696	369
B-21	1566	1510	PR-27	-106	220
B-22	2300	3029	PR-30	-93	-66
B-24	1248	525	PR-33	-81	208
B-26	1719	2261	PR-37	736	-216
B-36	1528	2564	PR-45	110	94
B-38	1775	1659	PR-53	722	-149
B-43	1799	3039	PR-54	331	-94
B-45	1074	1653	PR-55	251	-104
B-47	1965	2331	PR-62	-40	-222
B-52	1477	1952	PR-63	-17	7
B-54	760	970			
B-56	1660	1705			
B-64	2845	2710			
B-66	757	1727			
B-68	728	1679			

Table 10. Index of (Transfer SS/Pooled error and lack of fit SS) to show which experiments are contributing most to the P-statistic (Model 7)

Expt. No.	Index	Expt. No.	Index
B-09	1.79	PR-19	1.10
B-19	2.03	PR-20	1.27
B-20	1.08	PR-21	1.62
B-21	1.13	PR-27	1.72
B-22	1.67	PR-30	1.23
B-24	1.83	PR-33	1.32
B-26	1.53	PR-37	1.85
B-36	2.12	PR-45	1.17
B-38	1.16	PR-53	1.63
B-43	2.23	PR-54	1.23
B-45	1.24	PR-55	1.17
B-47	1.89	PR-62	1.18
B-52	1.41		
B-54	1.09		
B-56	1.14		
B-64	1.15		
B-66	1.97		
B-68	2.35		

A useful index of an experiment's potential contribution to the P-statistic is to divide the transfer sum of squares by the pooled experimental error and lack of fit sum of squares. Those which have large transfer sum of squares and low estimates of error and/or lack of fit will tend to have a net effect of causing the P-statistic to be larger. A listing of these ratios for the 31 experiments in the transfer set is given in Table 10. The Brazil experiments which have large indices are B-19, B-36, B-43 and B-68. The average index value for the Puerto Rico experiments was lower and there did not appear to be as many experiments with large indices.

Some remarks about the interpretation of the P-statistic seem in order. With small values of P (slightly larger than one) we would conclude that experiment-specific information is not necessary in order to draw fertilizer response inferences for a site-season. On the other hand, large values of the P-statistic reflect the introduction of considerable noise into the predictions by using data which are not experiment-specific. The question of what constitutes a large P-statistic then arises. As indicated previously, this is dependent upon the number of experiments. However, some generalizations will be made based upon our limited experience with the P-statistic. P-values of three to 10 such as would be obtained if the uncontrolled variables were not included in the model would be considered large regardless of the number of experiments. P-values in the range of 1 to 1.3 would seem relatively small even though with a large number of experiments significance might be obtained for P-values at the upper end of the range. Values of P between 1.3 and 3.0 would appear to be intermediate, reflecting severe distortion of prediction at the upper end of the range but only a moderate distortion at the lower end. The P-value of 1.5075 obtained with the present data set falls into the latter range.

d. Results Using the Graphical Procedure

Plottings of the experiment-specific response surfaces and those from plotting predictions from the other 30 experiments are shown in Fig. 6. These are paired by individual experiment.

In general the conformation of the surface obtained from non-specific data is similar to that for the specific-experiment plotting. This is especially true for the Brazil experiments. The Puerto Rico plottings have a similarity in conformation between the two types but the non-specific plottings have an uneven surface. This may be due to the use of the linear-plateau variable (X_1 = Truog P vector) which causes a plateau to occur at 14 ppm soil P. This variable apparently caused some discontinuities in the predicted values.

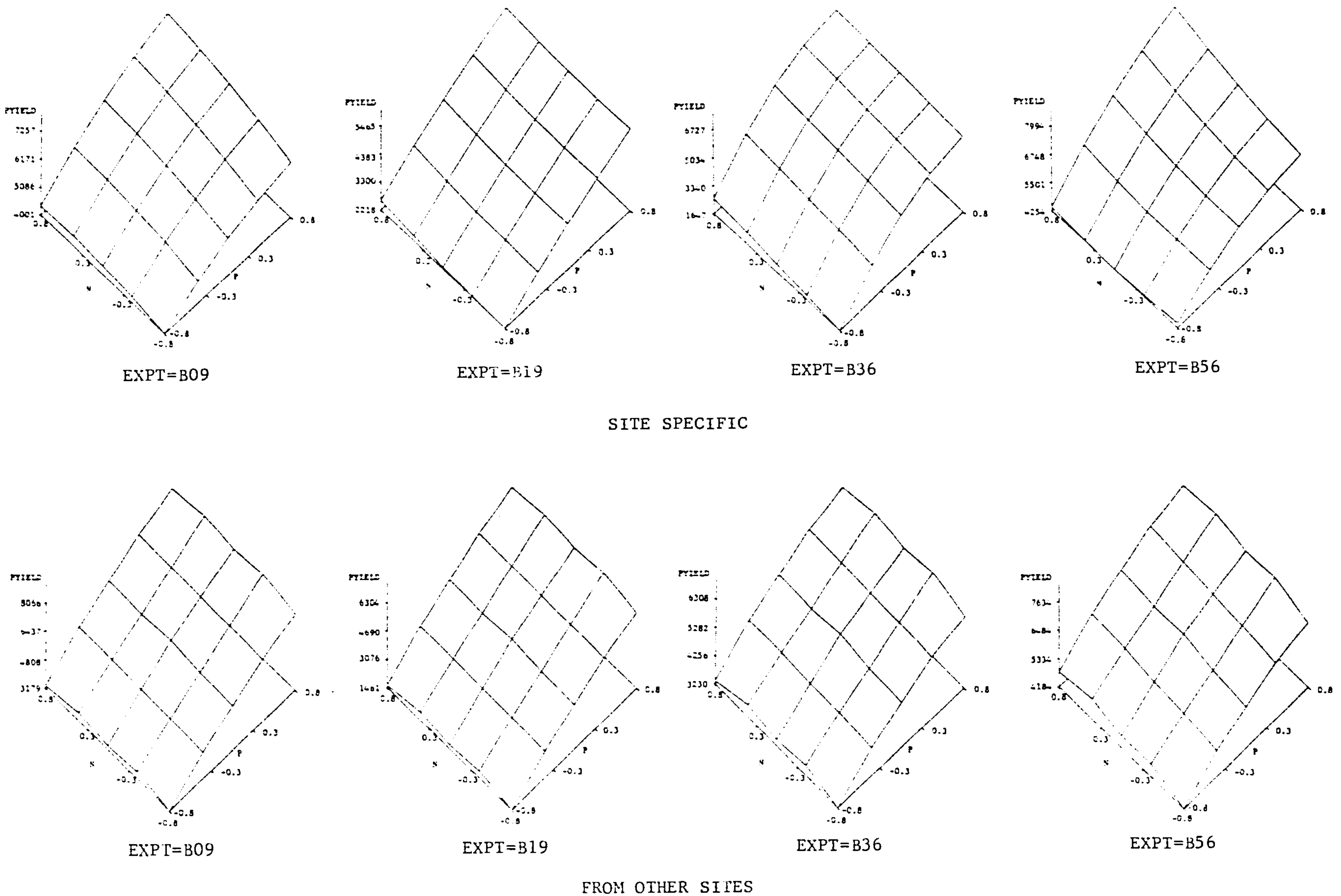


Fig. 6a. Comparison of response surface graphs plotted from experiment-specific data (top) with graphs plotted from data from 30 other experiments conducted in Brazil and Puerto Rico, Brazil sites

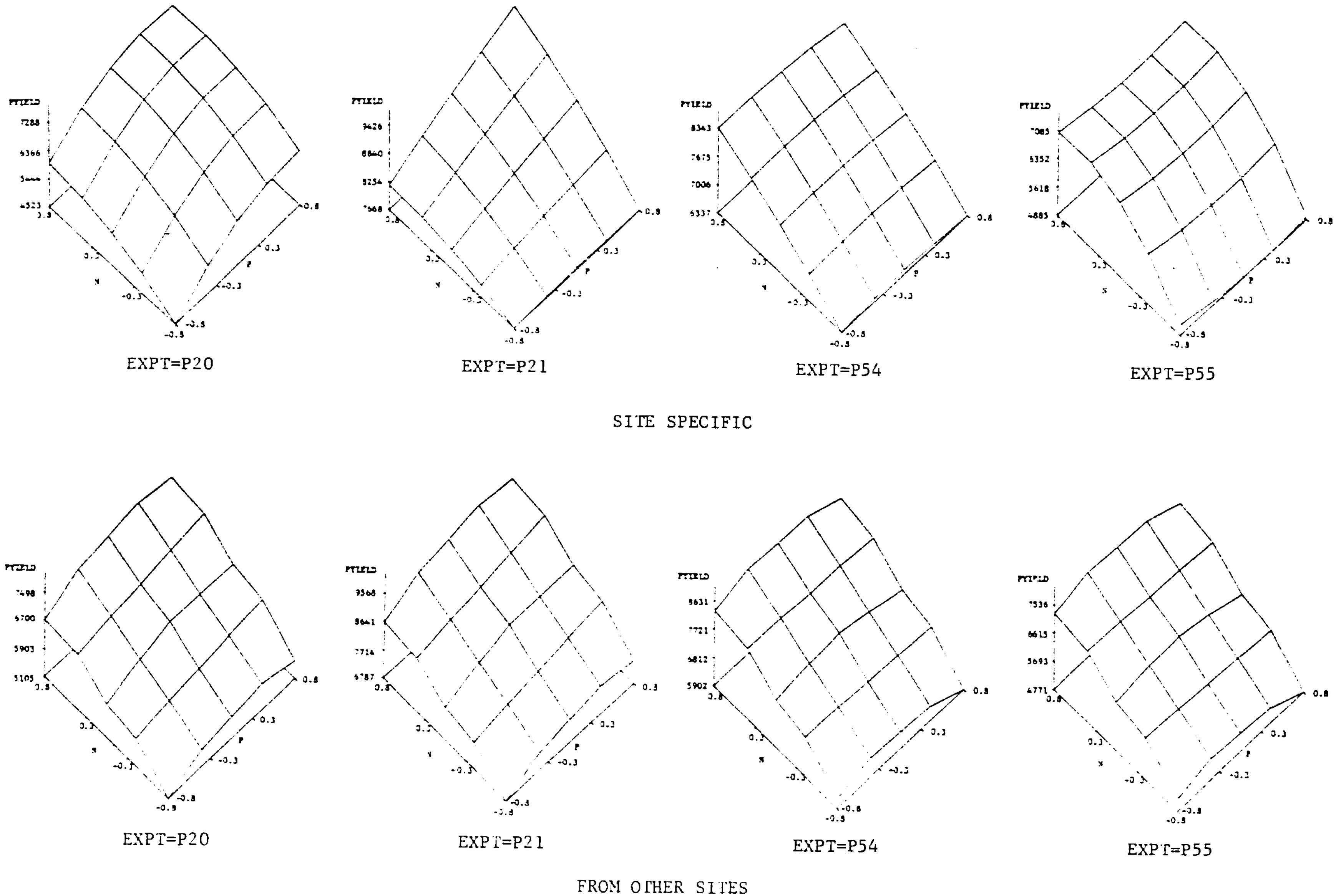


Fig. 6b. Comparison of response surface graphs plotted from experiment-specific data (top) with graphs plotted from data from 30 other experiments conducted in Brazil and Puerto Rico, Puerto Rico sites

5. CONCLUSIONS

Our data analysis strategy was to use several different procedures to verify transferability. We wanted confirmatory evidence from several distinctly different sources so that our conclusions would be well-founded. We therefore used three methods: (1) the confidence interval procedure, (2) the P-statistic procedure and (3) the graphical procedure.

As mentioned above, the results obtained with the confidence interval procedure were encouraging and suggest about 73.4 percent transfer of information. Although not perfect, we can conclude that transfer is occurring.

The P-statistic procedure did not give conclusive results. The calculated P-value of 1.5075 falls into the intermediate range of 1.3 to 3.0 and thus does not satisfactorily prove, nor disprove, the transfer conjecture. The P-value of 1.5075 for the Model 6 regression among 31 transfer experiments was significant at the .0001 level. Similar results--P=1.6574, significant at the .0001 level--were obtained when four Hawaii Eutrustox experiments were added to the transfer set.

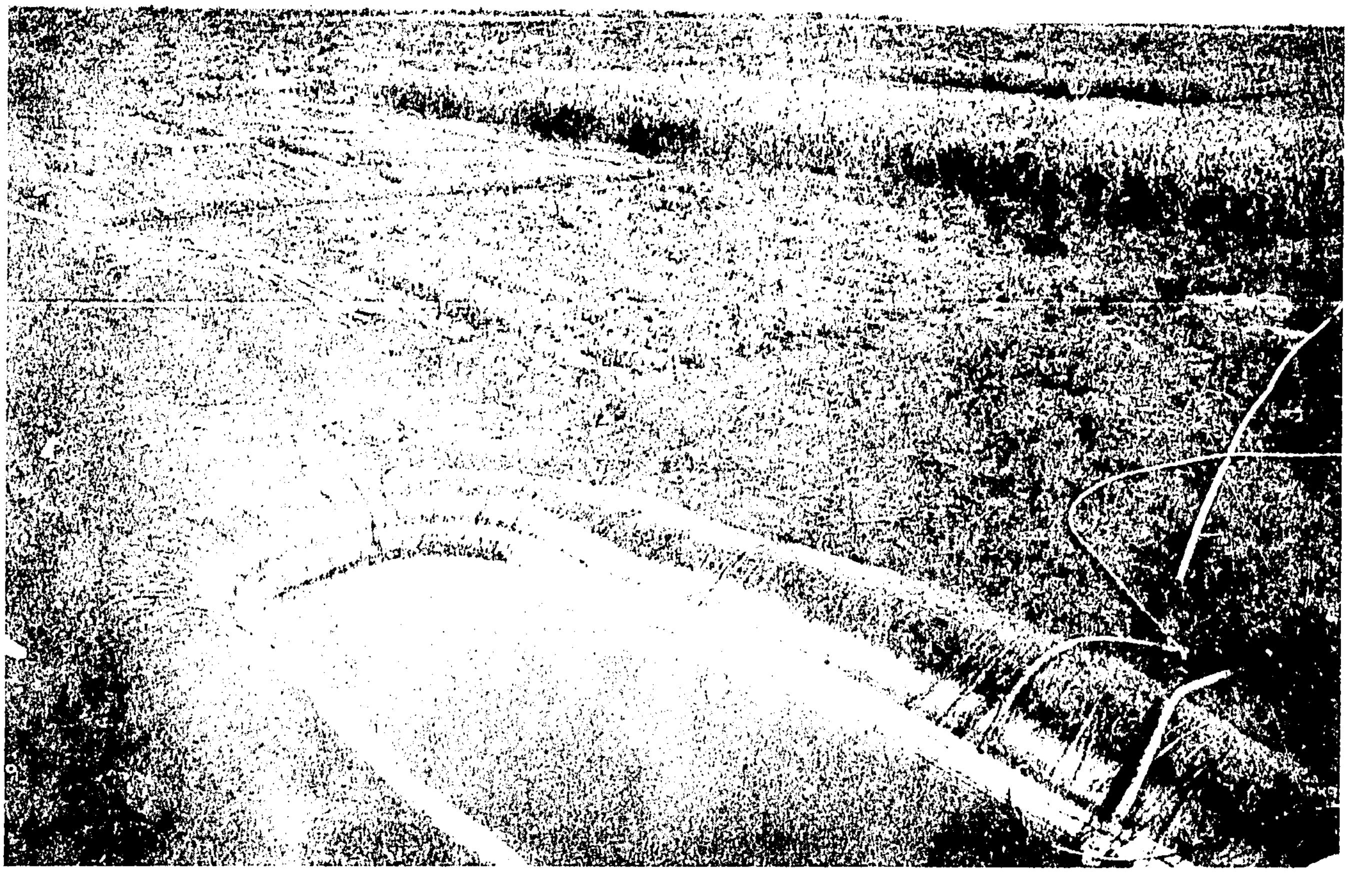
It appears that certain unusual experiments influenced the size of the P-statistic markedly. An example of such an unusual experiment is B-43. During this experiment, the environmental factors reacted positively with the controlled variables and, consequently, considerably more response to fertilizer was achieved than would have normally been expected (5,634 kg/ha range in the 13 design treatment means). This caused the linear response coefficient for P to be unusually large. One cannot dismiss this as a "bad" experiment and delete it because it is actually a "good" experiment in which results exceeded all expectations. The contribution of this experiment to the numerator of the expression used for calculating the P-statistic was 64,712,479, which was considerably above the contribution of any of the other experiments.

As seen in Fig. 6, the general shape of the surface estimated from a single experiment and that estimated from the other k-1 experiments for that experiment are very similar. The similarity of these two types of plots is particularly striking in the case of the Brazil experiments. We can also conclude that by using appropriate site variables we are able to explain the difference between the overall shape of the Brazil and Puerto Rico response surfaces.

No attempt was made to reconcile the results of the three methods. It is not uncommon for several statistical procedures applied to the same data to produce results which are not in total agreement. The P-statistic procedure uses an exact mathematical test whereas the other two procedures are more ad hoc. Further studies on the properties of the confidence limit procedure are needed. It would also seem appropriate to focus attention on the effect of unusual site-season conditions on the results of all three procedures.

The study showed that information on the uncontrolled variables is very essential in transferring fertilizer response results. These variables do not explain among experiment variability to any large degree, but they do account for changes in the shapes of the response surfaces from site to site.

In summary, the P-statistic method produced marginal results which may be attributed to the sensitivity to exceptional experiments of this new and not widely tested technique. Two other procedures, however, gave positive indications that information transfer is occurring. We thus believe that, on balance, the statistical studies provide a qualified validation of the conjecture of transfer postulated in the Benchmark Soils Project.



Water reservoir for irrigation at Jaiba, Brazil

IV. APPLIED RESEARCH

A. GENERAL

Although the thrust of the BSP field work was to generate the data base for the test of the transfer hypothesis through specifically designed transfer experiments, a variety of other experiments were also conducted. These experiments had the general objective of expanding the knowledge base for the agricultural use of Eutrustox, particularly by resource-poor farmers.

Twenty-two variety trials with maize and soybeans were conducted at the primary sites in Puerto Rico and Brazil. Their purpose was to identify varieties that are well adapted to the agroenvironment of Eutrustox and responsive to the fertility variables used in the transfer experiments. These trials also supplied information about regional yield potential and varietal performance.

Soil and crop management experiments were designed to provide ir ormation on economic and efficient agricultural practices, and data for subseq nt soil interpretation and land evaluation. Whereas the procedures for conducting transfer experiments were identical at all sites, the designs of the management experiments were more flexible and allowed the project to respond to host country priorities and to local farmer needs. A philosophic framework for the management experiments was developed at the first annual coordination meeting of the UH and UPR projects in 1976. Particular attention was paid to experiments on costly inputs and high energy use cultural practices, such as irrigation, fertilization and tillage.

Apart from phosphorus and nitrogen, limited soil moisture is probably the most severe constraint inherent in the soil family under study. A pronounced dry period of several months occurs at the Brazil sites and brief droughts are common during the wet season. At the Puerto Rico sites seasonality is less marked but severe dry spells may occur at any time of the year. These climatic uncertaintie , along with the low water holding capacity of the soil, combine to limit crop production, at times severely. For this reason moisture utilization studies have been emphasized in BSP management experiments in Puerto Rico and Brazil.

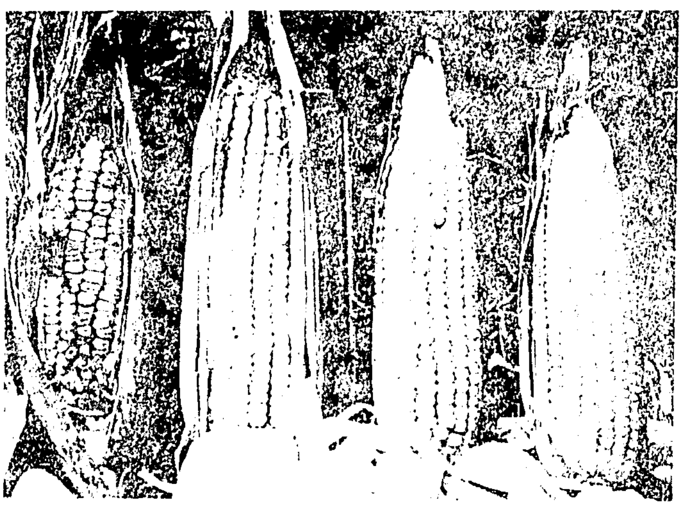
Thirty-three management experiments were conducted and focused on irrigation rates, plant population density, time of planting, mulching, minimum tillage, phosphorus rate and placement, liming, maize composite population improvement, and multicropping.

B. VARIETY TRIALS

1. MAIZE

Eight maize variety trials were conducted in Brazil and Puerto Rico to select the best adapted varieties for use in the transfer experiments in each country. Hybrids and open pollinated varieties believed to be well adapted to local conditions were selected for further study. In addition, available cultivars selected from those having performed best in the CIMMYT International Maize Adaptation Nursery (IMAN) at elevations and latitudes similar to UPR BSP sites and cultivars recommended by cooperators were also included. A total of 30 varieties and hybrids were tested in these trials. Appendix Table 7 shows grain yields of the leading five entries in each experiment. Pioneer brand hybrid X304C, when included, was consistently the highest or near highest yielding entry. On the strength of these trials and its performance in Hawaii, X304C was used as the testcrop variety in all subsequent transfer experiments on all Oxisol sites in Puerto Rico, Brazil and Hawaii.

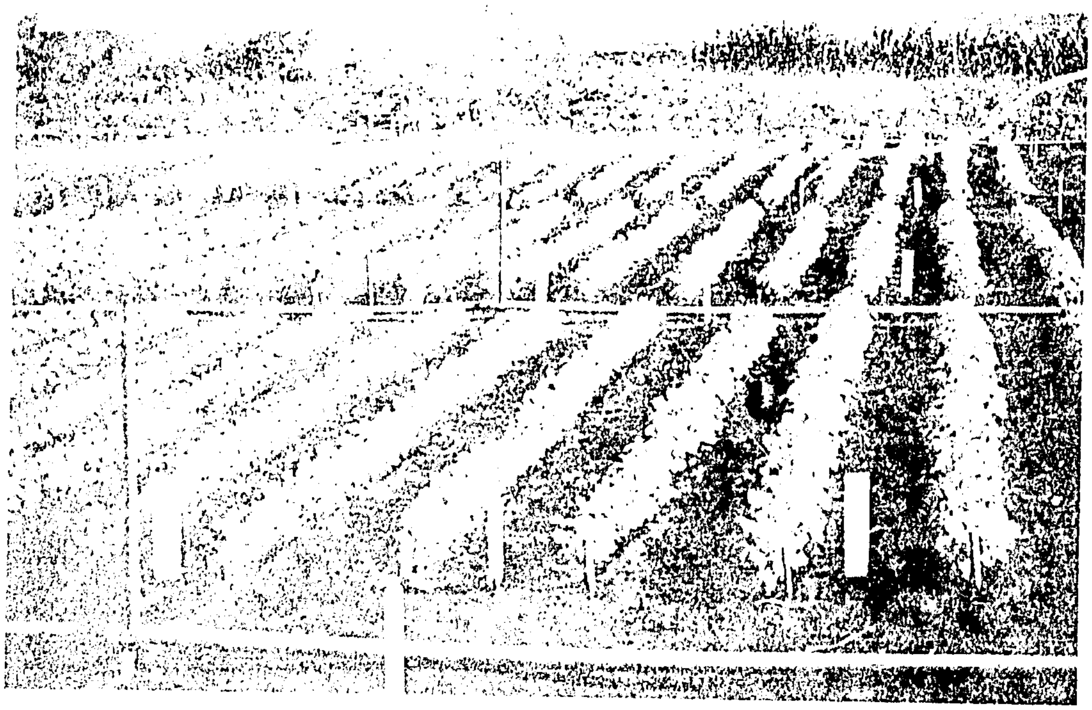
In Brazil, six maize trials with promising varieties selected for testing in the Jaiba region were completed in cooperation with EMBRAPA's Centro Nacional de Pesquisa de Milho e Sorgo (CNPMS). These experiments had 36 to 42 entries and each entry was replicated four times. The mean yields of the 10 top-ranked varieties in four experiments are shown in Appendix Table 8. Highest yields ranged from 6,770 kg/ha with variety DeKalb 7601 in 1978 to 8,500 kg/ha with Cargill 111S in 1980. Grain yields from the two other trials, with precocious maize, are presented in Appendix Table 9. Grain yields were generally high, considering that these were unirrigated experiments. The results of these maize variety trials were published by EMBRAPA for wide dissemination in Brazil.



Ears from a maize variety trial at Isabela, Puerto Rico. From left: QK 217 (Australia), QK 217, Pioneer X306B and Pioneer X304C. The soft endosperm of QK 217 makes this variety susceptible to disease and thus unsuitable for the tropics.

2. SOYBEANS

Soybean variety trials were conducted in Brazil to ascertain the potential of the Jaiba region for this crop hitherto not cultivated in the area, and to identify the best yielding varieties. International Soybean Program (INTSOY) trials were planted in 1976, 1977, and 1978 and provided information on both management and yield potential for many widely used soybean varieties. Grain yields (from 153 to 4,473 kg/ha) for these trials appear in Appendix Table 10. Two later trials emphasized the potential for irrigated soybean production in this region. The yield range for one experiment was 1,457 kg/ha (Jupiter) to 4,730 kg/ha (IPB 73-77) with a mean for all varieties of 2,698 kg/ha. Grain yield for the second experiment ranged from 2,925 kg/ha (IPB 242-77) to 5,310 (IPB 616-76) and 5,025 (Lancer) with a mean for all varieties of 3,769 kg/ha. The excellent mean yields over all varieties, as well as the outstanding performance of the highest varieties, clearly demonstrate the high potential of this area and soil family for soybean production.



An INTSOY soybean variety trial at Jaiba, Brazil

B. SOIL AND CROP MANAGEMENT

1. IRRIGATION

a. Puerto Rico

Four irrigation rate x nitrogen level experiments were completed, one during the wet season and three during dry seasons. The objectives of these trials were (1) to compare the performance of maize when grown without irrigation during the dry and wet seasons in an area with an ustic soil moisture regime, (2) to determine the effect of supplemental irrigation on crop yield in both seasons, and (3) to observe nitrogen-water interactions.

The experiments were similar to the line-source continuous variable method described by Hanks et al. (1976) but with a trickle irrigation system instead of sprinklers. The first experiment had a nitrogen gradient, produced by 24 levels from 0 to 230 kg/ha of N in 10-kg increments, and 12 levels of water applied from 0 to approximately 20 mm of water per application. Plots were watered when tensiometer readings in the center plots showed 20 centibars or more tension. The irrigation treatments were not assigned randomly but in a stepwise fashion across the nitrogen treatments. There were four replications. Plot size was very small in the first trial, with only two plants/plot. Since treatment gradients were essentially continuous, border effects were inconsequential and large plots were unnecessary. This first experiment, conducted during the wet season from May to August 1977, showed no response to N and only small yield increased with irrigation.

Subsequent experiments were laid out in a similar manner, but only half as many treatment levels of each variable were used and plot size was increased to 3 x 4 m (four 4-m rows); there was no replication of treatments and only the center two rows were harvested for yield measurements. Yield data from these later trials, conducted during the dry seasons of 1978, 1979 and 1980, are shown in Appendix Table 11. Response to N treatments was distinctly positive regardless of irrigation level in 1978, undetectable in 1979, and again apparent in 1980, especially with increasing irrigation rates. Highest grain yields were 9,969, 9,252 and 9,201 kg/ha for 1978, 1979 and 1980, respectively. Grain yield return in kg of grain per kg of N applied varied widely, from 0.4 to 53.8 in 1978, 2.2 to 13.5 in 1979 and 13.9 to 28.1 in 1980. The best return per unit of N was generally at intermediate rates of application.

Irrigation had practically no positive effect in the experiment conducted during the 1978 dry season and resulted in only about 12 percent more grain yield. In the 1979 and 1980 experiments, however, irrigation increased yield by about 36 percent with the higher applications of N.

These results allude to the unpredictability of rainfall in the Isabela area of Puerto Rico and to the nature of the dry season there. In the dry season of one out of three years irrigation had virtually no effect on yields and the effect in the other two years was only moderate. It thus appears that in many years it is possible to produce reasonable maize yields during the dry season without irrigation, especially if rains occur at the critical times. At Jaiba in Brazil, which also has an ustic soil moisture regime, this is predictably impossible as the rainfall pattern on Fig. 2 shows.

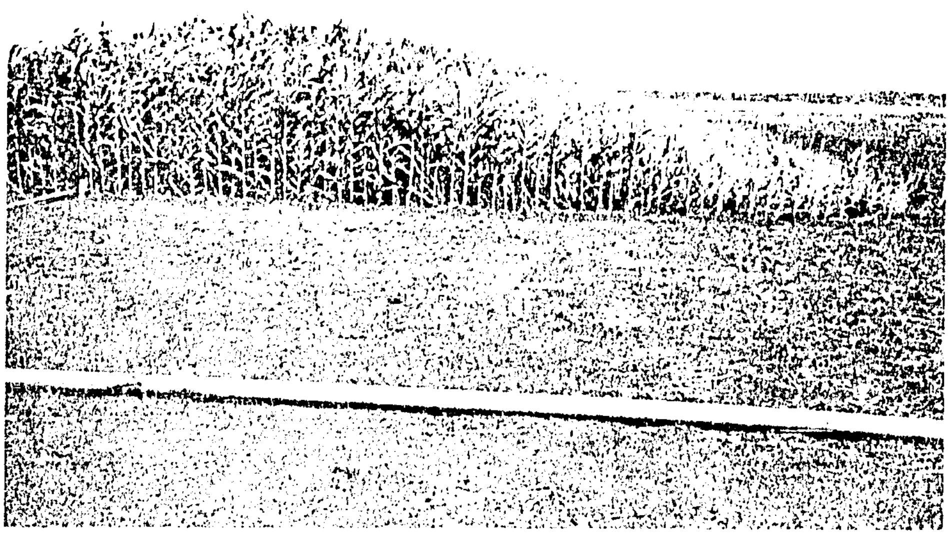
These observations, although tentative, lend substance to the revision of the ustic soil moisture regime as advanced by ICOMMORT. The intent of this proposal is to differentiate ustic soil moisture regimes such as at Isabela, Puerto Rico, which are marginal to the udic regime and set them apart from the central concept of the ustic moisture regime as exemplified at the BSP sites at Jaiba in Brazil. This revision will enhance the interpretation of soil taxa for crop production purposes.

BSP agronomist Steve Nightengale examines drought-stressed maize in an irrigation experiment at Isabela, Puerto Rico

b. Brazil

In cooperation with CNPMS and using a continuous variable line-source irrigation technique designed by our project consultant, Dr. Jack Keller of Utah State University, five irrigation rate trials with different maize and sorghum varieties were completed by the BSP at the primary site in Jaiba. Data from these experiments are now being processed by CNPMS for the development of a moisture utilization model for maize and sorghum in Brazil.

A moisture stress x P x plant density experiment was designed to investigate possible interactions of applied phosphorus, moisture stress and plant density and to determine the period of maize growth when moisture deficiencies would be most critical during the dry season at Jaiba. Moisture stress was imposed on main plots by withholding irrigation during the first, second or third 30-day period beginning 1 week after emergence of the plants. Sub-plots were assigned 4 P treatment levels and 3 plant densities, as shown in Appendix Table 12. The data illustrate the severe effect of moisture stress during the second 30-day period. Maize grain yield was reduced from 6,271 kg/ha to 3,003 kg/ha when no water was applied during this crucial growth period which coincides with flower formation.



A continuous variable sprinkler irrigation study at Jaiba, Brazil, showing a sharp growth gradient following moisture availability

2. LIMING AND SOIL FERTILITY

The surface soil pH at the Puerto Rico secondary site 2 (Calero) was low, pH 4.3 to 4.5, due to past fertilization with ammonium sulfate. Although this does not affect the classification of this soil as Tropeptic Eutrustox, it influenced maize growth, and response to P and N was limited and variable. Several pot experiments were therefore conducted with lime, phosphorus and micronutrients as controlled variables. Objectives of these studies were (1) to determine whether surface soil pH at the Calero site was a constraint to maize growth, (2) to further study the effect of micronutrients and (3) to observe the early plant growth response to P and lime applications separately and in combinations.

Results of the first experiment in which maize plants were grown for 34 days in pots of soil treated with lime at 0 to 8 meq Ca/100 g soil, are presented in Appendix Table 13. The strongest response was to the blanket application of complete fertilizer which was applied uniformly to all pots except one set of control pots without lime or fertilizer. Considering the short growth period of 34 days, there was a marked increase in maize dry matter production with lime applications up to 4 meq Ca/100 g soil which raised soil pH from 4.6 to 5.5.

In a second maize trial with various lime and micronutrient levels, 4 meq Ca, plus Zn and B produced the highest dry matter yield, 8.91 g/plant in 34 days (Appendix Table 14). This yield was superior to dry matter production from pots without lime but not significantly higher than other micronutrient combinations at the same lime level of 4 meq Ca. Micronutrients alone appeared to have little, if any, influence on yield while lime plus micronutrients showed considerable increase in maize growth. A comparison of these two pot experiments conducted at the same time and location suggests that both micronutrients and lime were effectively increasing maize growth.

A third maize experiment in pots with various levels of phosphorus added to the soil showed significantly more dry matter production when 43 kg/ha of P was added (Appendix Table 15); but apparent increases in yield with still higher P levels were not significant. Phosphorus and lime combinations were studied in a fourth pot trial. The data from this trial are presented in Appendix Table 16. Again, P alone increased dry matter production of 28-day old maize plants; however, the response to P was still greater when lime was applied at 2 to 4 meq Ca/100 g soil.

As a follow-up to the pot trials a lime x P field experiment was installed in 1979 at the Calero site. The objective of this study was to determine if the pot trial results were applicable under field conditions. Unfortunately hurricane damage obliterated treatment effects. To test for residual effect of the lime and P this experiment was replanted to maize in November 1979. Residual trial yields were higher and response to lime was significant, with the highest grain yield of 6,260 kg/ha at the highest lime level and 50 kg P/ha. Mean yields were generally low with both experiments and treatment effects not as strong as was expected.

On the basis of these studies lime was applied before planting initial transfer experiments at the Calero, Puerto Rico site. Calcium hydroxide was applied at a rate of 6 meq Ca/100 gram soil. The original surface soil pH at this site (before planting) ranged from pH 4.3 to 4.7. Analyses from post-harvest soil samples showed an increase in soil pH with liming to pH 6.1 (PR-48) and pH 6.4 (PR-55). As soils data from other BSP Eutrustox sites generally had a pH of 5.5 or higher, only the Calero site required liming.

The results of the above pot and field trials affirm the merit of applying blanket applications of certain micronutrients to all transfer experiments for partial control of soil variability. The studies also demonstrate that Eutrustox with acid surface soil benefit from liming. Such situations are rare, however, and are to be expected mainly in Eutrustox with a long history of cultivation and fertilization with acidifying fertilizers.

At the same level of lime, increasing amounts of phosphorus (treatments 10-13) resulted in better maize growth

3. PHOSPHORUS PLACEMENT

Two phosphorus placement trials were completed in Puerto Rico in 1977 and 1980 and another in Brazil in 1980. The objective of these experiments was to determine whether the effectiveness of given amounts of applied phosphate fertilizer can be optimized by placement in bands or rills rather than broadcast.

Four placement treatments were studied--rill (beneath seed row), 15-cm band, 45-cm band and broadcast--each at three or four levels of phosphorus using TSP in Puerto Rico and SSP in Brazil. Rows were spaced 75 cm apart. The amounts of P applied at each level corresponded to the treated portion of the total area; thus, the 15-cm band and 45-cm band treatments received 20% and 60%, respectively, as much P as did the broadcast (75 cm) treatment. Rill and broadcast treatments had the same amount of applied P in the 1977 experiment. Rill treatments were reduced to 20% of the broadcast levels in the 1980 trials. The Pioneer brand hybrid X306B was used as a testcrop in 1977 in Puerto Rico and X304C was used in 1980 at both locations.

Grain yield data for the first of these experiments appear in Appendix Table 17. Yields ranged from 5,311 to 8,338 kg/ha for the 1977 Puerto Rico experiment. In the 1980 trials yields were from 7,378 to 8,523 kg/ha for Puerto Rico and 5,759 to 8,427 kg/ha for Brazil. In Puerto Rico there were significant yield differences among treatments in 1977 but not in 1980. In the first trial broadcast applications generally gave the highest yields, even at lower levels of P, while the 15-cm band application gave the poorest yield response. In Brazil treatment effects were significant but less clearly defined. For all three experiments early growth of maize as evidenced by 30-day plant heights showed the strongest response to both rate and placement of phosphorus.

The yields obtained with the described methods of P placement did generally not vary greatly although they were significantly lower with the 15-cm band application in one experiment. However, the amount of P applied in bands was only 20 and 60 percent of the broadcast amount for the 15-cm and 45-cm band, respectively. The 45-cm band application thus produced about the same grain yield as the broadcast application but with 40 percent less P fertilizer. The advantage of band applications then is the reduced input of fertilizer with generally little or no sacrifice in yield resulting in a markedly improved efficiency.

4. TILLAGE

An experiment designed to determine the soil moisture level most suitable for plowing a Tropeptic Eutrustox in preparation for planting soybeans was conducted at Isabela, Puerto Rico in 1927. After wetting an area of land to field capacity, plots were plowed and disced at lengthening intervals after wetting. Table 11 illustrates the clear relationship between percent soil moisture at plowing and the resulting seedbed quality as reflected by soil aggregate size, number of plants established and soybean grain yield. With increasing soil moisture at the first plowing soil aggregate size was larger, the number of established plants declined and grain yields dropped. Stand counts and yields were best when the first plowing was done with 21 percent soil moisture. With over 23 percent soil moisture at the time of the first plowing, cloddy seedbeds resulted in much poorer stands and lower yields.

Table 11. Soil moisture level at the time of the first plowing operation and its effect on soil aggregate size, soybean stand and grain yield (PR-11). Adapted from BSP sponsored thesis research by H. R. Merino Garcés. Data are means of four replications.

Soil Moisture	Soil Aggregates 1-25 cm	Soil Aggregates >25 mm	Plants/Plot 1/	Grain Yield
%	%	%		kg/ha
25.7	43 b 2/	57 a	23 b	333 c
24.6	46 b	46 ab	33 b	414 bc
24.1	48 b	43 abc	41 ab	624 abc
23.6	53 ab	37 bcd	44 ab	668 ab
21.1	62 ab	27 cd	74 a	911 a
20.8	69 a	24 d	66 a	770 a

1/ Number of plants per plot 25 days after planting.

2/ Means within columns followed by a common letter are not significantly different at the 0.05 level of probability or error.

In this particular soil, 21 percent soil moisture is close to the water content at 15-bar tension or near the wilting point and field capacity (1/3 bar tension) is at about 26 percent water content. The best results were thus achieved when the soil was plowed when it was almost dry.

In three tillage experiments at Isabela in 1978, 1979 and 1980, standard complete tillage was compared with a minimum tillage method of seedbed preparation for maize planted at various in-row plant spacings. The objectives of these experiments were (1) to evaluate the suitability of minimum tillage for maize production in Tropeptic Eutrustox in order to minimize energy costs and reduce soil erosion and compaction, (2) to evaluate three different plant population densities -- the standard used in transfer experiments, one lower and one higher -- and (3) to obtain a basis for evaluating possible effects on maize yields of minimum tillage as practiced in the residual transfer experiments.

The experiment was established in a split-plot design with three replications. Tillage treatments, assigned to whole-plots, consisted of (1) complete tillage; plowing and discing twice followed by rotovating just before planting by hand, and (2) minimum tillage; weed control with Paraquat and planting by hand with no tillage. Later in the season weeds were controlled on all plots by shallow hoeing.

The effects of the three plant densities are discussed in a subsequent section. Maize, Pioneer hybrid X304C, was used as the testcrop. For the first two experiments yields were moderately low and neither tillage nor plant population treatments showed any significant effect. Maize yields were quite high, 7,770 to 9,446 kg/ha, in the third trial but, although high plant populations significantly increased yields, there was again no tillage treatment effect. The data from this last experiment appear in Appendix Table 18.

A tentative conclusion is that for maize production on Tropeptic Eutrustox sites such as at Isabela, complete tillage preparation for each season is not necessary and that the residual transfer trials were probably not adversely affected by the minimum tillage practices that were essential to avoid lateral mixing of treatments.

5. MULCHING

A multching experiment using Pioneer brand X304C maize as the testcrop was conducted during the 1980 dry season at the Jaiba, Brazil primary site. Eight levels of dry maize stover, ranging from 0 to 12,500 kg/ha, were applied before planting. (The higher levels of maize stover used in this experiment are representative of stover production possible for hybrid maize under good field conditions.) All plots were given a uniform application of 25, 30, and 25 kg/ha of N, P, and K, respectively.

The highest level of applied stover (12,500 kg/ha) produced significantly more grain and heavier ears than all other treatments except the second highest level. There were no significant differences among plant counts per plot, ruling out any population effects on yield. The low grain yields for all treatments, as seen in Appendix Table 19, resulted from moisture stress during growth as irrigations were applied only when plants displayed stress symptoms.

The marked yield increase from 657 to 2,544 kg/ha by using up to 12,500 kg/ha of dry maize stover is attributed largely to soil moisture conservation. The experiment thus showed that maize stover, as a crop mulch, can increase yields appreciably where moisture stress is a problem.

6. MAIZE PLANT DENSITY

Unirrigated studies were conducted at Jaiba, Brazil to determine possible maize grain yield improvement with increased plant populations through various planting patterns. The first of these trials was carried out in the 1976-77 wet season and had 3 varieties planted in rows 50, 75 and 100 cm apart and at 20,000, 40,000 and 60,000 plants/ha.

Regardless of variety and population, between row spacing had no significant effect on maize yields. Varietal differences in yield were not significant at 20,000 plants/ha, but the variety Piranao outyielded both Phoenix 1110 and Cateto de Colombia when all were grown at 40,000 and 60,000 plants/ha. Grain yields of Piranao and Cateto varieties were significantly improved from 4,837 to 6,615 and from 3,910 to 4,748 kg/ha, respectively, when populations were raised from 20,000 to 40,000 plants/ha. The responses for two varieties are shown in Fig. 7. Phoenix 1110 showed no significant response to increased plant populations.

A follow-up experiment, conducted in the 1977-78 wet season, was laid out in the plant density "wheel" design rather than a conventional pattern. The objective of the experiment was to evaluate a wide range of maize plant stands from low populations to relatively high plant densities using a well adapted hybrid maize. Fertilizer was applied but the trial received no supplemental irrigation. Twenty-five concentric circles plus borders were planted to 124 maize hills each. Space between concentric circles was adjusted to give plant populations from approximately 6,600 to 70,000 plants/ha from the outside to the inside circles.

A summary of the results of this experiment are presented in Appendix Table 20. Yield components such as number of ears per plant, grain weight

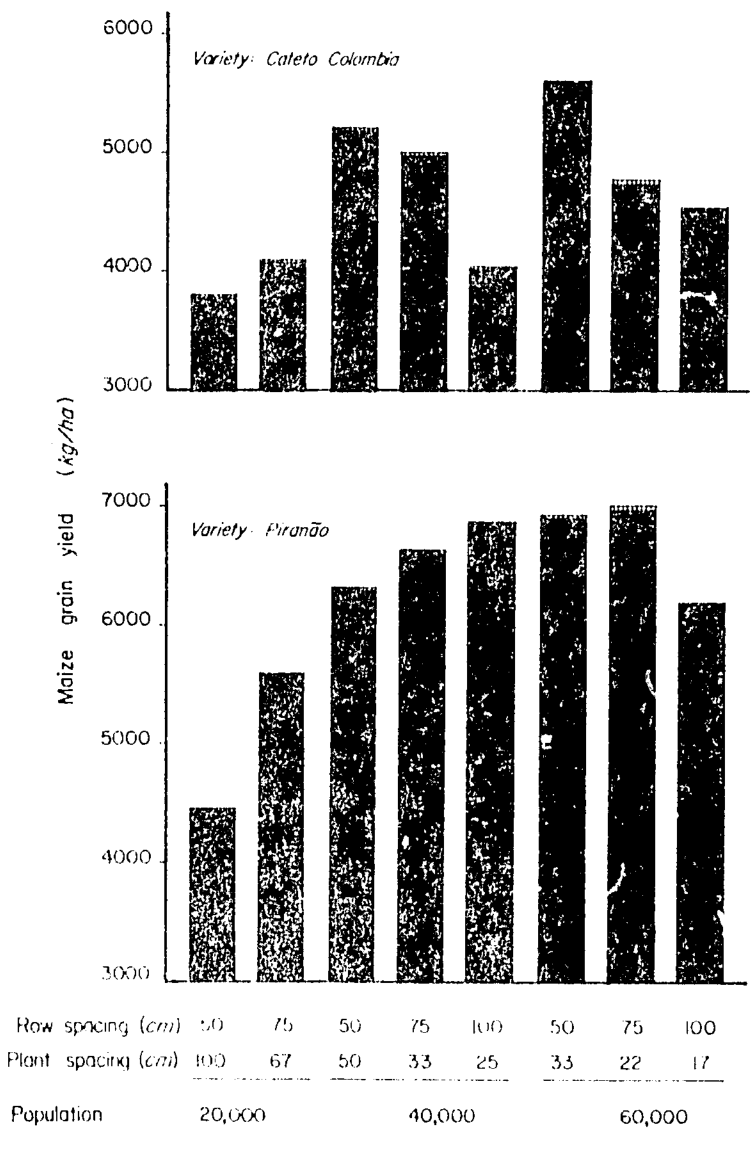


Fig. 7

Results of a maize variety trial conducted at Jaiba, Brazil, to determine optimum planting density per plant and mean ear weight were increased nearly three fold by reducing from 70,000 to 6,600 plants/ha. On the other hand, grain yield per unit of area was drastically reduced by lowered population density.

Although with a mechanized system of farming it would be difficult to duplicate the high density pattern found near the center of the density "wheel" experiment, much of the maize in tropical countries is planted and cultivated by hand and traditionally maize populations are low. These hand-sown and cultivated fields could be planted at higher densities similar to the best yielding part of the density "wheel" thereby increasing yields considerably, assuming that suitable maize varieties and other necessary inputs are available.

In the moisture stress x P level density trial described in a previous section the Cargill brand hybrid 111 produced significantly higher grain yields at 55,000 and 85,000 plants/ha than at 33,000 plants. Plant lodging at the highest density was serious (20%) but yield difference between 55,000 and 85,000 plants/ha was not significant, as shown in Appendix Table 12.

In a maize density experiment at Isabela, Puerto Rico, yields were higher and significantly increased by closer spacing; grain yields were 9,360 and 8,883 kg/ha with 20 and 23 cm between plants, respectively and 7,972 kg/ha with 27 cm plant spacing. The in-row spacings of 20, 23 and 27 cm corresponded to populations of about 66,700, 58,000, and 49,400 plants/ha. Experiment results are shown in Appendix Table 18.

The effect of maize plant density on yield varies with varieties, management and seasons but generally a population of 55,000 to 60,000 plants per hectare is recommended for Eutrustox sites on the basis of experiments in Puerto Rico and Brazil.

A maize density experiment, in wheel design, at Jaiba, Brazil, shows the concentrically increasing plant population

7. MAIZE PLANTING DATE

At the Brazil primary site, one variety each of maize (Cargill 111C) and sorghum (BR-300) was planted in the wet season at 20 day intervals from 15 October 1978 to 3 January 1979. All plots were fertilized uniformly with 20 kg/ha N, 60 kg/ha P_2O_5 and 30 kg/ha K_2O in this unirrigated experiment. Due to poor germination and bird damage at the maturity of sorghum, only maize will be discussed here.

The results of this experiment are presented in Appendix Table 21. The data show that grain yield and mean ear weight decreased as planting date was delayed. The final planting, 3 January 1979, was significantly lower in grain yield and mean ear weight and higher in lodging percentage at harvest than the other four plantings. The 15 October planting produced 6,286 kg/ha of grain vs 2,098 kg/ha for the January planting. The data strongly support early planting for the Jaiba area, preferably no later than mid-November. For unirrigated maize production in the Jaiba area lack of rainfall is often a severely limiting factor with later plantings as the dry season generally begins in March (see Fig. 2).

8. MAIZE COMPOSITE POPULATION IMPROVEMENT

This study was designed to develop a maize germplasm pool especially suited for the Cerrado region of northern Minas Gerais in Brazil. Four cycles of mass selection and recombination were completed from 1979 to 1980 in this continuing maize improvement scheme. The initial planting, or cycle, was composed of 88 varieties of maize from a world germplasm collection maintained by EMBRAPA. Mass selection was accomplished for three additional cycles before the BSP concluded work in Brazil but EPAMIG assumed responsibility for continuing this promising composite improvement.

Selection pressures were kept at a minimum in these early cycles of selection to prevent too much loss of genetic variability (inbreeding coefficient less than 5% per cycle). The effects of selecting for a desirable plant type and natural environment selection pressures have produced some pronounced changes in this composite in the first four generations. Observed population changes include lower and more uniform plant height, disease resistance, less susceptibility to lodging, and greater prolificacy (multiple ears per plant). This selection program is expected to produce the first maize composite germplasm pool for this area of Brazil. All maize currently grown in the Jaiba region was developed elsewhere and it is anticipated that from this adapted composite maize pool, after further cycles of selection, a new variety can be developed and released. Inbred maize lines and synthetic varieties could also be derived from this germplasm pool.

9. MULTIPLE CROPPING

A series of four multicropping experiments were conducted from August 1978 to December 1980 at the Jaiba, Brazil primary site. This study was designed to explore methods of optimizing food production on a small land area through irrigated, intensive farming techniques. The small area used for these experiments, 20 x 20m, required planning of row crop plantings to achieve the best utilization of the 400 square meter space.

The four cycles of this experiment involved interplanting and spacings of different combinations of row crops in an attempt to maximize utilization of inputs and obtain the highest economic return. Results of the four cycles, along with estimated economic returns, are presented in Appendix Table 22. Approximate values are used as commodity prices vary throughout the year in Brazil. From these data it can be seen that vegetable crops such as carrots and onions were steady income-earners. Dry beans are valuable as a fast maturing crop and can make an important contribution to the diet of the farm family. Maize showed potential for acceptable yields in this type of farming, but should perhaps be omitted as too strong a competitor, depressing yields of more valuable companion crops such as onions and beans. Cassava also appeared to be inappropriate to this type of management system. The two problems associated with cassava were strong competitiveness and the long growth period to harvest (9 months). Squash, if prevented from becoming too competitive through delayed planting or trellising, was very productive.

For the 27-months period during which the four cycles were completed the total estimated economic return from the produce was $1,160 (see Appendix Table 22) whereas total expenses for fertilizers and sprinkler irrigation equipment amounted to about $375. Use of furrow irrigation instead of a sprinkler system would reduce these costs to about $100.

The study demonstrated how small plots of land can be intensively utilized with modest inputs to effectively improve the quantity and quality of the diet of resource-poor farm families.

BSF agronomist Merv Olson in a multicrop experiment at Jaiba, Brazil, with maize, carrots and dry beans

BSP Field Day in Jaiba, Brazil

V. DISSEMINATION, LINKAGES AND IMPACT

A. CONFERENCES, SEMINARS AND WORKSHOPS

1. PROFESSIONAL CONFERENCES

The Benchmark Soils Project was exposed and discussed at many international meetings. Mentioned here, in chronological order, are those at which the UPR/BSP had direct inputs.

a. Medellin, Colombia

In an effort to familiarize agricultural scientists and institutions in Latin America with the BSP and to stimulate interest and cooperation, a paper describing the rationale, research strategy and experimental methodology of the project was presented, in Spanish, at the Fifth Latin American Congress of Soil Science held in Medellin, Colombia, in August 1975. The paper met with a very favorable response and was subsequently published in the transactions of the congress (see BIBLIOGRAPHY in the Appendix).

b. ICRISAT, India

The BSP concept of agrotechnology transfer on the basis of soil classification figured prominently at an international Seminar on the Use of Soil Survey and Classification in Planning and Implementing Agricultural Development in the Tropics held at ICRISAT in Hyderabad, India, in January 1976. The meeting was jointly sponsored by the University of Hawaii, ICRISAT and the US University Consortium on Soils of the Tropics. It was attended by senior natural resource planners and soil scientists from about thirty countries mainly in Africa and Asia. This very successful conference generated much enthusiasm for the BSP, reflecting a general acceptance of the concepts and procedures of the BSP. The papers presented at the conference were edited by Dr. L.D. Swindale and published by the University of Hawaii in a book, Soil Resource Data for Agricultural Development, that was distributed worldwide.

c. Kuala Lumpur, Malaysia

A paper co-authored by Drs. L.D. Swindale, J.A. Silva and F.H. Beinroth and titled "The Benchmark Soils Project--An innovative approach to agrotechnology transfer" was presented in a plenary session of the Conference on Classification and Management of Tropical Soils (CLAMATROPS) held in Kuala Lumpur, Malaysia, in August 1977. The meeting was organized by the Malaysian Soil Science Society as an activity of Commissions IV and V of the International Society of Soil Science. It was attended by over 300 scientists from 25 countries. The paper, forcefully presented by Dr. Swindale, was very well received and has been published in the conference proceedings.

d. Mayaguez, Puerto Rico

The First Conference on Fertilizer Technology Transfer in Puerto Rico, jointly sponsored by the University of Puerto Rico and the Tennessee Valley Authority and held in Mayaguez, Puerto Rico, in December 1980, provided the UPR/BSP with the opportunity to present a paper on the "Use of soil classification for agrotechnology transfer in the tropics" and to discuss project results. The audience, which comprised representatives from TVA and all agricultural agencies of Puerto Rico, included many extension workers. The proceedings of this conference are now in press and will be published in English and Spanish.

e. Palmerston North, New Zealand

The project's dissemination efforts to date climaxed at the international Conference on Soils with Variable Charge held at Massey University in Palmerston North, New Zealand, in February 1981. The BSP had been invited to present a symposium at this conference which was organized by the New Zealand Society of Soil Science as a meeting of several commissions of the International Society of Soil Science. About 300 pedologists, agronomists, meteorologists, and other scientists from all over the world were in attendance. The conference was acclaimed by many participants as one of the best such conferences they have attended. It is noteworthy that one complete day--one sixth of the conference--was dedicated to the BSP.

The program of the BSP symposium was designed to proceed from generalities to specifics. The first two papers thus had the purpose of providing the philosophical framework for soil-based agrotechnology transfer. It was advantageous that two speakers of unquestioned authority and international stature, Dr. L.D. Swindale, Director-General of ICRISAT and Dr. R. W. Arnold, Director of Soils, USDA-SCS, agreed to present the first papers. Their incisive speeches provided the proper perspective of agrotechnology transfer in a comprehensive context and added weight and substance to the concepts under study in the BSP. This was followed by a series of more specific papers by BSP staff on the project rationale, activities and progress to date. Special reports were presented by the BSP in-country Project Leaders and by heads of cooperating host country institutions.

Displays of project background and research findings together with a continuous narrated slide show were installed in a room adjacent to the main confe-rence hall. The "Benchmark Room" attracted a constant stream of visitors and many commendations were received.

The lively and perceptive discussions that followed all BSP presentations reflected a more than polite interest in the project and the overall reaction to the BSP was distinctly positive.

2. SEMINARS

In May 1978 UPR's Principal Investigator gave a one-hour seminar on the BSP in Rio de Janeiro, Brazil. The audience were staff of EMBRAPA's Servico de Levantament e Conservacao de Solos (SNLCS) and faculty and students of the Universidad Federal Rural de Rio de Janeiro. The illustrated lecture met with an excellent response. Enhanced by a vivid discussion, it created a keener awareness and perception of the BSP in the general context of agricultural development. More specifically, it also triggered SNLCS interest in establishing a national benchmark soils network.

Two BSP seminars were presented in 1980 and 1981 at the University of Puerto Rico, one to students of the College of Agricultural Sciences and one to a campus-wide audience.

Following an invitation by and with complete financial support from the Centro Nacional de Investigaciones Agropecuárias (CENIAP) in Maracay, Venezuela, three one-hour seminars were delivered in Maracay in December 1981 to CENIAP staff and faculty and students of the Postgraduate School of the University of Maracay. The lectures dealt with principles of soil-based agrotechnology transfer, the Benchmark Soils Project per se, and the utilization of BSP concepts and results on a broader scale. The response to these seminars and the interest they generated were very encouraging.

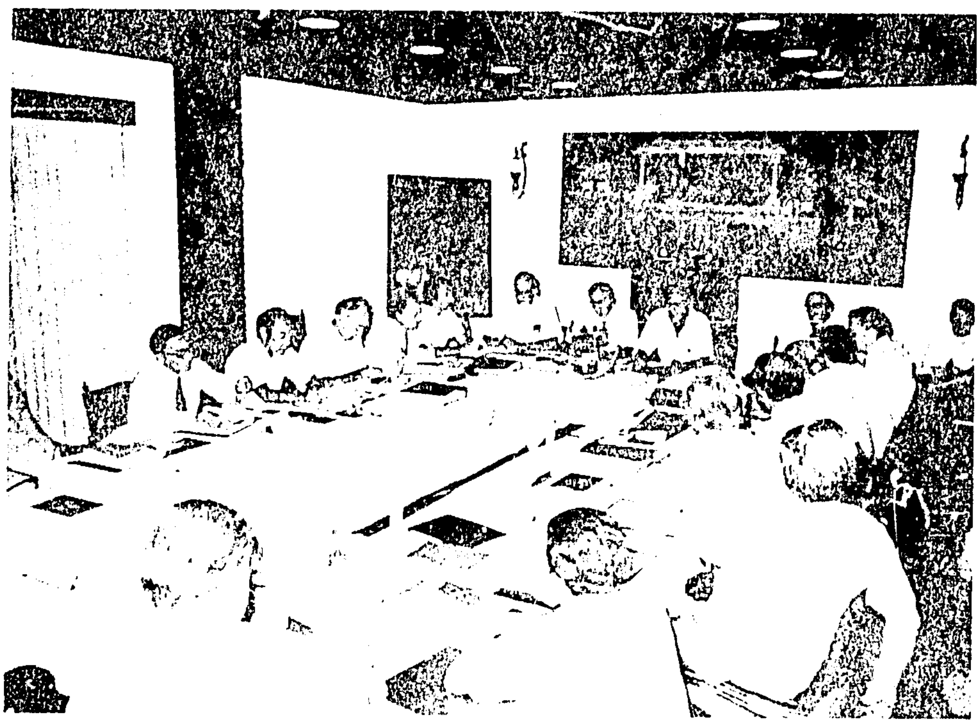
3. PLANNING MEETINGS

a. ICRISAT, India

In October 1978 a Workshop on Operational Implications of Agrotechnology Transference Research was held at ICRISAT in Hyderabad, India. The workshop was initiated by Dr. T.S. Gill of AID, co-sponsored by AID and ICRISAT, and organized and hosted by ICRISAT.

The purpose of the workshop was to explore the implications of the use of the benchmark soils concept for agrotechnology transfer beyond the limits of the current BSP and to make recommendations for follow-up activities. The workshop brought together twenty-two leaders in soil science and agricultural development planning, representatives of AID, the World Bank, FAO of the United Nations, the US University Consortium on Soils of the Tropics, several of the International Agricultural Research Centers, and the leadership of the BSP. Three participants were financially supported with funds from the UPR/BSP.

The workshop was an unqualified success and marked the first significant step toward the development of a strategy for the utilization of BSP concepts in a worldwide network.



Participants at the ICRISAT Workshop

b. FAO, Italy

In a further effort to pave the way for an effective utilization of the principles underlying the BSP and concepts related to it, a Panel Consultation on the Strategy for Land Evaluation and Agrotechnology Transfer in the Tropics and Subtropics was held at the headquarters of the Food and Agriculture Organization (FAO) of the United Nations in Rome, Italy, from 10 to 12 March 1980. The meeting was initiated by the Puerto Rico project, organized jointly by UPR/BSP and FAO, and hosted by FAO.

In attendance were twenty-two distinguished soil scientists and administrators of national and international programs. They represented ACSAD, Syria (1); AID (1) Cornell University (1); EMBRAPA, Brazil (1); EPAMIG, Brazil (1); FAO [illegible]; FIGNR, Federal Republic of Germany, (1); ISM, The Netherlands (1); ORSTOM, France (1); University of Ghent, Belgium (2); USDA-SCS (1); and the Hawaii and Puerto Rico BSP (3).

The intent of the meeting was to develop a strategy for land evaluation research and soil-based transfers of agroproduction technology at an international level in the tropics and subtropics. The specific objectives were:

1. To devise a framework for the effective utilization transference research that combines national and international efforts and promotes the application of its results in development work,

2. To determine what needs to be done by whom, when, where and how to establish the relationships between soil characteristics and crop requirements in order to obtain a sound basis for soil survey interpretation and land evaluation, and

3. To assist the Benchmark Soils Project in developing a modus operandi for the utilization phase of the project within the context of more comprehensive international efforts.

The format of the program emphasized discussion and dialogue rather than the formal presentation of papers. There were six technical sessions; one devoted to the presentation of background information and five to the various aspects of the general theme of the meeting.

The conclusions of the Panel Consultation were summarized in a set of ten specific recommendations which have been published as BSP Leaflet 03-E in October 1980. These recommendations will be valuable in conceiving and implementing a scientifically and operationally sound utilization phase of the current BSP. The Panel Consultation thus achieved its stated objectives. The success of the meeting can be attributed to the high professional caliber of the participants, the congenial atmosphere of the discussions, and to a well-conceived program that provided a specific framework for the deliberations.

4. INTERNATIONAL SOIL CLASSIFICATION WORKSHOPS

With the objective to refine Soil Taxonomy relative to the soils of the tropics and subtropics, a series of four international soil classification workshops were conducted as a companion activity to the BSP. The workshops were initiated and orchestrated by UPR's Principal Investigator, Dr. F. H. Beinroth, in cooperation with host country institutions, the USDA Soil Conservation Service, the University of Ghent, Belgium, and the BSP. Three of the workshops were funded under grants from AID to UPR and one by an AID-sponsored program of the USDA Soil Conservation Service. The workshops were held in:

Brazil, 20 June to 1 July 1977, in cooperation with the Servico Nacional de Levantamento e Conservacao de Solos of EMBRAPA,

Malaysia and Thailand, 28 August to 9 September 1978, in cooperation with the Department of Agriculture of Malaysia, the Land Development Department of Thailand, and the Southeast Asian Center for Graduate Study and Research in Agriculture (SEARCA),

Syria and Lebanon, 14 to 24 April 1980, in cooperation with the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) with a follow-up meeting in Athens, Greece, 1 to 3 May 1980, in collaboration with the Soil Science Institute, Ministry of Agriculture of Greece, and

Rwanda, 2 to 12 June 1981, in cooperation with the Institute des Sciences Agronomiques du Rwanda (ISAR), the Algemeen Bestuur voor Ontwikkelings Samenwerking (ABOS) of Belgium, and the Soil Management Support Services of the USDA-SCS.[1]

The workshops focused on the redefinition of certain Soil Taxonomy differentiae and classes of soils of the lower latitudes in an attempt to better identify these soils and thus improve the quality of soil surveys and soil interpretations. The particular kinds of soils under study at the workshops were Alfisols and Ultisols with low activity clays, Oxisols, Aridisols, and soils dervided from volcanic ash. With the exception of Aridisols, members of all of the mentioned classes of soils are studied by the BSP.

[1] Future activities are planned for the Sudan in 1982 and Latin America in 1983. They will concern Vertisols and Andisols.

Dr. M. L. Leamy from New Zealand (on ladder) examines soil profile during the Fourth International Soil Classification Workshop in Rwanda

The workshops had a balanced number of conference sessions and field trips. The more theoretical considerations advanced during the indoor sessions could thus be examined in the field in the light of critical examples of the soils under scrutiny. The proceedings of the first two workshops have been published and distributed worldwide; the two others are in preparation.

The workshops were attended by exceptional groups of internationally renowned pedologists representing multinational institutions, universities, national and bilateral soil survey programs, and various government agencies from all over the world. They also enjoyed the active participation of large numbers of soil scientists from the host countries. At the first two workshops the presence of the late Dr. Guy D. Smith, the principal author of Soil Taxonomy, was of particular impact.

There can be no doubt that the four workshops were highly successful and that real progress was made in the refinement of Soil Taxonomy. These activities also generated a wealth of comprehensive and reliable analytical and soil and site characterization data on key soils of the tropics and subtropics. These data constitute valuable additions to the BSP Soil Data Bank. It was also obvious at the meetings that Soil Taxonomy is emerging as the de facto language for international communication among pedologists and is becoming a unifying element of pedology, thus providing a solid base for the international transfer of agrotechnology.

The soil classification workshops clearly made a contribution of central importance to the utilization of BSP concepts by refining the soil taxonomic units that are the basis for knowledge transfers and by promoting the use of Soil Taxonomy in the Third World.

Field trip during the Fourth International Soil Classification Workshop in Rwanda

B. FIELD DAY

A field day was held at Jaiba and Janauba in Brazil in October 1980 to familiarize a larger in-country audience with the philosophy, research and implication of the Benchmark Soils Project.

The meeting was convened by EPAMIG, UPR's collaborating agency in Minas Gerais, and its president extended personal invitations to all relevant organizations and individuals in Minas Gerais and to EMBRAPA, the national research agency.

Forty-seven professionals representing universities, national and state agencies, private companies, and various research, development and extension agencies mainly from Minas Gerais participated in the field day. They included 6 agronomists, 7 soil scientists, 1 horticulturist, 1 climatologist, 10 irrigation specialists, 3 veterinarians, 10 extension specialists, 2 professors of soil science, 1 forage specialist, 1 forester, and 5 other professionals. The diverse professional concerns of the participants illustrate the wide interest in the BSP concept of agrotechnology transfer.

The 3-day event included a first-evening orientation session, followed by a full day of on-site inspection. Huge soil pits had been excavated to allow the participants to study soil profiles. The final morning was spent summing-up the previous days' experiences, which was followed by a lively discussion period. At the conclusion of the field day, each participant was given a specially prepared set of brochures and general information about the BSP along with an official certificate of participation.

The field day fully achieved its objective of creating a wider and keener awareness of the Benchmark Soils Project in Minas Gerais and demonstrating its sizeable research efforts in the field. EPAMIG considered the BSP field day an outstandingly successful activity.

Dr. Jorge Olmos of EMPRAPA explains soil profile during BSP Field Day in Jaiba, Brazil

C. INFORMATION DISSEMINATION AND PUBLICATIONS

Under the leadership of Ms. Cynthia L. Garver, Editor and Communication Coordinator with the UH/BSP, the project has developed a sizeable and effective information dissemination and publication program. Only some of the publications produced with inputs from the UPR/BSP are mentioned here.

Two illustrated leaflets describing the BSP and its concepts were published in English, French and Spanish in 1978 and widely distributed. A series of "BSP Technical Reports" covered research aspects such as the soils of the BSP network and statistical procedures. The informal "BSP Communiqué" keeps the BSP personnel dispersed in six countries up-to-date and cumunicado. The quarterly "Benchmark Soils News" provides the main vehicle for the rapid dissemination of project results and other relevant developments. It is routinely mailed to 1,275 individuals and organizations in 89 countries.

Specifically addressed to an audience in Brazil were four technical articles on the BSP and its work in Minas Gerais which, together with an interview with UPR's Principal Investigator, were published in Portuguese in the "Informe Agropecuário," a Brazilian journal of agriculture (no. 61, 1980, pp. 69-79 and 83-84).

In October 1978, Dr. Nyle C. Brady, editor of Advances in Agronomy, invited Drs. F. H. Beinroth and G. Uehara to prepare an article on the benchmark soils concept for the 1980 issue of this prestigious journal. To ensure a complete and authoritative coverage of the subject and a paper of high professional standards, Drs. R. W. Arnold, F. B. Cady and J. A. Silva were included as co-authors. After editing by Ms. Garver, the manuscript was submitted to Dr. Brady in November 1979 and published in Volume 33 of Advances in Agronomy.

This and other publications prepared by UH/BSP staff are listed in the BIBLIOGRAPHY contained in the Appendix.

D. LINKAGES

The establishment and maintenance of linkages was an essential element of the BSP and has been actively pursued since project inception. These efforts resulted in a worldwide network of viable connections.

In the course of project activities, the UPR/BSP was contractually affiliated with the Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG) in Brazil, North Carolina State University, the University of Kentucky, and Utah

State University. Formal linkages which ensued collaborative activities were established with the Food and Agriculture Organization (FAO) of the United Nations, the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), ICRISAT in India, the International Soybean Program (INTSOY), the Centro Nacional de Pesquisa de Milho e Sorgo (CNPMS) in Brazil, and the USDA Soil Conservation Service.

Also involved in UPR/BSP activities were the Federal Institute for Geosciences and Natural Resources of West Germany; the Office de la Recherche Scientifique et Technique d'Outre-Mer (ORSTOM) of France; the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) in Syria; the University of Ghent, Belgium; Cornell University; the International Soil Museum (ISM) in The Netherlands; and soil survey organizations in Colombia, the Dominican Republic and Venezuela.

In addition a large number of close contacts with individuals and institutions from all over the world were developed at the four international soil classification workshops, and at other international conferences, meetings and workshops. They are too numerous to be listed here.

The UPR/BSP thus has excellent personal and institutional contacts in many countries of Africa, the Near East, Southeast Asia and Latin America. These operational linkages constitute an extremely important asset of the BSP. They will prove invaluable in implementing follow-up activities at a worldwide scale.

E. PROJECT IMPACT

The central concern of the BSP is the testing of a soil classification based methodology for agrotechnology transfer. The first results obtained with a large set of experiment data are published in the present report. It is consequently premature to assess the reaction to the findings of the project at this time. Similarly, as the BSP was not involved in the actual transfer of agrotechnology, it could not have had direct impact on the agricultural development in LDCs at this point.

The project was, however, very successful in creating wide awareness of and familiarity with the BSP and in promoting the use of the benchmark soils concept for the transfer of agrotechnology. Project impact in this area is evidenced by the invitation extended to the BSP by the organizers of the New Zealand conference who considered the BSP important enough to dedicate one complete day to it. Further evidence of interest in the BSP was the invitation by Dr. N.C. Brady to prepare a position paper for Advances in Agronomy. Another indication of project impact was the willingness of FAO and ICRISAT to organize and host BSP-related strategy planning meetings. And the extensive circulation of the Benchmark Soils News in 89 countries, constant requests for BSP publications and frequent inquiries about the project clearly show that many individuals and institutions in all parts of the world are familiar with and interested in the BSP.

Impact in Brazil has been more direct and at an operational level. Reflecting the acceptance of project concepts, the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), the national agricultural research agency, is now initiating the establishment of a national benchmark soils network in Brazil. EMBRAPA's Servico Nacional de Levantamento e Conservacao de Soles will be executing this program and has begun to identify Brazilian benchmark soils. The development of an appropriate research strategy and design has been deliberately postponed to ensure compatibility of the Brazilian efforts with similar research conducted elsewhere under a possible follow-up program to the BSP.

The existence and performance of the BSP provided the justification and raison d'etre and thus was instrumental in the implementation of a new AID-sponsored program, the Soil Management Support Services (SMSS) of the USDA Soil Conservation Service. This program was established in 1980 and may be considered an outgrowth of the international soil classification workshops initiated by UPR. The overall purpose of the SMSS is to assist LDCs in producing the quality resource inventories that are the prerequisite for soil-based transfers of agrotechnology. The specific objectives of SMSS are to facilitate the utilization of BSP concepts by providing short-term technical assistance to LDCs in all aspects of soil survey, further refining Soil Taxonomy with respect to soils of the lower latitudes, training LDC soil scientists in soil survey, soil classification and soil interpretation, and promoting the use of Soil Taxonomy in the tropics and subtropics. The close relationships between the SMSS and the BSP, and the critical importance of SMSS activities to the utilization of BSP concepts are obvious.

The main impact of the BSP to date, then, has been the creating of wide awareness and familiarity with the project and its philosophy, instigating support activities, and generating considerable momentum for the use of the benchmark soils concept for agrotechnology transfer. The BSP thus fostered a very favorable environment for a more comprehensive follow-up program of wider geographical scope.

VI. RESULTS IN PERSPECTIVE

The results of the UPR/BSP constitute a first quantitative substantiation of the general validity of a Soil Taxonomy-based hypothesis of agrotechnology transfer as postulated by the BSP and implicitely of the benchmark soils concept. These encouraging results are expected to be reinforced by the ongoing research of the University of Hawaii project which involves a larger set of experiment data obtained with a wider variety of soils.

In view of the complexity of the conjecture under study and considering the difficulties inherent in its mathematical corroboration, the results of the UPR/BSP are very reassuring. It should therefore be useful to evaluate the significance of the findings in the context of a broader perspective.

In the project crops yields were used as the ultimate measure for the transferability of soil management practices. It is well to remember here that yields are the overall integrator of the agroenvironment and the husbandry practices imposed at a specific site. Maximum yields result from optimum conditions at all times with respect to a balanced supply of plant nutrients, an adequate rooting zone with sufficient water and oxygen, suitable temperature and day length, plant varieties with the genetic potential to make effective use of environmental and management inputs, and protection from diseases, predators and weeds. The intricacy of this biologic system is characterized by multiple interactions which are exceedingly difficult to quantify and to express mathematically

This perplexity alludes to some of the problems encountered by the BSP in scientifically testing the transferability of agrotechnology by statistically comparing crop responses across a network of soils belonging to the same soil family. First, for the reasons explained in a previous section, it was necessary to disaggregate the total system response and to confine the statistical evaluation of transferability to the response to phosphorus. It was also necessary to refine the soil and climatic parameters specified by the definition of the soil family by including additional site factors bearing on crop performance in the statistical prediction models. These were soil and weather variables that were not constant over all experiment sites because they are not quantified by soil family differentiae. They are, however, closely related to soil family criteria. Second, since no adequate statistical procedures for the verification of agrotechnology transfer existed prior to the project, new techniques had to be developed under the auspices of the BSP. In spite of the experimental and statistical difficulties the project succeeded in providing strong quantitative evidence in support of the stated transfer hypothesis.

Moreover, the agronomic results of the project demonstrate that soil families as defined in Soil Taxonomy indeed provide groupings of soils that have relative homogeneity in properties important to plant growth, common and predictable responses to management practices, and similar crop production potential and thus stratify the agroenvironment into distinct niches of agroproduction. This is evidenced, for example, by the very similar maximum yields obtained in Puerto Rico and Brazil with comparable inputs, the absence of response to potassium at both locations, and the fact that one specific variety of maize performed best in the two countries.

The combined analysis of larger sets of experiment data still being accumulated by the University of Hawaii project for three distinctly different families of Eutrustox, Hydrandepts and Paleudults will be particularly useful in further validating the soil family concept. Even a casual interfamily comparison of data obtained so far shows that the three soil families are characterized by distinctly different patterns of soil behavior. The P-isotherms, for example, which are in large measure conditioned by soil family characteristics, are markedly different for the three soil families but very similar for all soils of the same family.

The highest mean maize yields were about 9,000 kg/ha for the Eutrustox in Puerto Rico and Brazil, 7,000 kg/ha for the Hydrandepts and 6,700 kg/ha for the Paleudults. Although these yields are not vastly different, the fertilizer inputs necessary to achieve them definitely are. Whereas the Eutrustox required only about 40 kg P/ha to obtain these yields, the Dystrandepts needed 150 kg/ha and the Paleudults 100 kg/ha. Furthermore, the Dystrandepts and Paleudults required substantial applications of potassium and lime which were not needed for the Eutrustox. The soil management technology developed for Eutrustox is therefore clearly not applicable to either Dystrandepts or Paleudults, reflecting the soil-specificity of agrotechnology transfer as implied in the BSP transfer hypothesis.

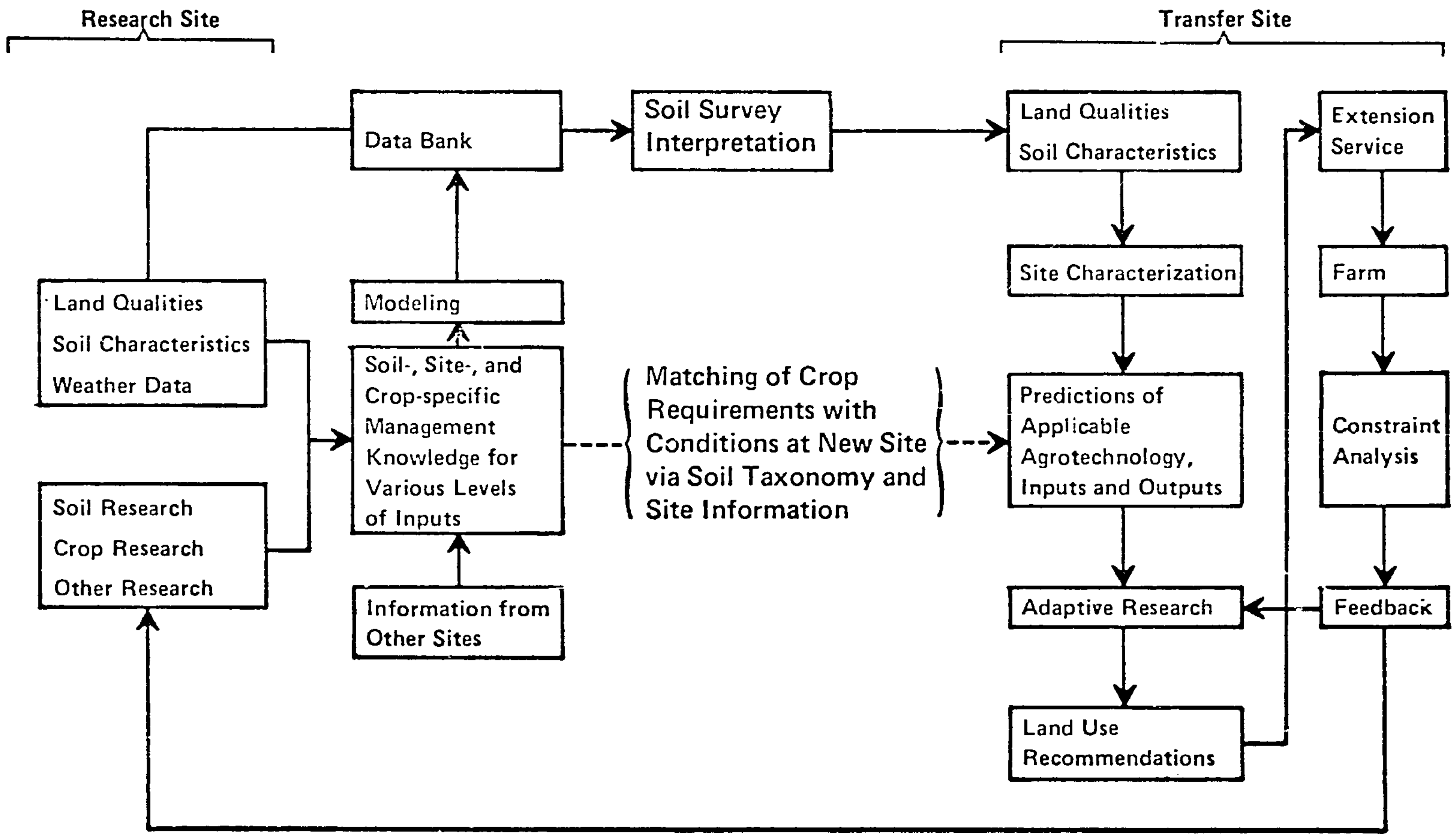
A very important, yet frequently ignored, attribute of the soil family is that it incorporates an element of time. Temporal variation, or lack thereof, is introduced into the taxa of Soil Taxonomy through the soil moisture and temperature regimes which are cyclic in nature. Appreciation of this fact is of considerable consequence. For example, one crop of corn can be grown in many non-isohyperthermic soils of the temperate region but two or more crops are only possible in the isohyperthermic soils that are unique to the tropics. In view of the time dependence of many management practices, the soil family, consequently, also provides a basis for the transfer of experience with perennial crops, farming and cropping systems, and agroforestry. These land use patterns are of particular importance in the tropics as they allow the most effective utilization of land resources and the year-round growing seasons.

It should be mentioned in this context that long-season crops such as bananas, cassava or rubber would have been better testcrops for the BSP experiments than maize as they integrate soil family-specific annual variations in heat flux and precipitation in their yield performance and also are less susceptible to surface soil variability. This was not feasible in the project, however, as it would have prevented to conduct a large number of consecutive experiments in a relatively short time. Conversely, as the transfer test with maize was quite successful, it is reasonable to assume that it would have been even more convincing with a long-season indicator crop.

In the course of the project it became also evident that Soil Taxonomy-based transfers of agroproduction technology transcend the boundaries of specific soil families. If the cause-and-effect relationships of cultural practices are known and related to soil taxonomic differentiae, these practices can be extrapolated to all other classes of soils that have the combination of characteristics critical to a given land use. Soil classification therefore defines the sphere of applicability of agrotechnology developed at a research site. It is thus a key element in the transfer process and, in conjunction with resource inventories, provides the vehicle for the wide geographic diffusion of agricultural experience.

On the basis of this and other concepts developed by the BSP, a conceptual model for the effective utilization of the benchmark soils concept in the analogue transfer of agrotechnology has been designed and is shown in Fig. 8. This model represents a holistic approach and involves both horizontal and vertical transfers. Central to this model is the realization that horizontally transferred

Fig. 8. **General Model of Analogue Transfer of Agrotechnology**



technology requires a varying amount of site-specific adaptation before it can be of impact at the local farm level.

With the overall success of the University of Puerto Rico project, the BSP has begun to scientifically establish the validity of the soil family and benchmark soils concepts for the transfer of agrotechnology. The UH and the UPR projects have also generated worldwide awareness of and momentum for the BSP and at the same high expectations for putting its underlying concepts into action.

In our judgement the Benchmark Soils Project is thus succeeding in creating the scientific and other background conditions that provide a sound basis for the implementation of a follow-up program of wider scope and geographical extent. The logical culmination of the present efforts should be the establishment of a prototype network of national and international agricultural research centers designed to demonstrate the steady flow of agroproduction technology from research sites to farmer fields in the tropics and subtropics.

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A P P E N D I X

APPENDIX INDEX

PROJECT PERSONNEL

Puerto Rico

Principal Investigator:	Friedrich H. Beinroth	Jan 75 - Dec 81
Senior Agronomist:	Gene L. Spain	Jan 75 - Aug 81
Agronomists:	José Badillo Feliciano*	Jul 75 - Dec 80
	Luis Calduch	Jun 75 - Oct 77
	Stevan P. Nightengale	Jan 77 - Dec 80
Soil Chemists:	Lillian Costa Mayoral	Sep 76 - Jun 81
	Milagros Miró*	Feb 77 - Jun 81
	Carlos Sarmiento	Jul 75 - Dec 78
Soil Scientist:	Juan A. Vega López	Jul 75 - Aug 78
Administrative Aide:	Elsie G. Sánchez	Jan 78 - Dec 81
Secretaries:	Lucy Vélez	Jan 75 - Dec 81
	Ingrid A. Vélez Ramos	Sep 75 - Aug 81
Research Aides:	Rubén García*	Jul 78 - Jun 81
	José A. Robles	Feb 77 - May 80
Consultants:	Jack Keller	Oct 76 - Nov 76
	Larry A. Nelson	Aug 76 - Dec 81

Brazil

EPAMIG Liaison	Derli Prudente Santana**	Jun 76 - Nov 79
	Fernando Zinho Antunes**	Nov 79 - Oct 80
Project Leaders:	Christopher C. Seubert	Apr 76 - Nov 77
	Donald C. L. Kass	Oct 77 - Dec 77
	Mervyn L. Olson	Apr 78 - Dec 81
Agronomists:	Narbal de Sá	Jul 76 - Dec 80
	Umbemar Silveira Dias*	Aug 77 - Aug 78
	Marcos A. C. Torres	Jul 76 - Dec 80
EPAMIG Counterpart:	Antonio M. Coelho**	Apr 78 - Jun 79
Secretary:	Carole Seubert*	Jul 76 - Nov 77
Typist:	Ademar Fernandes dos Anjos	Jul 76 - Dec 80
Field Foreman:	Delcino C. Jorge	Jul 76 - Dec 80
Driver/Mechanic:	Ivandir Pereira Miranda	Jul 78 - Dec 80

* Part-time employment with UPR/BSP
** On EPAMIG payroll

SOIL PROFILE DESCRIPTIONS AND LABORATORY DATA

COTO SERIES -- ISABELA, PUERTO RICO

Classification
Soil Taxonomy: Tropeptic Eutrustox, clayey, kaolinitic, isohyperthermic
FAO-UNESCO Legend: Orthic Ferralsol
French classification system: Sol ferrallitique faiblement désaturé en (B) typique; humique (X/115)
Brazilian classification system: Latosol Vermelho Amarelo Eutrófico; A moderado, textura argilosa
U.S. system of 1938: Yellowish-brown Lateritic soil
Location of sample site
Latitude: 18° 28′ 2″ N
Longitude: 67° 3′ 25″ W
Elevation above sea level: 131 m
General description: NW Puerto Rico; Municipality Isabela, Barrio Guerrero, USGS Quadrangle Moca; Agr. Exp. Substation Isabela; 400 m N of km 115.2 on highway PR 2. Sampled in a pit located 500 m NW of SCS pit S63PR-6-1, see Soil Survey Staff (1967, pp. 174–175). The Coto series is of moderate extent in the NW coastal areas of Puerto Rico.
Sampling date: March 1975
Described and collected by: F.H. Beinroth
Vegetation and land use
Natural vegetation: Tropical moist forest
Land use and crop: Experiment site with citrus, normally used for sugarcane
Climate
Mean annual rainfall: 1700 mm
Mean annual air temperature: 25°C
Thornthwaite type: B/CA′r—subhumid to humid tropical
Parent material and geology
Parent material: Highly weathered clay sediments
Geologic formation: Blanket deposits of Pliocene and Pleistocene age derived mainly from andesitic volcaniclastics; unconformably overlying Miocene limestone
Geomorphology
Slope: 0–3%
Landform: Slightly undulating plain
Geomorphic surface: Depositional surface of mainly Pleistocene age; sediments deposited on a marine degradation terrace of Late Tertiary/Early Pleistocene age; occasional dolines
Drainage: Well drained; moderate permeability; slow runoff
Principal associated soils: Tropeptic Eutrorthox, Typic Palehumults, Lithic Tropudalfs

Horizon	Description
Ap	0 to 13 cm; dark brown (7.5YR 4/4, moist) and brown (7.5YR 5/4, dry) clay; moderate fine granular and very fine subangular blocky structure; slightly sticky, slightly plastic, friable consistence; clear smooth boundary.
A12	13 to 25 cm; strong brown (7.5YR 5/6, moist) and strong brown to reddish yellow (7.5YR 5.5/6, dry) clay; weak to moderate fine and very fine subangular blocky structure; slightly sticky, slighty plastic, friable consistence; few fine hard black nodules; gradual smooth boundary.
B21	25 to 45 cm; strong brown to yellowish red (7.5YR 5/6 to 5YR 5/8, moist) and reddish yellow (7.5YR 6/6, dry) clay; very weak fine and very fine subangular blocky structure; slightly sticky, slightly plastic, friable consistence; very few pressure faces; few reddish brown coatings in root channels; few fine black nodules; abrupt failure; gradual smooth boundary.
B22	45 to 65 cm; yellowish red (5YR 5/6, moist) and reddish yellow (5YR 6/6 to 7.5YR 6/6, dry) clay; structure and consistence as in B21; few pressure faces; few coatings in root channels; few fine black nodules; abrupt failure; gradual smooth boundary.
B23	65 to 90 cm; yellowish red (5YR 5/6, moist) and reddish yellow (7.5YR 6/6, dry) clay, weak to moderate fine and very fine subangular blocky structure; slightly sticky, slightly plastic, friable consistence; few clay films, few coatings in root channels; few fine black nodules; abrupt failure; gradual smooth boundary.
B24	90 to 125+ cm; yellowish red to reddish yellow (5YR 5/6 to 5YR 6/6, moist) and reddish yellow (7.5YR 6/6, dry) clay; moderate fine subangular blocky structure parting to very fine angular blocky and granular aggregates; slightly sticky, slightly plastic, friable consistence; few thin discontinuous clay films; common fine black nodules and streaks; abrupt failure.

Soil name: Coto taxadjunct
Soil no.: S63PR-6-2

Classification: Tropeptic Eutrustox, clayey, kaolinitic, isohyperthermic
Location: Isabela, Puerto Rico

Depth	Horizon	Particle size analysis: Sand 2–.05	Silt .05–.002	Clay <.002	Bulk density	Water content: .1-bar	.3-bar	15-bar	Organic C	Total N	C/N	Extractable iron: Fe	Fe_2O_3
--- cm ---		---- pct < 2 mm ----			--- g/cc ---	---- pct ----			---- pct ----			---- pct ----	
0–13	Ap	22.3	7.0	70.7	1.39		25.0	22.5	2.44	0.252	10	9.6	
13–25	A12	21.8	7.1	71.1	1.44		28.0	22.8	1.69	0.197	9	9.8	
25–45	B21	18.8	5.3	75.9	1.41		31.5	23.7	0.99	0.143	7	10.1	
45–65	B22	14.5	5.9	79.6	1.38		30.6	26.4	0.62	0.127	5	10.6	
65–90	B23	11.4	6.7	81.9	1.32		33.3	26.8	0.46	0.113	4	11.5	
90–125+	B24	13.3	10.5	76.2	1.48		27.3	25.0	0.25			11.2	

Depth	Extractable bases: Ca	Mg	Na	K	Sum	Extractable acid	Cation-exchange capacity: NH_4OAc	Sum	Extractable Al	Base saturation: NH_4OAc	Sum	pH: H_2O	KCl	Difference
--- cm ---	---- meq/100 g soil ----									---- pct ----				
0–13	3.6	0.9	0.1	0.4	5.0	20.4	13.3	25.4	0.6	38	20	4.8	4.1	-0.7
13–25	2.1	0.5	0.1	0.1	2.8	20.0	10.6	22.8	1.4	26	12	4.5	3.9	-0.6
25–45	1.2	0.4	0.1	0.1	1.8	16.4	7.1	18.2	1.6	25	10	4.5	3.9	-0.6
45–65	3.7	0.6	0.1	0.1	4.5	15.6	5.8	20.1	0.9	78	22	4.6	4.1	-0.5
65–90	3.6	0.7	0.1	0.1	4.5	9.7	5.8	14.2		78	32	5.9	5.5	-0.4
90–125+	4.1	0.6	0.1	0.1	4.9	8.5	5.7	13.4		86	37	6.3	5.9	-0.4

Source: Soil Survey Investigation Report No. 12 (Soil Survey Staff, 1967, p. 174)

SOIL PROFILE DESCRIPTIONS AND LABORATORY DATA

JAIBA SERIES -- JAIBA, BRAZIL

Classification
Soil Taxonomy: Tropeptic Eutrustox, clayey, kaolinitic, isohyperthermic
FAO-UNESCO Legend: Rhodic Ferralsol
French classification system: Sol ferrallitique faiblement désaturé en (B) typique; modal (X 111)
Brazilian classification system: Latosol Vermelho Escuro Euiróﬁco; A moderado, textura argilosa
U.S. system of 1938: Reddish-brown Lateritic soil
Location of sample site
Latitude: 15° 23′ S
Longitude: 43° 46′ W
Elevation above sea level: 510 m
General description: SE corner of Distrito Agroindustrial de Jaiba, approximately 10 km W of Jaiba, Minas Gerais, Brazil; on EPAMIG experiment farm
Sampling date: dry season 1976
Described and collected by: D. Prudente Santana and F.H. Beinroth
Vegetation and land use
Natural vegetation: Deciduous dry forest
Land use and crop: Experiment site planted to maize and soybeans; where cleared usually used for cotton, castorbeans, maize, beans, or sugarcane
Climate
Mean annual rainfall: 895 mm
Mean annual air temperature: 24.5°C
Thornthwaite type: C/B′w—subhumid to humid tropical; dry winters
Parent material and geology
Parent material: Highly weathered clayey sediments derived from rocks of Bambuí Group
Geologic formation: Bambuí Group; limestones, shales and some quartzite of Silurian age
Geomorphology
Slope: 0-3%
Landform: Slightly undulating plain
Geomorphic surface: Depositional surface of probably Quarternary age in large graben-like structure
Drainage: Well drained; moderately rapid permeability; slow runoff
Principal associated soils: Typic Eutrustox, Typic and Tropeptic Haplustox, Vertic Ustropepts, Ustoxic Quartzipamments, and Udic Pellusterts
Remarks: Taxonomically, this soil is on the borderline to Typic Eutrustox because of the degree of structure in the oxic horizon.

Horizon	Description
Ap	0 to 10 cm; dark reddish brown (2.5YR 3/4, moist) and reddish brown (2.5YR 5/4, dry) clay; moderate fine and medium granular structure; slightly sticky, slightly plastic, slightly hard consistence; many fine pores, many roots; clear smooth boundary.
A3	10 to 20 cm; dark reddish brown (2.5YR 3/4, moist) and reddish brown (2.5YR 4/4, dry) clay; weak to moderate fine and medium granular and subangular blocky structure; slightly sticky, slightly plastic, slightly hard consistence; many fine pores, many roots, gradual smooth boundary.
B21	20 to 50 cm; dusky red (10R 3/4, moist) and dark red (10R 3/6, dry) clay; weak to moderate medium subangular blocky structure parting to fine and very fine granules; slightly sticky, slightly plastic, soft to slightly hard consistence; abrupt failure; many fine pores, common roots; gradual smooth boundary.
B22	50 to 120 cm; dark red (10R 3/6, moist) clay; weak medium and fine subangular blocky structure parting to fine and very fine granules; slightly sticky, slightly plastic, friable consistence; abrupt failures; many fine pores, few roots; diffuse smooth boundary.
B23	120 to 200+ cm; dark red (10R 3/6, moist) clay; weak medium and fine subangular blocky structure parting to fine and very fine granules; slightly sticky, slightly plastic, friable consistence; abrupt failure; many fine and medium hard nodules; many fine pores, few roots.

Soil name: Jaiba
Soil no.: 76BR-1-1

Classification: Tropeptic Eutrustox, clayey, kaolinitic, isohyperthermic
Location: Distrito Agroindustrial de Jaiba, MG, Brazil; EPAMIG experiment farm, BSP Paraná site

Depth	Horizon	Particle size analysis: Sand 2-.05	Particle size analysis: Slit .05-.002	Particle size analysis: Clay < .002	Bulk density	Water content: .1-bar	Water content: .3-bar	Water content: 15-bar	Organic C	Total N	C/N	Extractable iron: Fe	Extractable iron: Fe_2O_3
----cm----		pct < 2 mm			---g/cc---	pct			pct			pct	
0-10	Ap	20.5	23.1	56.4			31.6	22.2	3.10	0.35	9		
10-20	A3	19.5	17.4	63.1					1.10	0.34	3		
20-50	B21	16.5	25.2	58.3			28.1	20.4	0.55	0.07	8		
50-120	B22	19.6	28.2	52.2					0.35	0.06	6		
120-200+	B23	20.4	26.4	53.2					0.31	0.06	5		

Depth	Extractable bases: Ca	Extractable bases: Mg	Extractable bases: Na	Extractable bases: K	Extractable bases: Sum	Extractable acid	Cation-exchange capacity: NH_4OAc	Cation-exchange capacity: Sum	Extractable Al	Base saturation: NH_4OAc	Base saturation: Sum	pH: H_2O	pH: KCl	pH: Difference
--- cm ---	meq/100 g soil									pct				
0-10	10.3	2.1	0.1	0.34	12.8		18.9		—	68		6.1	5.5	-0.6
10-20	5.9	0.8	0.1	0.07	6.9		10.9		—	63		6.5	5.6	-0.9
20-50	4.5	0.6	0.1	0.05	5.3		9.4		—	56		6.3	5.5	-0.8
50-120	3.5	1.0	0.1	0.05	4.7		7.7		—	61		6.1	5.5	-0.6
120-200+	3.4	0.7	0.1	0.06	4.3		8.0		—	54		5.7	5.4	-0.3

Source: Puerto Rico Benchmark Soils Project

LIST OF FIELD EXPERIMENTS CONDUCTED BY UPR/BSP

I. Experiments conducted at Isabela, Puerto Rico

Exp.	Crop	Type of Experiment	Site	Season	Planted	Harvested
PR-01	Soybean	Uniformity	Primary	Wet	07-24-75	10-20-75
PR-02	Soybean	Transfer[1] (PxK)	Primary	Int.	03-05-76	08-03-76
PR-03	Maize	Transfer (PxK)	Primary	Wet	04-02-76	08-06-76
PR-04	Maize	Variety x P	Primary	Wet	05-14-76	08-30-76
PR-05	Maize	Variety x P	Primary	Wet	07-12-76	11-05-76
PR-06	Soybean	Transfer (PxK)	Secondary 1	Wet	07-30-76	11-29-76
PR-07	Maize	Transfer (PxK)	Secondary 1	Wet	08-02-76	11-16-76
PR-08	Soybean	P x Density x Var.	Primary	Wet	09-05-76	01-03-77
PR-09	Soybean	Transfer (PxK)	Secondary 1	Dry	12-09-76	03-28-77
PR-10	Maize	Transfer (PxK)	Secondary 1	Dry	12-12-76	04-18-77
PR-11	Soybean	Seedbed Preparation	Substation	Dry	12-13-76	05-31-77
PR-12	Soybean	Transfer (PxK)	Primary	Dry	12-21-76	04-14-77
PR-13	Maize	Transfer (PxK)	Primary	Dry	12-22-76	04-26-77
PR-14	Maize	P-placement x levels	Primary	Wet	04-04-77	08-02-77
PR-15	Maize	Water (irrig) x N	Primary	Wet	05-05-77	08-25-77
PR-16	Maize	Transfer (PxK)	Primary	Wet	05-20-77	09-20-77
PR-17	Maize	Transfer (PxK)	Secondary 1	Wet	06-02-77	09-27-77
PR-18	Maize	Variety x P	Primary	Wet	06-17-77	10-04-77
PR-19	Maize	Transfer (PxN)[2]	Primary	Wet	06-23-77	10-17-77
PR-20	Maize	Transfer	Secondary 1	Dry	11-15-77	03-27-78
PR-21	Maize	Transfer	Primary	Dry	12-12-77	04-20-78
PR-22	Maize	Variety	Primary	Dry	12-13-77	04-18-78
PR-23	Maize	Residual transfer	Primary	Dry	01-12-78	05-22-78
PR-24	Maize	Water (irrig) x N	Primary	Dry	01-18-78	05-31-78
PR-25	Soybean	Residual transfer (PxK)	Secondary 1	Dry	02-17-78	07-24-78
PR-26	Maize	Residual transfer	Secondary 1	Wet	04-10-78	08-02-78
PR-27	Maize	Transfer	Primary	Wet	04-25-78	08-08-78
PR-28	Maize	Variety x P x N	Primary	Wet	04-25-78	08-10-78

1/ Unless designated as residual, all transfer experiments listed were initial transfer experiments.

2/ Experiment PR-19 and all maize transfer experiments thereafter were with P and N as variables.

Experiments conducted at Isabela, Puerto Rico (cont'd)

PR-29	Maize	Water (irrig) x N	Primary	Wet	04-26-78	rain damage, abandoned
PR-30	Maize	Transfer	Secondary 1	Wet	05-08-78	08-30-78
PR-31	Maize	Residual transfer	Primary	Wet	05-10-78	08-28-78
PR-32	Maize	Tillage (Min. vs. Plow) x Density	Primary	Wet	05-18-78	09-11-78
PR-33	Maize	Transfer	Secondary 2	Wet	06-08-78	09-26-78
PR-34	Maize	Residual transfer	Primary	Dry	11-17-78	03-21-79
PR-35	Maize	Residual transfer	Secondary 1	Dry	11-17-78	03-19-78
PR-36	Maize	Residual transfer	Secondary 2	Dry	11-21-78	03-27-79
PR-37	Maize	Transfer	Primary	Dry	12-06-78	04-19-79
PR-38	Maize	Transfer	Secondary 1	Dry	12-06-78	04-17-79
PR-39	Maize	Transfer	Secondary 2	Dry	12-12-78	04-24-79
PR-40	Maize	Water (irrig) x N	Secondary 1	Dry	12-14-78	04-30-79
PR-41	Maize	Residual transfer	Secondary 1	Wet	05-02-79	08-27-79
PR-42	Maize	Residual transfer (2nd residual)	Secondary 1	Wet	05-02-79	08-27-79
PR-43	Maize	Residual transfer	Primary	Wet	05-03-79	08-29-79
PR-44	Maize	Transfer	Secondary 1	Wet	05-17-79	09-06-79
PR-45	Maize	Transfer	Primary	Wet	05-18-79	09-07-79
PR-46	Maize	Residual transfer	Secondary 2	Wet	05-25-79	09-11-79
PR-47	Maize	Lime x P	Secondary 2	Wet	05-25-79	09-12-79
PR-48	Maize	Transfer	Secondary 2	Wet	05-30-79	09-10-79
PR-49	Maize	Tillage x population	Primary	Wet	06-04-79	09-13-79
PR-50	Maize	Residual transfer	Primary	Dry	11-14-79	03-19-80
PR-51	Maize	Residual transfer	Secondary 1	Dry	11-14-79	03-24-80
PR-52	Maize	Residual Lime x P	Secondary 2	Dry	11-16-79	03-17-80
PR-53	Maize	Transfer	Primary	Dry	12-01-79	04-07-80
PR-54	Maize	Transfer	Secondary 1	Dry	12-01-79	04-08-80
PR-55	Maize	Transfer	Secondary 2	Dry	12-05-79	03-31-80
PR-56	Maize	Tillage x population	Primary	Dry	12-07-79	04-17-80
PR-57	Maize	Water (irrig) x N	Secondary 1	Dry	12-18-79	05-01-80
PR-58	Maize	Residual Transfer	Primary	Wet	04-22-80	08-11-80
PR-59	Maize	Residual Transfer	Secondary 1	Wet	04-22-80	08-12-80
PR-60	Maize	Residual Transfer	Secondary 2	Wet	04-24-80	08-15-80
PR-61	Maize	Transfer	Secondary 2	Wet	04-25-80	08-19-80
PR-62	Maize	Transfer	Primary	Wet	04-29-80	08-22-80
PR-63	Maize	Transfer	Secondary 1	Wet	04-30-80	08-25-80
PR-64	Maize	P-placement x levels	Primary	Wet	05-08-80	08-28-80

II. Experiments conducted at Jaiba, MG, Brazil

Exp.	Crop	Type of Experiment	Site	Season	Planted	Harvested
B-01	Maize	Transfer[1/] (PxK)	Primary	Wet	10-21-76	03-11-77
B-02	Maize	Variety x P	Primary	Wet	10-26-76	03-15-77
B-03	Maize	Variety x Density	Primary	Wet	10-28-76	03-16-77
B-04	Maize	Variety, Nat'l.	Primary	Wet	10-30-76	03-22-77
B-05	Maize	Variety Annex	Primary	Wet	10-30-76	03-22-77
B-06	Soybean	Transfer (PxK)	Primary	Wet	11-24-76	04-29-77
B-07	Soybean	Variety, INTSOY	Primary	Wet	11-25-76	02-03-77
B-08	Maize	Transfer (PxK)	Primary	Dry	06-07-77	12-15-77
B-09	Maize	Transfer (PxN)[2/]	Primary	Dry	06-08-77	12-16-77
B-10	Maize	Irrigation, EMBRAPA	Primary	Dry	06-11-77	11-23-77
B-11	Sorghum	Irrigation, EMBRAPA	Primary	Dry	06-12-77	10-05-77
B-12	Soybean	Variety, INTSOY	Primary	Dry	06-23-77	10-07-77
B-13	Soybean	Variety x P	Primary	Dry	07-11-77	11-10-77
B-14	Maize	Variety x P	Primary	Dry	07-25-77	01-26-78
B-15	Maize	Density	Primary	Wet	11-06-77	04-17-78
B-16	Soybean	Density	Primary	Wet	11-08-77	03-15-78
B-17	Maize	Variety, Nat'l.	Primary	Wet	11-09-77	04-10-78
B-18	Maize	Variety	Primary	Wet	11-10-77	03 31-78
B-19	Maize	Transfer	Primary	Wet	11-10-77	03-30-78
B-20	Maize	Transfer	Secondary 1	Wet	11-20-77	04-26-78
B-21	Maize	Transfer	Secondary 2	Wet	11-21-77	05-05-78
B-22	Maize	Transfer	Primary	Dry	06-20-78	12-15-78
B-23	Maize	Residual Transfer	Primary	Dry	06-16-78	12-14-78
B-24	Maize	Transfer	Secondary 1	Dry	06-20-78	11-29-78
B-25	Maize	Residual Transfer	Secondary 1	Dry	06-17-78	11-22-78
B-26	Maize	Transfer	Secondary 2	Dry	06-19-78	12-05-78
B-27	Maize	Residual Transfer	Secondary 2	Dry	06-19-78	12-02-78
B-28	Maize	Irrigation, EMBRAPA	Primary	Dry	07-20-78	11-28-78
B-29	Sorghum	Irrigation, EMBRAPA	Primary	Dry	07-20-78	11-28-78
B-30	Soybean	Variety, INTSOY	Primary	Dry	07-27-78	11-30-78

1/ Unless designated as residual, all transfer experiments listed were initial transfer experiments.

2/ Experiment B-09 and all transfer experiments thereafter were with P and N as variables.

Experiments conducted at Jaiba, MG, Brazil (cont'd)

B-31	Multicrop	Intensive Mgmt.	Primary	Dry/Wet	08-18-78	09-18-79
B-32	Maize/Sorghum	Planting Schedule EPAMIG	Primary	Wet	10-15-78	05-21-79
B-33	Maize	Varieties, normal EMBRAPA	Secondary 2	Wet	11-13-78	05-10-79
B-34	Maize	Varieties, precocious EMBRAPA	Secondary 2	Wet	11-13-78	05-14-79
B-35	Soybean	Varieties, IPB	Primary	Wet	01-15-79	05-30-79
B-36	Maize	Transfer	Primary	Wet	01-09-79	06-16-79
B-37	Maize	Residual Transfer	Primary	Wet	01-16-79	07-10-79
B-38	Maize	Transfer	Secondary 1	Wet	01-12-79	06-12-79
B-39	Maize	Residual	Secondary 1	Wet	01-15-79	07-06-79
B-40	Maize	Transfer	Secondary 2	Wet	01-10-79	06-12-79
B-41	Maize	Residual Transfer	Secondary 2	Wet	01-12-79	07-06-79
B-42	Maize	Composite	Primary	Dry	04-11-79	09-20-79
B-43	Maize	Transfer	Primary	Dry	06-06-79	11-22-79
B-44	Maize	Residual Transfer	Primary	Dry	06-28-79	01-03-80
B-45	Maize	Transfer	Secondary 1	Dry	06-09-79	11-21-79
B-46	Maize	Residual Transfer	Secondary 1	Dry	06-28-79	01-03-80
B-47	Maize	Transfer	Secondary 2	Dry	06-08-79	11-20-79
B-48	Maize	Residual Transfer	Secondary 2	Dry	07-04-79	01-03-80
B-49	Maize/Sorghum	Irrig., line-source (EMBRAPA)	Primary	Dry	06-05-79	10-26-79
B-50	Maize	Density x P x Irrig.	Primary	Dry	07-25-79	01-05-80
B-51	Multicrop	Intensive Mgmt.	Primary	Dry/Wet	09-20-79	07-03-80
B-52	Maize	Transfer	Primary	Wet	11-26-79	05-08-80
B-53	Maize	Residual Transfer	Primary	Wet	12-19-79	05-30-80
B-54	Maize	Transfer	Secondary 1	Wet	11-28-79	05-07-80
B-55	Maize	Residual Transfer	Secondary 1	Wet	12-19-79	05-29-80
B-56	Maize	Transfer	Secondary 2	Wet	11-28-79	05-07-80
B-57	Maize	Residual Transfer	Secondary 2	Wet	12-19-79	05-29-80
B-58	Maize	Composite Cycle 1	Primary	Wet	10-30-79	03-12-80
B-59	Maize	Variety, Normal EMBRAPA	Secondary 2	Wet	11-09-79	05-22-80
B-60	Maize	Variety, Precocious EMBRAPA	Secondary 2	Wet	11-09-79	05-23-80
B-61	Soybean	Variety, IPB	Primary	Wet	01-08-80	05-06-80
B-62	Maize	P-placement x levels	Primary	Wet/Dry	02-08-80	06-30-80

Experiments conducted at Jaiba, MG, Brazil (cont'd)

B-63	Maize	Composite, Cycle 2	Primary	Dry	04-02-80	09-04-80
B-64	Maize	Transfer	Primary	Dry	04-26-80	10-14-80
B-65	Maize	Residual Transfer	Primary	Dry	05-17-80	11-05-80
B-66	Maize	Transfer	Secondary 1	Dry	04-26-80	10-14-80
B-67	Maize	Residual Transfer	Secondary 1	Dry	05-23-80	10-27-80
B-68	Maize	Transfer	Secondary 2	Dry	04-26-80	10-15-80
B-69	Maize	Residual Transfer	Secondary 2	Dry	05-23-80	11-05-80
B-70	Maize	Mulching	Primary	Dry	06-29-80	12-17-80
B-71	Multicrop	Intensive Mgmt.	Primary	Dry/Wet	07-11-80	12-24-80
B-72	Maize	Composite, Cycle 3	Primary	Wet	09-19-80	03-02-81

TABLE I. WEATHER VARIABLES COLLECTED FOR EXPERIMENTS CONDUCTED AT JAIBA, BRAZIL AND ISABELA, PUERTO RICO

SITE/SEASON		VARIETY	PLANTING DATES	HARVEST DATE	SOLAR RADIATION (LANGLEYS/DAY)	CUMULATIVE RAINFALL (MM)	TEMPERATURE (°C)		RELATIVE HUMIDITY		WIND RUN (KM/HR)	YIELD(KG/HA)		
							MAX.	MIN.	MAX.	MIN.		PARTIAL CONTROL	MEAN	HIGH
BRAZIL														
309	DRY	CARGILL 111	06/08/77	12/17/77	446	375	31.7	16.3	96	38	2.41	3414	5692	8383
319	WET	CARGILL 111	11/10/77	05/30/78	466	855	30.7	19.0	93	50	1.12	.	3955	6515
320	WET	CARGILL 111	11/20/77	04/26/78	451	.	34.9	22.1	.	.	.	.	5953	7677
321	WET	CARGILL 111	11/20/77	04/26/78	430	.	29.3	17.5	.	.	1.22	.	4031	7298
322	DRY	PIONEER 304C	06/20/78	12/15/78	422	332	31.2	15.0	98	40	2.13	655	4142	7882
323	DRY	PIONEER 304C	06/16/78	12/14/78	421	325	31.2	14.9	98	40	2.12	1533	2818	4712
324	DRY	PIONEER 304C	06/20/78	11/29/78	411	195	32.5	14.4	.	.	.	7097	5963	7251
325	DRY	PIONEER 304C	06/17/78	11/22/78	414	111	32.6	14.1	.	.	.	7659	5667	7960
326	DRY	PIONEER 304C	06/19/78	12/05/78	442	216	33.4	14.3	.	.	3.13	1396	6783	9774
327	DRY	PIONEER 304C	06/19/78	12/02/78	440	213	33.4	14.3	.	.	3.14	2819	4152	7150
336	WET	PIONEER 304C	01/09/79	06/16/79	428	578	29.9	16.4	98	50	1.28	633	4836	7659
337	WET	PIONEER 304C	01/16/79	07/10/79	436	445	29.8	15.4	98	48	1.39	583	1721	5742
338	WET	PIONEER 304C	01/12/79	06/12/79	406	574	30.5	16.4	.	.	.	4062	6604	9281
339	WET	PIONEER 304C	01/15/79	06/06/79	411	510	30.7	16.7	.	.	.	4833	4255	5984
340	WET	PIONEER 304C	01/10/79	06/12/79	430	552	31.4	16.6	.	.	1.44	1510	4047	6672
341	WET	PIONEER 304C	01/12/79	07/06/79	427	501	31.1	15.7	.	.	1.56	1369	3766	6342
343	DRY	PIONEER 304C	06/06/79	11/22/79	454	458	31.0	13.4	99	39	2.28	2354	6932	10886
344	DRY	PIONEER 304C	06/28/79	01/03/80	469	704	31.4	14.9	98	43	2.03	949	3163	6104
345	DRY	PIONEER 304C	06/09/79	11/21/79	412	290	31.9	13.6	.	.	.	4243	7115	10780
346	DRY	PIONEER 304C	06/28/79	01/03/80	429	583	32.4	14.9	.	.	.	2670	3585	5059
347	DRY	PIONEER 304C	06/08/79	11/20/79	449	286	32.3	13.5	.	.	2.38	3899	6690	9492
348	DRY	PIONEER 304C	07/04/79	01/03/80	470	553	32.8	15.1	.	.	2.55	2235	3519	5667
352	WET	PIONEER 304C	11/26/79	05/08/80	461	640	30.6	17.7	82	70	1.10	4094	5766	8616
353	WET	PIONEER 304C	12/19/79	05/30/80	441	595	30.5	17.3	89	63	1.14	3504	5912	9378
354	WET	PIONEER 304C	11/28/79	05/07/80	412	626	32.2	17.5	.	.	.	4372	5795	9140
355	WET	PIONEER 304C	12/19/79	05/29/80	386	607	32.0	17.1	.	.	.	3811	6047	8952
356	WET	PIONEER 304C	11/28/79	05/07/80	484	611	32.3	17.5	.	.	1.36	3418	5049	8645
357	WET	PIONEER 304C	12/19/79	05/29/80	462	597	32.1	17.1	.	.	1.35	5023	6069	8440
364	DRY	PIONEER 304C	04/26/80	10/14/80	400	39	31.2	13.0	99	38	2.12	1606	4895	7744
365	DRY	PIONEER 304C	05/17/80	11/05/80	404	40	31.4	13.2	99	36	2.31	3075	3192	5087
366	DRY	PIONEER 304C	04/26/80	10/14/80	383	53	32.7	13.0	.	.	.	5994	6234	8559
367	DRY	PIONEER 304C	05/17/80	10/27/80	380	56	33.0	12.9	.	.	.	2525	4194	5938
368	DRY	PIONEER 304C	04/26/80	10/15/80	447	71	32.9	12.6	.	.	2.30	3897	6140	8506
369	DRY	PIONEER 304C	05/17/80	11/05/80	465	72	33.5	12.8	.	.	2.45	2775	4405	6199
PUERTO RICO														
PR19	WET	PIONEER 305B	06/23/77	10/17/77	462	513	30.0	21.2	81	59	5.52	3755	4783	6452
PR20	DRY	PIONEER 304C	11/15/77	03/27/78	353	438	28.1	18.5	79	55	5.08	5646	6415	8681
PR21	DRY	PIONEER 304C	12/12/77	04/20/78	360	469	27.9	18.5	79	55	5.55	7369	8330	9533
PR23	DRY	PIONEER 304C	01/12/78	05/22/78	409	672	28.1	18.7	79	56	5.46	1571	3742	7444
PR27	WET	PIONEER 304C	04/25/78	08/03/78	483	654	29.7	20.7	77	61	4.89	3559	4956	6896
PR30	WET	PIONEER 304C	05/08/78	08/30/78	484	718	29.8	21.0	75	62	5.25	6240	7290	8888
PR31	WET	PIONEER 304C	05/10/78	08/28/78	483	580	29.8	21.0	75	62	5.25	1599	4897	7446
PR33	WET	PIONEER 304C	06/08/78	09/26/78	463	680	30.0	21.2	75	60	4.73	3515	4575	7738
PR34	DRY	PIONEER 304C	11/17/78	03/21/79	379	221	28.0	18.5	77	56	6.08	813	4473	7398
PR35	DRY	PIONEER 304C	11/17/78	03/19/79	379	220	28.0	18.5	77	56	5.97	3040	5471	7978
PR36	DRY	PIONEER 304C	11/21/78	03/27/79	360	276	27.9	18.4	77	56	6.01	2074	1952	4269
PR37	DRY	PIONEER 304C	12/06/78	04/19/79	400	246	27.8	18.4	77	56	6.66	4931	6319	8608
PR38	DRY	PIONEER 304C	12/06/78	04/17/79	393	246	27.8	18.4	77	56	6.71	6985	7479	8644
PR39	DRY	PIONEER 304C	12/12/78	04/24/79	398	431	27.8	18.4	78	56	6.57	4286	3232	5702
PR41	WET	PIONEER 304C	05/02/79	08/27/79	443	645	29.5	21.1	83	56	4.96	2805	6597	8914
PR42	WET	PIONEER 304C	05/02/79	08/29/79	444	646	29.5	21.1	83	55	4.93	1578	5555	10002
PR43	WET	PIONEER 304C	05/03/79	08/29/79	444	645	29.5	21.1	83	55	4.93	2099	5518	9038
PR44	WET	PIONEER 304C	05/17/79	09/06/79	431	599	29.5	21.2	84	57	5.12	4218	6455	9930
PR45	WET	PIONEER 304C	05/18/79	09/07/79	426	602	29.5	21.2	84	58	5.17	5549	6452	8057
PR46	WET	PIONEER 304C	05/25/79	09/11/79	428	501	29.5	21.3	84	57	5.28	3469	4312	7035
PR48	WET	PIONEER 304C	05/30/79	09/10/79	424	498	29.5	21.3	84	57	5.33	4252	4895	8035
PR50	DRY	PIONEER 304C	11/14/79	03/19/80	372	365	27.4	18.3	90	56	4.91	3769	5439	8441
PR51	DRY	PIONEER 304C	11/14/79	03/24/80	380	366	27.4	18.3	90	56	4.95	4699	7207	9053
PR53	DRY	PIONEER 304C	12/01/79	03/07/80	371	200	27.2	18.1	90	55	4.74	4136	6340	8354
PR54	DRY	PIONEER 304C	12/01/79	04/09/80	405	210	27.5	18.2	90	54	5.12	5333	7373	9469
PR55	DRY	PIONEER 304C	12/05/79	03/31/80	395	251	27.4	18.1	90	55	5.11	5195	6262	8018
PR58	WET	PIONEER 304C	04/22/80	08/11/80	454	663	30.3	21.0	85	57	3.32	1649	5173	8348
PR59	WET	PIONEER 304C	04/22/80	08/12/80	454	663	30.3	20.9	86	57	3.32	2582	5758	10023
PR60	WET	PIONEER 304C	04/24/80	08/15/80	455	667	30.3	20.9	86	57	3.36	2705	5155	8106
PR61	WET	PIONEER 304C	04/25/80	08/19/80	457	711	30.3	21.0	86	57	3.38	4477	6112	10494
PR62	WET	PIONEER 304C	04/29/80	08/22/80	462	655	30.5	21.0	86	57	3.34	6164	7195	8690
PR63	WET	PIONEER 304C	04/30/80	08/25/80	462	670	30.5	21.0	85	56	3.33	4903	6629	8354

VALUES ARE MEANS FOR THE PERIOD FROM PLANTING TO HARVEST

Table 2a. Maize yields and fertilizer treatments (kg/ha) for P x N transfer experiments conducted at Jaiba, Brazil, from 1977 to 1980

LINE NO.	SITE[2] EXPT.NO.	SEASON[3] YEAR	VARIETY	OPTIMUM P, -0.85 N TREATMENT P	N	YIELD/REP 1	2	3	4	OPTIMUM P, +0.85 N TREATMENT P	N	YIELD/REP 1	2	3	4
1	B-09	D 77	CARGILL 111	50	26	6910	4459	5470		50	26	6497	6400	6239	
2	B-19	W 77	CARGILL 111	15	14	3468	4552	4083	2604	19	166	4806	5416	4392	3623
3	B-20	W 77	CARGILL 111	10	14	6674	5903	6449	5262	10	166	7012	4918	6102	5719
4	B-21	W 77	CARGILL 111	31	14	5390	5957	3666	3449	31	166	4502	4910	3282	5857
5	B-22	D 78	PIONEER 304C	14	14	4183	4615	4667		14	166	4135	4686	3643	
6	B-23	D 78	PIONEER 304C	.	14	2648	3088	3391		.	166	2850	2664	3266	
7	B-24	D 78	PIONEER 304C	4	14	6246	6263	6625		4	166	4962	6139	6874	
8	B-25	D 78	PIONEER 304C	.	14	5254	5554	4437		.	166	5663	5321	6712	
9	B-26	D 78	PIONEER 304C	29	14	7999	6686	7013		29	166	7186	7072	7237	
10	B-27	D 78	PIONEER 304C	.	14	5684	2682	3204		.	166	5659	3045	4655	
11	B-36	W 79	PIONEER 304C	29	14	2183	6034	5743		29	166	6205	5781	5449	
12	B-37	W 79	PIONEER 304C	.	14	1424	1190	2502		.	166	1715	1896	885	
13	B-38	W 79	PIONEER 304C	14	14	6140	7113	6923		14	166	6360	6727	6865	
14	B-39	W 79	PIONEER 304C	.	14	3912	5506	4786		.	166	1912	2611	4574	
15	B-40	W 79	PIONEER 304C	29	14	2606	2032	3068		29	166	4380	4943	5962	
16	B-41	W 79	PIONEER 304C	.	14	5097	3430	3954		.	166	2182	2668	3739	
17	B-43	D 79	PIONEER 304C	29	14	8046	8242	8392		29	166	6931	6893	9122	
18	B-44	D 79	PIONEER 304C	.	14	4276	1106	3302		.	166	2559	3933	2416	
19	B-45	D 79	PIONEER 304C	14	14	6165	7586	9217		14	166	6468	7369	9403	
20	B-46	D 79	PIONEER 304C	.	14	4675	4246	3501		.	166	3623	3948	3616	
21	B-47	D 79	PIONEER 304C	29	14	7246	7450	8552		29	166	7564	7488	7014	
22	B-48	D 80	PIONEER 304C	.	14	2606	2264	2610		.	166	2243	4649	5667	
23	B-52	W 80	PIONEER 304C	14	29	6611	5761	7735		14	186	7193	4726	6384	
24	B-53	W 80	PIONEER 304C	.	29	7229	5232	7810		.	186	5827	5397	8224	
25	B-54	W 80	PIONEER 304C	11	29	6591	5848	7050		11	186	7925	7687	9140	
26	B-55	W 80	PIONEER 304C	.	29	5987	6696	6417		.	186	5385	5836	6846	
27	B-56	W 80	PIONEER 304C	21	29	6105	6233	5663		21	166	7456	6740	6282	
28	B-57	W 80	PIONEER 304C	.	29	5070	5336	5535		.	186	6411	6526	7018	
29	B-64	D 80	PIONEER 304C	13	29	4962	4220	4970		13	186	5058	5639	5206	
30	B-65	D 80	PIONEER 304C	.	29	4127	2673	5087		.	186	3790	2896	3650	
31	B-66	D 80	PIONEER 304C	11	29	6488	7348	8559		11	186	5102	7618	6357	
32	B-67	D 80	PIONEER 304C	.	29	3536	2785	3546		.	186	4665	4620	5184	
33	B-68	D 80	PIONEER 304C	12	29	6829	4802	4114		12	186	6277	5864	5908	
34	B-69	D 80	PIONEER 304C	.	29	4386	4838	3712		.	186	5312	4926	4112	

[1] YIELDS ADJUSTED TO 15.5% MOISTURE AND EXPRESSED IN KG/HA

[2] SITE ABBREVIATIONS REFER TO EXPERIMENT NUMBER IN BRAZIL

[3] D = DRY SEASON; W = WET SEASON

SYMBOL:
. = NO ADDITIONAL P APPLIED SINCE THIS WAS A RESIDUAL TRANSFER

Table 2a (continued)

OPTIMUM P, OPTIMUM N[1]

LINE NO.	SITE[2] EXPT.NO.	SEASON[3] YEAR	VARIETY	TREATMENT P	TREATMENT N	YIELD/REP 1	YIELD/REP 2	YIELD/REP 3	YIELD/REP 4
1	B-09	D 77	CARGILL 111	50	234	4761	5259	7244	
2	B-19	W 77	CARGILL 111	19	90	4732	4348	4777	4755
3	B-20	W 77	CARGILL 111	10	90	5694	5566	5385	5428
4	B-21	W 77	CARGILL 111	31	90	4007	6680	4255	4165
5	B-22	D 78	PIONEER 304C	14	90	4165	4105	4243	
6	B-23	D 78	PIONEER 304C	.	90	3176	2416	3035	
7	B-24	D 78	PIONEER 304C	4	90	5532	5218	6559	
8	B-25	D 78	PIONEER 304C	.	90	4537	5430	6629	
9	B-26	D 78	PIONEER 304C	29	90	8544	8332	7340	
10	B-27	D 78	PIONEER 304C	.	90	5928	2808	4379	
11	B-36	W 79	PIONEER 304C	29	90	5722	5527	5274	
12	B-37	W 79	PIONEER 304C	.	90	820	1116	1443	
13	B-38	W 79	PIONEER 304C	14	90	7210	7750	7821	
14	B-39	W 79	PIONEER 304C	.	90	3587	5272	5480	
15	B-40	W 79	PIONEER 304C	29	90	5977	4667	6095	
16	B-41	W 79	PIONEER 304C	.	90	5663	3440	4150	
17	B-43	D 79	PIONEER 304C	29	90	6884	6646	6778	
18	B-44	D 79	PIONEER 304C	.	90	5332	3220	2337	
19	B-45	D 79	PIONEER 304C	14	90	6120	6046	9153	
20	B-46	D 79	PIONEER 304C	.	90	3184	3752	4348	
21	B-47	D 79	PIONEER 304C	29	90	7688	6404	7982	
22	B-48	D 80	PIONEER 304C	.	90	2446	3757	3222	
23	B-52	W 80	PIONEER 304C	14	108	6034	6823	6225	
24	B-53	W 80	PIONEER 304C	.	108	5682	7089	4002	
25	B-54	W 80	PIONEER 304C	11	108	5884	7124	7619	
26	B-55	W 80	PIONEER 304C	.	108	5442	5025	7254	
27	B-56	W 80	PIONEER 304C	21	108	6328	6952	5529	
28	B-57	W 80	PIONEER 304C	.	108	7585	4391	7211	
29	B-64	D 80	PIONEER 304C	13	108	5390	5208	5042	
30	B-65	D 80	PIONEER 304C	.	108	3650	2607	3030	
31	B-66	D 80	PIONEER 304C	11	108	5740	7658	6837	
32	B-67	D 80	PIONEER 304C	.	108	4398	5059	5117	
33	B-68	D 80	PIONEER 304C	12	108	7186	6374	6876	
34	B-69	D 80	PIONEER 304C	.	108	4098	4530	5340	

OPTIMUM N, -0.85 P

LINE NO.	TREATMENT P	TREATMENT N	YIELD/REP 1	YIELD/REP 2	YIELD/REP 3	YIELD/REP 4
1	12	130	4725	5195	4303	
2	3	90	1964	2351	2099	2146
3	2	90	6237	6478	4817	4337
4	5	90	2562	2156	1356	2253
5	2	90	1214	1069	960	
6	.	90	1371	1120	2652	
7	1	90	5560	4769	6205	
8	.	90	6269	5910	4462	
9	4	90	3689	3263	4083	
10	.	90	2035	1145	2408	
11	4	90	2189	1942	1754	
12	.	90	956	872	371	
13	2	90	4244	3560	8210	
14	.	90	4853	2877	5573	
15	4	90	4095	1231	1289	
16	.	90	1457	2106	3070	
17	4	90	3400	2249	5467	
18	.	90	1257	858	1222	
19	2	90	4539	5341	7166	
20	.	90	2928	2278	4701	
21	4	90	3351	4958	4134	
22	.	90	5208	1718	2836	
23	2	108	2650	3175	2556	
24	.	108	3939	2516	5399	
25	2	108	7259	5039	6560	
26	.	108	5485	4772	6446	
27	3	108	4156	3593	4148	
28	.	108	3666	5841	4172	
29	2	108	2674	2459	1855	
30	.	108	2340	2323	1728	
31	2	108	6004	4864	3484	
32	.	108	5414	3632	3840	
33	2	108	7734	5742	3288	
34	.	108	4068	2708	2243	

OPTIMUM N, +0.85 P

LINE NO.	TREATMENT P	TREATMENT N	YIELD/REP 1	YIELD/REP 2	YIELD/REP 3	YIELD/REP 4
1	75	130	7013	7440	5971	
2	36	90	6213	6258	4784	4785
3	19	90	6718	6153	5070	6438
4	57	90	4361	4970	3697	7298
5	27	90	6068	7236	5862	
6	.	90	4351	3768	3652	
7	8	90	6573	5781	7045	
8	.	90	6047	5598	5280	
9	53	90	7488	9393	8428	
10	.	90	4973	4595	6392	
11	53	90	6810	6819	5235	
12	.	90	2315	3067	2893	
13	27	90	7759	7623	8129	
14	.	90	4308	2322	5080	
15	53	90	4796	4776	4275	
16	.	90	5196	6342	4956	
17	53	90	7563	10886	8310	
18	.	90	5651	5575	3752	
19	27	90	7737	8221	9702	
20	.	90	4270	5059	4023	
21	53	90	7539	6680	8734	
22	.	108	4299	5408	1538	
23	27	108	6716	5688	8616	
24	.	108	7009	9378	6488	
25	20	108	7658	7797	7419	
26	.	108	6127	6527	8235	
27	39	108	8645	6937	6734	
28	.	108	6663	7276	7130	
29	25	108	6694	7506	6442	
30	.	108	4309	2788	507	
31	20	108	6958	7591	6817	
32	.	108	4712	4840	4715	
33	22	108	8506	8166	7069	
34	.	108	6199	6026	5305	

[1] YIELDS ADJUSTED TO 15.5% MOISTURE AND EXPRESSED IN KG/HA

[2] SITE ABBREVIATIONS REFER TO EXPERIMENT NUMBER IN BRAZIL

[3] D = DRY SEASON; W = WET SEASON

SYMBOL:
. = NO ADDITIONAL P APPLIED SINCE THIS WAS A RESIDUAL TRANSFER

Table 2b. Maize yields and fertilizer treatments (kg/ha) for P x N transfer experiments conducted at Isabela, Puerto Rico, from 1977 to 1980

LINE NO.	SITE[2] EXPT.NO.	SEASON[3] YEAR	VARIETY	OPTIMUM P, -0.85 N TREATMENT P	N	YIELD/REP[1] 1	2	3	OPTIMUM P, +0.85 N TREATMENT P	N	YIELD/REP 1	2	3
1	PR-19	W 77	PIONEER 306B	92	20	4115	4854	3742	92	240	3368	6051	5118
2	PR-20	D 77	PIONEER 304C	22	14	5355	6260	7781	22	166	6888	7814	5669
3	PR-21	D 77	PIONEER 304C	17	14	6817	7274	8549	17	166	9097	8558	9360
4	PR-23	D 78	PIONEER 304C	_	_	2694	2303	2135	_	_	4941	6288	3572
5	PR-27	W 78	PIONEER 304C	31	14	5177	2963	3415	31	166	5738	5036	5689
6	PR-30	W 78	PIONEER 304C	12	14	7515	6249	5372	12	166	8434	8790	8285
7	PR-31	W 78	PIONEER 304C	•	14	2040	2527	2530	•	166	6753	7195	6781
8	PR-33	W 78	PIONEER 304C	23	14	3594	2929	4047	23	166	3943	4412	3589
9	PR-34	D 79	PIONEER 304C	•	14	1842	808	690	•	166	6454	7108	5662
10	PR-35	D 79	PIONEER 304C	•	14	3338	2246	2313	•	166	6841	6194	6482
11	PR-36	D 79	PIONEER 304C	•	14	937	525	1993	•	166	1867	2857	471
12	PR-37	D 79	PIONEER 304C	23	14	5353	4250	5584	23	166	7849	7292	7894
13	PR-38	D 79	PIONEER 304C	18	14	8396	7565	6326	18	166	7894	7828	7219
14	PR-39	D 79	PIONEER 304C	18	14	5374	3588	3783	18	166	2206	3179	1753
15	PR-41	W 79	PIONEER 304C	•	14	3466	4661	3419	•	166	8562	8719	7997
16	PR-42	W 79	PIONEER 304C	•	14	2482	1307	1681	•	166	9341	10002	8621
17	PR-43	W 79	PIONEER 304C	•	14	3206	1151	1324	•	166	8649	7731	6499
18	PR-44	W 79	PIONEER 304C	23	14	6964	5049	4639	23	166	4437	7989	7229
19	PR-45	W 79	PIONEER 304C	45	14	6036	4374	6747	45	166	7506	6321	6084
20	PR-46	W 79	PIONEER 304C	•	14	4812	4339	2706	•	166	5854	4647	3071
21	PR-48	W 79	PIONEER 304C	21	14	4314	5114	5655	21	166	4789	5485	4641
22	PR-50	D 80	PIONEER 304C	•	29	4970	4147	4942	•	186	6305	5703	5068
23	PR-51	D 80	PIONEER 304C	•	29	5580	4966	4674	•	186	8608	8626	7453
24	PR-53	D 80	PIONEER 304C	52	29	4729	4769	3743	52	186	7459	7272	7110
25	PR-54	D 80	PIONEER 304C	31	29	5481	6525	6737	31	186	9055	8411	7246
26	PR-55	D 80	PIONEER 304C	26	29	4249	4154	5342	26	186	6707	7522	6405
27	PR-58	W 80	PIONEER 304C	•	29	2561	2936	1307	•	186	7200	6433	6996
28	PR-59	W 80	PIONEER 304C	•	29	2557	5072	5488	•	186	9988	8993	8182
29	PR-60	W 80	PIONEER 304C	•	29	2603	2645	3792	•	186	5522	5161	4499
30	PR-61	W 80	PIONEER 304C	28	29	5928	4713	4919	28	186	5965	4663	4851
31	PR-62	W 80	PIONEER 304C	42	29	6348	6898	6551	42	186	7035	8403	7007
32	PR-63	W 80	PIONEER 304C	32	29	6112	6812	6468	32	186	7030	5179	6789

[1] YIELDS ADJUSTED TO 15.5% MOISTURE AND EXPRESSED IN KG/HA

[2] SITE ABBREVIATIONS REFER TO EXPERIMENT NUMBER IN PUERTO RICO

[3] D = DRY SEASON; W = WET SEASON

SYMBOLS:
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• = NO ADDITIONAL P APPLIED SINCE THIS WAS A RESIDUAL TRANSFER

Table 2b (continued)

LINE NO.	SITE[2] EXPT.NO.	SEASON[3] YEAR	VARIETY	OPTIMUM P, OPTIMUM N. TREATMENT P	N	YIELD/REP 1	2	3	OPTIMUM N, -0.85 P TREATMENT P	N	YIELD/REP 1	2	3	OPTIMUM N, +0.85 P TREATMENT P	N	YIELD/REP 1	2	3
1	PR-19	W 77	PIONEER 3068	92	130	5413	5440	4245	13	130	4194	4127	5929	127	130	4992	4031	4517
2	PR-20	D 77	PIONEER 304C	22	90	6021	6463	8061	3	90	5501	6545	5661	41	90	6176	7899	6799
3	PR-21	D 77	PIONEER 304C	17	90	8640	7737	5414	2	90	6923	7472	7781	32	90	9533	9234	9407
4	PR-23	D 78	PIONEER 304C	_	_	3475	2805	2236	_	_	3614	2519	3799	_	_	4706	7173	2327
5	PR-27	W 78	PIONEER 304C	31	90	6090	6896	5798	5	90	5387	4183	6619	57	90	5586	5268	5637
6	PR-30	W 78	PIONEER 304C	12	90	7024	6924	6960	2	1	7567	6565	8049	23	90	6957	7055	7488
7	PR-31	W 78	PIONEER 304C	•	90	5480	4115	6371	•	90	6188	5701	5484	•	90	5106	4983	5453
8	PR-33	W 78	PIONEER 304C	23	90	5419	4723	6169	4	90	4366	4720	4791	42	90	6578	4728	3960
9	PR-34	D 79	PIONEER 304C	•	90	5831	4701	4226	•	90	3856	6053	4462	•	90	5090	4272	3927
10	PR-35	D 79	PIONEER 304C	•	90	5861	6626	4812	•	90	5763	5309	5831	•	90	5735	4316	3993
11	PR-36	D 79	PIONEER 304C	•	90	1868	2210	3594	•	90	1484	4269	2510	•	90	763	963	1740
12	PR-37	D 79	PIONEER 304C	23	90	7600	7187	5982	4	90	7501	•	6588	43	90	7706	6565	5079
13	PR-38	D 79	PIONEER 304C	18	90	7748	6050	8546	3	90	8417	5612	7301	33	90	7356	7727	7838
14	PR-39	D 79	PIONEER 304C	18	90	1958	3508	1078	3	90	5275	2208	3249	33	90	4140	2479	2080
15	PR-41	W 79	PIONEER 304C	•	90	6698	7577	8220	•	90	8142	4216	7628	•	90	5349	7551	8488
16	PR-42	W 79	PIONEER 304C	•	90	5616	3685	4135	•	90	6135	5340	7004	•	90	4700	5111	9327
17	PR-43	W 79	PIONEER 304C	•	90	8257	6065	4331	•	90	6569	6751	6795	•	90	7274	5580	6240
18	PR-44	W 79	PIONEER 304C	23	90	5341	7502	5080	3	90	5359	6993	6217	42	90	4006	5581	7303
19	PR-45	W 79	PIONEER 304C	45	90	7301	7436	4414	7	90	6881	6403	6615	83	90	7469	7738	5778
20	PR-46	W 79	PIONEER 304C	•	90	4430	4652	2027	•	90	6861	3200	4412	•	90	5975	3239	2831
21	PR-48	W 79	PIONEER 304C	21	90	4651	6486	3805	3	90	5170	2408	5351	40	90	5911	6879	4483
22	PR-50	D 80	PIONEER 304C	•	108	7862	5563	4081	•	108	4670	5321	5066	•	108	6586	5062	6506
23	PR-51	D 80	PIONEER 304C	•	108	6985	6467	7358	•	108	7869	7540	6706	•	108	9053	7507	7381
24	PR-53	D 80	PIONEER 304C	52	108	6387	4957	7461	8	108	6590	6591	7563	95	108	6592	4963	7911
25	PR-54	D 80	PIONEER 304C	31	108	3122	7116	6257	5	108	6654	8451	6385	58	108	6809	8505	6812
26	PR-55	D 80	PIONEER 304C	26	108	6397	5704	6833	4	108	6110	6882	7298	48	108	5669	6703	6875
27	PR-58	W 80	PIONEER 304C	•	108	6439	4584	6189	•	108	5334	5236	5549	•	108	6528	4954	5569
28	PR-59	W 80	PIONEER 304C	•	108	7223	6562	6076	•	108	6903	7685	5266	•	108	8027	7349	6570
29	PR-60	W 80	PIONEER 304C	•	108	5905	4453	6194	•	108	6706	4963	6111	•	108	6160	5941	4931
30	PR-61	W 80	PIONEER 304C	28	108	7701	5744	7155	4	108	6695	6698	5321	52	108	9002	5162	6650
31	PR-62	W 80	PIONEER 304C	42	108	7029	7195	7026	6	108	6569	6962	7115	78	108	7108	6475	6997
32	PR-63	W 80	PIONEER 304C	32	108	7215	6710	6791	5	108	6603	7114	7448	59	108	7612	6966	5771

1 YIELDS ADJUSTED TO 15.5% MOISTURE AND EXPRESSED IN KG/HA

2 SITE ABBREVIATIONS REFER TO EXPERIMENT NUMBER IN PUERTO RICO

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SYMBOLS:
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Table 3a. Treatment means of maize yields by experiment for the Jaiba, Brazil, sites

CODED P	-.85	-.85	+.85	+.85	-.40	-.40	+.40	+.40	0	-.85	+.85	0	0	PART.	0	---	
LEVEL N	-.85	+.85	-.85	+.85	-.40	+.40	-.40	+.40	0	0	0	-.85	+.85	CONT.•	---	0	GEN. MEAN
SITE	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8	T-9	T-10	T-11	T-12	T-13	T-15	T-16	T-17	T 1-13
B- 9	3745	4034	6345	7323	5274	5586	5817	6574	5755	4741	6808	5613	6379	3514	5577	4345	5692
B- 19	2439	2591	5478	5328	3131	3043	4517	4352	4653	2140	5510	3677	4559	•	5574	2059	3955
B- 20	5165	5352	6760	6522	6142	5837	6067	6517	5518	5467	6095	6072	5938	•	6311	4981	5958
B- 21	2938	2261	4965	5135	3275	3684	4549	4402	4777	2082	5082	4616	4638	•	5190	2191	4031
B- 22	1455	1585	6229	6451	3130	2803	5813	6029	4171	1081	6389	4555	4155	655	7267	853	4142
B- 23	1639	1647	4467	4087	2089	1863	3230	3134	2876	1714	3924	3042	2927	1533	5061	1968	2819
B- 24	5655	6035	6187	6636	4745	5684	6124	6402	5770	5511	6466	6378	5992	7097	8331	6523	5968
B- 25	5043	5507	5800	6968	5283	5845	5426	6094	5532	5547	5642	5082	5899	7659	7683	5871	5667
B- 26	4337	4144	7849	8453	6467	6327	7543	7713	8072	3952	8436	7233	7155	1396	8805	3049	6783
B- 27	3158	2662	5562	5620	3991	3061	4853	4874	4705	1863	5320	3857	4453	2819	6641	3141	4152
B- 36	1665	2683	6302	6815	4454	4106	6353	6266	5508	1962	6288	4653	5812	633	5122	810	4836
B- 37	595	1071	2553	2325	1341	1234	2273	3161	1126	733	2758	1705	1499	583	2148	562	1721
B- 38	5318	4131	7607	8239	5638	6502	6655	7410	7594	5338	7837	6725	6657	4062	7753	4544	6604
B- 39	4737	4908	4232	4727	2922	4207	4281	4420	4780	4434	3903	4735	3032	4833	4856-	3817	4255
B- 40	2369	3931	4446	5094	2831	4264	4795	4811	5586	2205	4016	2569	5095	1510	4840	4357	4047
B- 41	2847	2511	5705	4883	2937	3136	4370	3426	4418	2211	5498	4157	2863	1369	4856	2500	3760
B- 43	3819	3578	8112	6656	5670	5905	9192	9187	7503	3705	8920	8227	7649	2354	6233	2185	6932
B- 44	1107	1663	5250	4692	2368	2082	5054	3906	2963	1112	5059	2895	2969	949	3393	1262	3163
B- 45	4492	5207	8357	6181	7376	7420	7134	7583	7106	5682	8553	7663	7740	4243	6446	3675	7115
B- 46	3039	2299	4454	4122	3193	3161	3797	4456	3775	3302	4451	4141	3729	2670	4273	2354	3686
B- 47	3357	5533	8278	8891	5411	5916	7516	7794	7358	4161	7651	7749	7355	3899	7172	4838	6690
B- 48	2148	3659	3218	4363	3191	3927	4203	4203	3142	3271	3748	2493	4186	2255	3641	3874	3519
B- 52	3188	4525	7078	7039	5118	6104	6002	6942	6361	2794	7007	6702	6101	4094	5327	2868	5766
B- 53	3839	4807	6473	7078	4017	5705	6804	7701	5618	3951	7625	6757	6483	3034	4148	3545	5912
B- 54	5814	6018	7197	7680	5753	5929	7597	6830	6876	6286	7625	6496	8251	4372	6175	6578	6796
B- 55	3997	5475	6921	5995	6269	6186	6020	6924	5907	5568	6963	6367	6022	3811	5388	5324	6047
B- 56	4534	4203	6884	7975	5644	6222	6045	6635	6270	3966	7439	6000	6826	3418	5504	4513	6049
B- 57	3268	6211	7568	7296	4889	5850	7168	6636	6396	4560	7090	5314	6052	5023	5650	5152	6069
B- 64	1719	2792	6590	6912	3909	4216	6656	6396	5213	2329	6881	4717	5301	1606	5205	1446	4895
B- 65	2254	3120	4209	3700	2670	3342	2964	3737	3429	2130	2535	3962	3445	3075	2841	2173	3192
B- 66	4937	3856	7837	7469	4836	6065	7272	6296	6745	4784	7122	7465	6359	5994	5915	4136	6234
B- 67	3398	3601	4883	4265	3141	3792	4674	4683	4858	4295	4756	3289	4823	2525	3745	4396	4194
B- 68	4120	4485	7367	7647	5949	5200	6485	6991	6812	5588	7914	5248	6016	3897	6135	4391	6140
B- 69	3214	3975	5831	5111	3150	3844	4683	4852	4656	3006	5843	4312	4783	2775	3899	3935	4405

•No partial control (Treatment 15)

Table 3b. Treatment means of maize yields by experiment for the Isabela, Puerto Rico, sites

CODED LEVEL SITE																	
P	-.85	-.85	+.85	+.85	-.40	-.40	+.40	+.40	0	-.85	+.85	0	0	PART.	0	---	
N	-.85	+.85	-.85	+.85	-.40	+.40	-.40	+.40	0	0	0	-.85	+.85	CONT.	---	0	GEN. MEAN
	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8	T-9	T-10	T-11	T-12	T-13	T-15	T-16	T-17	T 1-13
PR-19	5120	5235	4395	4810	4656	4616	5607	4357	5033	4750	4513	4237	4846	37[illegible]5	3883	4478	4783
PR-20	4033	6043	6252	7536	6360	6398	6456	7140	7055	5902	6958	6465	6790	5646	5694	6153	6415
PR-21	7976	8409	7499	9122	8290	8471	7982	8611	8597	7392	9391	7547	9005	7369	7285	7677	8330
PR-23	2753	4572	4129	5158	3539	3063	3888	3344	2839	3311	4735	2377	4934	1571	1860	5673	3742
PR-27	4055	4327	3637	5550	4352	5427	4445	6141	6261	5396	5497	3852	5488	3559	3731	4813	4956
PR-30	6793	7874	6925	7905	7025	7746	6492	7590	6976	7394	7167	6379	8503	6240	5810	7707	7290
PR-31	2215	6198	2303	6827	4431	5768	4806	5544	5322	5791	5181	2366	6910	1599	1850	4837	4897
PR-33	3701	4885	4667	4587	4405	4993	5177	4405	5437	4626	5089	3523	3981	3515	3148	4546	4575
PR-34	972	6045	2481	6598	4288	67:7	3933	5439	4919	4790	4430	1133	6408	813	1401	5152	4473
PR-35	4424	7274	4247	6662	5603	6134	4302	6588	5766	5634	5348	2632	6506	3040	1659	6351	5471
PR-36	1244	2607	1735	2214	2113	2016	2139	1959	2557	2754	1155	1152	1732	2074	1264	2008	1952
PR-37	4900	5984	4841	7462	6694	7222	4977	6629	5923	7045	6450	5062	7678	4931	4916	5876	6319
PR-38	7617	7577	7387	7556	7489	7946	6329	7383	8115	7110	7640	7429	7647	6986	6265	8342	7479
PR-39	3250	3269	3599	3077	3035	3687	2724	4084	2181	3577	2900	4248	2379	4286	3217	3815	3232
PR-41	4660	7671	5664	8519	6598	7763	4434	6892	7493	6662	7129	3849	8426	2805	2602	6958	6597
PR-42	3173	8232	2898	7115	5986	7233	4036	7718	4479	6100	6379	1823	9321	1678	902	6123	5666
PR-43	2011	7583	2254	7026	5057	7486	4540	6733	6218	6838	6365	1894	7626	2099	2289	6376	5518
PR-44	6124	6634	6020	6444	6601	6948	7233	7878	5974	6190	5763	5551	6552	4218	5290	6683	6455
PR-45	5252	7101	6023	6407	6121	7123	7032	6454	6384	6633	6995	5719	6637	5549	6143	6292	6452
PR-46	3302	4657	3872	4848	4674	4360	4372	4955	3703	4824	4015	3952	4524	3469	2708	5030	4312
PR-48	3620	5243	4852	6021	4350	4942	5088	4428	4981	4310	5758	5028	4972	4252	4906	4995	4895
PR-50	4091	6744	4038	5502	5222	6394	5032	6402	5835	5019	6051	4686	5692	3769	4182	6164	5439
PR-51	6644	7969	6175	7387	7142	7652	7160	7299	7603	7372	7980	5073	8229	4699	4477	6964	7207
PR-53	5396	7561	5081	7378	5758	7007	5921	6953	6268	6915	6489	4414	7280	4136	3329	6386	6340
PR-54	6489	8513	6249	7891	7278	7873	7235	8127	7165	7163	7375	6248	8237	6338	6346	7616	7373
PR-55	5032	6932	5238	6942	6745	6917	5708	6938	6311	6763	6416	4582	6878	5195	4553	5843	6262
PR-58	2765	7577	2433	7132	4488	6211	3906	6796	5737	5373	5684	2268	6876	1649	1108	5761	5173
PR-59	4974	8285	3461	9020	6228	8004	5763	8008	6754	6618	7315	4372	9054	2582	2879	7021	6758
PR-60	3174	6985	3157	6219	4948	5670	5272	6400	5517	5927	5677	3013	5061	2705	2272	4807	5155
PR-61	4706	5882	5853	7745	6614	6033	5819	6416	6867	6238	6938	5187	5160	4477	3494	5989	6112
PR-62	7461	6990	5900	6652	7884	7832	7877	7039	7083	6882	6860	6599	7482	6164	6264	7473	7196
PR-63	6638	6258	5475	7304	6151	6870	6924	7011	6905	7055	6783	6464	6333	4903	6284	6865	6629

Table 3c. P and N main effect means for Jaiba, Brazil, experiments

EXPT	CODED P LEVEL 1/					CODED N LEVEL 2/				
	-.85	-.40	0	+.40	+.85	-.85	-.40	0	.40	+.85
B-09	4174	5430	5915	6195	6825	5234	5546	5768	6080	5912
B-19	2390	3087	4296	4434	5479	3864	3824	4101	3698	4160
B-20	5328	5989	5843	6292	6459	5999	6105	5693	6177	5937
B-21	2427	3479	4677	4475	5060	4173	3912	3980	4043	4011
B-22	1374	2967	4294	5921	6356	4080	4472	3880	4416	4064
B-23	1567	1976	2948	3182	4159	3049	2660	2838	2498	2887
B-24	5734	5215	6046	6263	6430	6073	5435	5916	6043	6221
B-25	5365	5564	5504	5760	6137	5308	5355	5574	5970	6125
B-26	4144	5647	7487	7628	8246	6473	7005	6820	7270	6584
B-27	2561	3526	4338	4864	5501	4192	4422	3963	3968	4245
B-36	2103	4280	5324	6310	6468	4207	5403	4586	5186	5103
B-37	800	1288	1443	2717	2546	1518	1807	1539	2197	1632
B-38	4929	6170	6992	7033	7894	6550	6247	6923	6956	6343
B-39	4693	3565	4182	4350	4287	4568	3602	4372	4314	4222
B-40	2835	3548	4417	4803	4719	3129	3813	4136	4538	4707
B-41	2523	3038	3913	3858	5362	4236	3654	4042	3282	3419
B-43	2701	5787	7793	9190	8563	6719	7431	6709	7546	6628
B-44	1294	2225	2942	4480	5000	3084	3711	3045	2994	3108
B-45	5127	7398	7503	7358	9364	6837	7255	7114	7501	7043
B-46	2880	3177	3891	4127	4342	3878	3495	3843	3809	3333
B-47	4350	5664	7499	7655	8273	6461	6464	6390	6855	7260
B-48	3026	3559	3274	4203	3777	2620	3697	3387	4065	4070
B-52	3502	5611	6398	6472	7041	5656	5560	5387	6523	5889
B-53	4199	4861	6286	7253	7058	5690	5411	5731	6703	6122
B-54	6039	5841	7208	7213	7501	6502	6675	6929	6380	7316
B-55	5013	6227	6099	6472	6626	5762	6144	6146	6555	5831
B-56	4234	5933	6365	6340	7433	5806	5845	5891	6429	6335
B-57	4680	5370	6120	6902	7318	5383	6029	6015	6243	6720
B-64	2290	4062	5077	6526	6794	4342	5283	4808	5306	5002
B-65	2501	3006	3612	3351	3481	3475	2817	2698	3540	3422
B-66	4526	5451	6856	6784	7476	6747	6054	6217	6181	5895
B-67	3785	3467	4323	4679	4635	3857	3908	4636	4238	4250
B-68	4731	5575	6026	6738	7543	5579	6217	6771	6096	6050
B-69	3398	3497	4594	4767	5595	4452	3917	4502	4348	4623

1/ P main effect means are averaged over replications and N levels and are unadjusted for differences in the N levels used

2/ N main effect means are averaged over replications and P levels and are unadjusted for differences in the P levels used

Table 3d. P and N main effect means for Isabela, Puerto Rico, experiments

EXPT	CODED P LEVEL 1/ -.85	-.40	0	+.40	+.85	CODED N LEVEL 2/ -.85	-.40	0	.40	+.85
PR-19	5035	4636	4705	4982	4573	4584	5131	4765	4486	4963
PR-20	5326	6379	6770	6798	6916	5584	6408	6638	6769	6790
PR-21	7926	8381	8783	8297	8671	7674	8136	8460	8541	88[illegible]5
PR-23	3545	3301	3383	3616	4674	3087	3713	3628	3204	4888
PR-27	4593	4890	5200	5293	4895	3848	4399	5718	5734	5122
PR-30	7354	7385	7286	7041	7332	6599	6759	7179	7668	8094
PR-31	4735	5100	4866	5175	4770	2295	4619	5431	5656	6645
PR-33	4404	4699	4314	4791	4781	3964	4791	5050	4699	4484
PR-34	3936	5502	4154	4686	4503	1529	4110	4713	6078	6350
PR-35	5778	5869	4968	5445	5419	3768	4953	5583	6361	6814
PR-36	2202	2065	1814	2049	1701	1377	2126	2156	1987	2186
PR-37	6071	6958	6555	5803	6251	4780	5336	6722	6926	7375
PR-38	7435	7718	7730	6856	7528	7478	6909	7622	7665	7593
PR-39	3365	3361	2936	3404	3192	3699	2880	2886	3986	2908
PR-41	6331	7181	6591	5663	7104	4724	5516	7097	7328	8205
PR-42	5855	616[illegible]	5208	5877	5464	2531	4561	5673	7476	8223
PR-43	5511	6272	5246	5636	5215	2053	4799	6474	7110	7445
PR-44	6316	6775	6026	7556	6075	5898	6917	5976	7413	6543
PR-45	6329	6622	6267	6743	6475	5664	6577	6671	6789	6715
PR-46	4261	4517	4060	4664	4245	3709	4523	4191	4658	4676
PR-48	4391	4666	4993	4759	5543	4500	4739	5016	4685	5412
PR-50	5285	5808	5405	5717	5197	4272	5127	5635	6393	5979
PR-51	7328	7397	6969	7230	7181	5964	7151	7652	7476	7862
PR-53	6624	6383	5987	6437	6316	4964	5840	6557	6930	7406
PR-54	7389	7575	7217	7681	7172	6329	7257	7235	8000	8214
PR-55	6242	6831	5924	6323	5199	4950	6226	6497	6928	6917
PR-58	5238	5350	4961	5351	5083	2489	4197	5598	6504	7195
PR-59	6626	7116	6727	6866	6599	4265	5996	6395	8005	8797
PR-60	5362	5309	4530	5836	5018	3115	5110	5707	6035	6088
PR-61	5609	6324	5738	6117	6865	5249	6217	6681	6224	6252
PR-62	7111	7858	7055	7458	6304	6987	7881	6942	7436	7041
PR-63	6650	6510	6567	6968	6521	6192	6538	6914	6941	6632

1/ P main effect means are averaged ocer replications and N levels and are unadjusted for differences in the N levels used

2/ N main effect means are averaged over replications and P levels and are unadjusted for differences in the P levels used

Table 4a

SUMMARY OF REGRESSION STATISTICS FOR INDIVIDUAL SITES -- BRAZIL, CROP = MAIZE

Site	Season	Error DF	Standard Deviation (kg/ha, 15.5% moisture)	Over-all Mean (kg/ha, 15.5% moisture)	Coefficient of Variation	b_o	b_1	b_2	b_3	b_4	b_5	R^2 †	Lack of Fit MS (7 DF)	Error MS	(F for lack of fit)
						Estimates of the Six Parameters of the Quadratic Polynomial Model (Std. Error in Parenthesis)									
B-9	Dry	24	979	5692	17.20	5692 (157)	1482** (253)	433 (253)	-522 (502)	-216 (502)	260 (382)	0.94	314,111	959,003	.328
B-19	Wet	36	566	3955	14.31	3997 (144)	1779** (126)	131 (126)	-258 (251)	147 (251)	-105 (191)	0.94	590,648	320,123	1.845
B-20	Wet	36	714	5958	11.98	5958 (99)	628** (160)	-20 (160)	-155 (316)	155 (316)	-85 (241)	0.73	436,749	509,502	.857
B-21	Wet	36	779	4031	19.32	4031 (108)	1510** (175)	-62 (175)	-1047** (346)	399 (346)	238 (263)	0.94	437,782	606,203	.722
B-22	Dry	24	678	4142	16.37	4407 (199)	3029** (176)	-17 (176)	-775* (348)	83 (348)	70 (265)	0.98	332,783	459,732	0.72
• B-23	Dry	24	433	2818	15.37	2640 (127)	1471** (112)	-109 (112)	118 (222)	347 (222)	-118 (169)	0.98	105,090	187,718	0.56
B-24	Dry	24	645	5968	10.80	5737 (189)	525** (167)	173 (167)	166 (331)	437 (331)	-25 (252)	0.61	511,541	415,812	1.23
• B-25	Dry	24	770	5667	13.58	5531 (226)	427* (199)	517* (199)	250 (394)	106 (394)	240 (300)	0.83	213,706	592,341	0.36
B-26	Dry	24	762	6783	11.23	6783 (122)	2260** (197)	100 (197)	-1681** (391)	-297 (391)	249 (298)	0.95	601,260	580,669	1.035
• B-27	Dry	24	861	4152	20.74	4196 (253)	1722** (223)	-46 (223)	-447 (441)	333 (441)	252 (336)	0.91	617,238	741,493	0.83
B-36	Wet	24	828	4836	17.12	5447 (243)	2564** (214)	424 (214)	-1565** (424)	-31 (424)	-148 (323)	0.98	281,393	685,244	0.41
• B-37	Wet	24	756	1721	43.90	1785 (222)	1125** (196)	70 (196)	16 (387)	-182 (387)	-159 (295)	0.81	662,540	570,982	1.16

Table 4a (continued)

Site	Season	Error DF	Standard Deviation (kg/ha, 15.5% moisture)	Over-all Mean	Coefficient of Variation	Estimates of the Six Parameters of the Quadratic Polynomial Model (Std. Error in Parenthesis) b_o	b_1	b_2	b_3	b_4	b_5	R^2 †	Lack of Fit MS (7 DF)	Error MS	(F for lack of fit)
B-38	Wet	24	828	6604	12.53	6964 (243)	1659** (214)	8 (214)	-542 (424)	-398 (424)	606 (323)	0.90	685,320	684,831	1.00
● B-39	Wet	24	1052	4255	24.73	3961 (309)	-82 (272)	-62 (272)	582 (539)	187 (539)	23 (410)	0.13	1,813,082	1,107,153	1.64
B-40	Wet	24	1327	4047	32.80	4419 (389)	1167** (344)	926* (344)	-777 (680)	-194 (680)	-405 (518)	0.77	1,620,540	1,761,991	0.92
● B-41	Wet	24	843	3766	22.39	3613 (247)	1594** (218)	-479* (218)	438 (432)	-38 (432)	-244 (329)	0.90	706,701	711,138	0.99
B-43	Dry	24	1000	6932	14.43	7851 (303)	3038** (268)	-28 (268)	-2325** (531)	-76 (531)	242 (404)	0.97	703,409	1,004,771	0.70
● B-44	Dry	24	803	3163	25.40	3191 (241)	2262** (212)	-103 (212)	70 (420)	-143 (420)	-431 (319)	0.96	471,833	571,651	0.83
B-45	Dry	24	1435	7115	20.17	7594 (409)	1653** (361)	145 (361)	-1030 (716)	-222 (716)	-265 (545)	0.84	1,260,385	1,009,075	1.25
● B-46	Dry	24	583	3686	15.84	3830 (173)	902** (153)	-203 (153)	-228 (303)	-148 (303)	185 (231)	0.86	320,597	366,668	0.87
B-47	Dry	24	709	6690	10.60	6913 (192)	2331** (170)	472 (170)	-1430** (336)	849* (336)	-532* (256)	0.95	657,707	374,295	1.76
● B-48	Dry	24	1103	3519	31.33	3711 (353)	488 (311)	802* (311)	-132 (617)	-367 (617)	-174 (470)	0.83	420,368	1,495,826	0.28
B-52	Wet	24	927	5766	16.08	6[illegible]83 (264)	1952** (233)	274 (233)	-1584** (461)	494 (461)	-457 (351)	0.91	944,871	737,637	1.28
● B-53	Wet	24	1379	5912	23.33	6165 (418)	1950** (368)	430 (368)	-906 (729)	245 (729)	-177 (555)	0.84	1,569,733	2,133,989	0.74

Table 4a (continued)

Site	Season	Error DF	Standard Deviation (kg/ha, 15.5% moisture)	Over-all Mean	Coefficient of Variation	Estimates of the Six Parameters of the Quadratic Polynomial Model (Std. Error in Parenthesis) b_o	b_1	b_2	b_3	b_4	b_5	R^2 †	Lack of Fit MS (7 DF)	Error MS	(F for lack of fit)
B-54	Wet	24	910	6796	13.39	6789 (247)	970** (218)	370 (218)	-280 (431)	299 (431)	23 (328)	0.74	1,122,368	639,967	1.75
● B-55	Wet	24	1048	6047	17.33	6446 (314)	866** (277)	101 (277)	-473 (550)	-571 (550)	-721 (419)	0.79	651,251	816,683	0.80
B-56	Wet	24	758	6049	12.53	6223 (222)	1705** (196)	365 (196)	-719 (388)	265 (388)	470 (296)	0.93	555,582	559,273	0.99
● B-57	Wet	24	898	6069	13.21	6139 (256)	1599** (226)	719** (226)	-200 (447)	18 (447)	-1170** (339)	0.97	251,182	805,699	0.31
B-64	Dry	24	489	4895	9.99	5369 (144)	2710** (126)	341* (126)	-899** (250)	-310 (250)	-288 (191)	0.99	152,966	239,043	0.64
● B-65	Dry	24	753	3192	23.58	3140 (226)	558** (199)	89 (199)	-880* (395)	1018** (395)	-446 (301)	0.77	504,210	566,382	0.89
B-66	Dry	24	769	6234	12.33	6420 (227)	1726** (201)	-416* (201)	-907* (396)	421 (396)	74 (302)	0.88	1,012,178	591,562	1.71
● B-67	Dry	24	772	4194	18.40	4358 (228)	630** (201)	255 (201)	110 (399)	-540 (399)	-337 (304)	0.57	943,917	595,752	1.58
B-68	Dry	24	831	6140	13.53	6422 (316)	1679** (279)	222 (279)	406 (552)	-1142* (552)	63 (420)	0.94	469,420	690,672	0.68
● B-69	Dry	24	772	4405	17.52	4256 (219)	1330** (194)	157 (194)	109 (385)	279 (385)	-527 (293)	0.92	373,379	595,777	0.63

†Tmt SS(12 d.f.) used as denominator for calculating R^2

*Significant at .05 level

**Significant at .01 level

●Residual transfer experiment

b_o is the "intercept", the estimated yield when P and N are both zero (in the coded values, this is the center of the design).

b_1 is the change in yield for each coded unit of P (since this variable is orthogonal to the other variables in the equation, b_1 is the same value as estimating the straight line relationship between y and P alone.

b_2 is the change in yield for each coded unit of N.

b_3, b_4 and b_5 are estimates of the P and N quadratic (degree of curvature) and interaction terms respectively.

Table 4b

SUMMARY OF REGRESSION STATISTICS FOR INDIVIDUAL SITES -- PUERTO RICO, CROP = MAIZE

Site	Season	Error DF	Standard Deviation (kg/ha, 15.5% moisture)	Over-all Mean	Coefficient of Variation	Estimates of the Six Parameters of the Quadratic Polynomial Model (Std. Error in Parenthesis) b_o	b_1	b_2	b_3	b_4	b_5	R^2 †	Lack of Fit MS (7 DF)	Error MS	(F for lack of fit)
PR-19	Wet	24	979	4783	18.38	4762 (257)	-181 (227)	91 (227)	89 (450)	-36 (450)	10 (343)	0.12	683,919	772,691	.885
PR-20	Dry	24	828	6415	12.91	6415 (133)	882** (215)	676** (215)	-767 (424)	-494 (424)	-192 (323)	0.86	508,123	685,423	.741
PR-21	Dry	24	469	8330	5.63	8330 (75)	368** (122)	666** (122)	-54 (240)	-214 (240)	425* (183)	0.68	630,275	220,044	2.864*
•PR-23	Dry	24	1,553	3742	41.51	3198 (455)	629 (402)	841* (402)	965 (796)	456 (796)	-266 (606)	0.76	1,011,934	2,411,857	0.420
PR-26	---	Data not reliable ---													
PR-27	Wet	24	747	4956	15.07	4956 (119)	220 (193)	876** (193)	-325 (383)	-1400** (383)	587** (291)	0.84	610,991	557,959	1.095
PR-30	Wet	24	866	7290	11.88	7290 (139)	-66 (224)	861** (224)	73 (444)	295 (444)	-6 (338)	0.85	292,411	749,976	.390
•PR-31	Wet	24	632	4897	12.91	5411 (175)	30 (154)	2397** (154)	-84 (305)	-1258** (305)	135 (233)	0.95	627,339	399,492	1.570
PR-33	Wet	24	937	4575	20.49	4866 (275)	208 (242)	252 (242)	385 (481)	-1144** (481)	-517 (365)	0.71	483,714	878,542	.551
•PR-34	Dry	24	979	4473	21.89	5093 (260)	159 (230)	2788** (230)	-229 (456)	-1391* (456)	-383 (347)	0.86	1,185,904	958,990	1.24
•PR-35	Dry	24	818	5471	14.96	5468 (220)	-252 (195)	1788** (195)	641 (385)	-635 (385)	-15 (294)	0.79	1,082,288	669,758	1.62
•PR-36	Dry	24	823	1952	42.18	2097 (237)	-259 (209)	392 (209)	166 (416)	-544 (416)	-298 (316)	0.42	760,808	678,042	1.12

Table 4b (continued)

Site	Season	Error DF	Standard Deviation (kg/ha, 15.5% moisture)	Over-all Mean	Coefficient of Variation	Estimates of the Six Parameters of the Quadratic Polynomial Model (Std. Error in Parenthesis) b_o	b_1	b_2	b_3	b_4	b_5	$R^{2\dagger}$	Lack of Fit MS (7 DF)	Error MS	(F for lack of fit)
PR-37	Dry	24	789	6319	12.49	6712 (210)	-94 (185)	1505** (185)	-338 (366)	-686 (366)	106 (279)	0.76	589,754	622,845	0.95
PR-38	Dry	24	811	7479	10.84	7476 (226)	-91 (199)	181 (199)	-109 (395)	116 (395)	113 (300)	0.36	828,108	657,716	1.26
PR-39	Dry	24	1160	3232	35.89	3064 (297)	-82 (262)	-243 (262)	167 (520)	271 (520)	127 (396)	0.46	1,696,966	1,345,070	1.26
• PR-41	Wet	24	1458	6597	22.10	6663 (428)	152 (377)	2076** (377)	439 (747)	-611 (747)	43 (569)	0.80	2,332,507	2,125,653	1.10
• PR-42	Wet	24	1033	5666	18.23	5810 (303)	-246 (267)	3334** (267)	294 (529)	-671 (529)	-166 (403)	0.90	2,670,626	1,066,781	2.50
• PR-43	Wet	24	884	5518	16.02	6333 (259)	-254 (229)	3135** (229)	209 (453)	-2340** (453)	-314 (345)	0.99	194,814	781,868	0.25
PR-44	Wet	24	1428	6453	22.13	6745 (419)	3 (370)	410 (370)	-431 (732)	-328 (732)	-6 (557)	0.27	1,510,481	2,039,959	0.74
PR-45	Wet	24	1015	6452	15.74	6704 (298)	94 (253)	572* (253)	111 (520)	-769 (520)	-599 (396)	0.84	272,020	1,031,058	0.26
• PR-46	Wet	24	1005	4312	23.32	4411 (295)	15 (260)	517 (260)	-4 (515)	-255 (515)	-59 (392)	0.47	701,850	1,010,834	0.69
PR-48	Wet	24	1091	4895	22.29	4813 (320)	606* (282)	459 (282)	130 (559)	83 (559)	-238 (426)	0.65	690,994	1,190,301	0.58
• PR-50	Dry	24	1014	5439	18.64	5866 (309)	-59 (273)	1080** (273)	-319 (542)	-798 (542)	-378 (412)	0.82	695,143	1,018,260	0.68
• PR-51	Dry	24	926	7207	12.85	7426 (272)	-103 (240)	1025** (240)	422 (475)	-997* (475)	-64 (361)	0.77	850,332	957,734	0.99

Table 4b (continued)

Site	Season	Error DF	Standard Deviation (kg/ha, 15.5% moisture)	Over-all Mean (kg/ha, 15.5% moisture)	Coefficient of Variation	Estimates of the Six Parameters of the Quadratic Polynomial Model (Std. Error in Parenthesis) b_o	b_1	b_2	b_3	b_4	b_5	R^2†	Lack of Fit MS (7 DF)	Error MS	(F for lack of fit)
PR-53	Dry	24	1056	6340	16.65	6345 (359)	-149 (316)	1435** (316)	585 (626)	-598 (626)	28 (477)	0.98	101,598	1,044,982	0.10
PR-54	Dry	24	790	7373	10.71	7494 (235)	-94 (206)	1086** (206)	-140 (410)	-177 (410)	-104 (311)	0.92	233,162	554,239	0.42
PR-55	Dry	24	767	6262	12.25	6545 (233)	-104 (205)	1121** (205)	225 (408)	-965* (408)	13 (310)	0.89	382,968	555,179	0.69
●PR-58	Wet	24	813	5173	15.72	5471 (255)	-79 (224)	2783** (224)	272 (445)	-1051* (445)	48 (339)	0.98	294,987	652,401	0.45
●PR-59	Wet	24	894	6758	13.22	7071 (284)	-51 (250)	2639** (250)	-233 (496)	-584 (496)	776* (378)	0.98	260,103	761,776	0.34
●PR-60	Wet	24	1001	5155	19.42	5562 (306)	-92 (269)	1673** (269)	691 (533)	-1752** (533)	-217 (406)	0.91	758,094	1,130,704	0.67
PR-61	Wet	24	1318	6112	21.57	6327 (380)	601 (335)	521 (335)	698 (664)	-1260 (664)	323 (505)	0.68	1,115,009	956,452	1.17
PR-62	Wet	24	648	7196	9.00	7486 (169)	-222 (149)	-44 (149)	-496 (295)	-292 (295)	16 (225)	0.30	761,457	351,308	2.17
PR-63	Wet	24	850	6629	12.82	6861 (267)	7 (236)	290 (236)	56 (466)	-665 (466)	682 (355)	0.71	356,518	836,640	0.43

†Tmt SS (12 d.f.) used as denominator for calculating R^2

*Significant at .05 level

**Significant at .01 level

●Residual transfer experiment

b_o is the "intercept", the estimated yield when P and N are both zero (in the coded values, this is the center of the design).

b_1 is the change in yield for each coded unit of P (since this variable is orthogonal to the other variables in the equation, b_1 is the same value as estimating the straight line relationship between y and P alone.

b_2 is the change in yield for each coded unit of N.

b_3, b_4 and b_5 are estimates of the P and N quadratic (degree of curvature) and interaction terms respectively.

Table 5a

ANALYSIS OF VARIANCE FOR TRANSFER EXPERIMENTS, P x N, BRAZIL

		MEAN SQUARES			DF	MEAN SQUARES				
SOURCE	DF	W	W	W	DF	D	D	D	D	D
		B-19	B-20	B-21		B-9	B-22	B-23+	B-24	B-25+
Blocks	3	1,700,179	2,094,111	6,567,164	2	664,426	1,281.749	99,029	1,565,748	29,352
Treatments	12	5,6[illegible]2,934	932,065	4,562,167	12	3,308,131	11,801,512	2,827,461	762,749	371,984
N	1	341,792	7,986	76,211	1	2,801,024	4,377	177,809	449,176	3,994,175*
P	1	62,998,305**	7,855,905**	45,373,822**	1	32,784,730**	136,936,774**	32,315,703**	4,120,925**	2,719,659*
N^2	1	44,513	78,798	160,060	1	430,891	26,230	459,543	727,776	42,552
P^2	1	339,338	121,682	5,567,828**	1	1,038,808	2,288,881	149,014	270,119	296,781
NP	1	96,715	63,164	398,613	1	443,343	32,399	91,833	4,207	378,512
Lack of Fit	7	590,648	436,749	437,782	7	314,111	332,783	105,090	511,541	213,706
Error	36	320,123	509,502	606,203	24	959,003	459,732	187,718	415,812	592,341
TOTAL	51				38					

SOURCE	DF	D	D	W	W	W	W	W	W	D
		B-26	B-27+	B-36	B-37+	B-38	B-39	B-40	B-41	B-43
Blocks	2	553,001	6,087,861**	1,581,116	837,046	3,050,476*	4,707,169	174,456	552,373	1,983,622
Treatments	12	7,793,403	2,083,628	9,397,376	1,990,468	4,204,070	1,211,000	4,031,009	3,950,475	13,754,794
N	1	146,122	31,549	2,688,884	72,951	849	58,380	12,787,923	3,420,552*	11,952
P	1	76 264,834**	44,254,453**	98,107,358**	18,879,161**	41,058,635**	99,701	20,342,710	37,902,692**	137,834,225**
N^2	1	1,734,734	422,615	3,765	126,644	603,399	133,194	143,042	5,638	21,809
P^2	1	10,757,234**	561,242	9,855,562**	2,081	1,572,209	1,545,622	2,677,346	738,203	21,881,976**
NP	1	407,0[illegible]	416,550	143,193	167,009	2,416,512	3,532	1,077,308	391,704	383,701
Lack of Fit	7	601.260	617,238	281,393	662,540	685,320	1,813,082	1,620,540	706,701	703,409
Error	24	580,669	41,493	685,244	570,982	684,831	1,107,153	1,761,991	711,138	1,004,771
TOTAL	38									

Table 5a (continued)

SOURCE	DF	D B-44	D B-45	D B-46	D B-47	D B-48	W B-52	W B-53	W B-54	W B-55
Blocks	2	2,138,992	17,462,021	102,237	1,510,745	639,066	2,020,759	288,251	2,059,788	6,032,864
Treatments	12	6,763,090	4,598,676	1,298,759	8,319,742	1,416,630	6,304,061	5,680,834	2,038,168	1,832,162
N	1	158,314	313,066	615,704	3,327,553**	9,607,761*	1,119,550	2,753,959	2,039,682	153,469
P	1	76,392,832**	40,766,577**	12,145,114**	81,092,051**	3,558,204	56,892,799**	51,035,993**	14,032,749**	11,201,668*
N^2	1	77,725	187,272	83,298	2,741,241*	513,029	928,081	228,488	340,754	1,239,78[illegible]
P^2	1	6,150	4,634,190*	270,922	6,210,020**	178,293	8,720,739**	2,906,620	184,770	1,415,[illegible]08
NP	1	1,219,224	460,208	225,888	1,862,095*	199,698	1,373,471	206,809	3,479	3,416,459
Lack of Fit	7	471,833	1,260,385	320,597	657,707	420,368	944,871	1,569,733	1,122,365	6[illegible]1,251
Error	24	571,651	1,009,075	366,668	374,295	1,495,826	737,637	2,133,989	639,967	8[illegible],683
TOTAL	38									

SOURCE	DF	W B-56	W B-57	D B-64	D B-65	D B-66	D B-67	D B-68	D B-69
Blocks	2	832,546	62,848	224,461	990,800	833,877	841,700	7,831,962	29,992
Treatments	12	4,394,037	4,731,459	97,661,107	1,273,624	4,794,600	1,280,179	4,267,902	2,635,157
N	1	1,986,796	7,724,669**	1,743,226*	117,355	2,587,356*	967,148	734,964	367,910
P	1	43,384,023**	38,146,745**	109,614,216**	4,640,414**	44,493,955**	5,931,295**	42,098,284**	26,404,557**
N^2	1	267,376	1,261	440,214	3,943,120*	673,137	1,109,351	4,967,319*	295,888
P^2	1	1,749,188	154,214	3,776,690**	1,744,425	2,659,518*	157	101,867	113,780
NP	1	1,451,981	8,992,343**	548,173	1,308,708	35,989	746,779	26,457	1,826,102
Lack of Fit	7	555,582	251,182	152,966	504,210	1,012,178	942,488	469,420	373,379
Error	24	559,273	805,699	239,042	566,382	591,562	595,752	650,672	595,777
TOTAL	51								

+Residual Transfer Experiment

*Significant at .05 level

**Significant at .01 level

D = dry season, W = wet season

Table 5b

ANALYSIS OF VARIANCE FOR TRANSFER EXPERIMENTS, P x N, PUERTO RICO, CROP = MAIZE

MEAN SQUARES

SOURCE	DF	W PR-19	D PR-20	D PR-21	D PR-23+	W PR-27	W PR-30	W PR-31+	W PR-33	D PR-34+
Blocks	2	847,520	622,120	962,390	6,571,247	1,272,704	820,962	434,312	683,097	3,532,020
Treatments	12	452,725	2,164,548	1,204,423	2,443,376	2,311,282	1,132,835	8,065,220	983,018	11,177,411
N	1	123,044	6,825,641**	6,610,220**	10,565,380*	11,444,854**	11,076,489**	85,726,490**	948,377	116,002,825**
P	1	490,017	11,615,191**	2,026,048**	5,906,483	720,260	65,622	13,737	645,549	379,142
N^2	1	4,833	927,856	174,592	791,670	7,464,445**	330,987	6,027,042**	4,986,023*	8,281,682**
P^2	1	26,658	3,046,480*	39,886	4,509,610	1,566,594	73,832	504,049	76,262	200,165
NP	1	722	242,550	1,189,503*	463,834	2,262,299	209	119,952	1,754,009	963,793
Lack of Fit	7	683,919	508,123	630,275*	1,011,934	610,991	292,411	627,339	483,714	1,185,904
Error	24	772,691	685,423	220,045	2,411,857	557,959	749,976	399,492	878,542	958,991
TOTAL	38									

SOURCE	DF	D PR-35+	D PR-36+	D PR-37	D PR-38	D PR-39	W PR-41+	W PR-42	W PR-43+	W PR-44
Blocks	2	1,277,574	746,904	2,967,854	1,243,198	6,958,333	6,871,086	4,176,788	10,348,586**	973,366
Treatments	12	4,898,212	861,332	3,408,018	547,487	1,121,072	6,898,955	15,628,236	14,240,427	1,208,313
N	1	47,702,947**	2,288,381	33,824,991**	487,123	884,919	64,304,516**	165,959,357	146,724,975**	2,511,968
P	1	946,714	1,002,285	130,864	122,763	99,905	346,212	901,382	961,140	103
N^2	1	985,761	1,032,551	2,302,013	34,045	377,343	1,420,548	1,714,121	20,840,389**	409,081
P^2	1	1,565,508	104,801	435,994	45,601	106,403	376,576	89,063	347,256	1,004,966
NP	1	1,598	562,312	74,070	83,561	105,538	12,056	180,537	647,655	272
Lack of Fit	7	1,082,288	760,808	589,754	828,108	1,696,966	2,332,507	2,670,626	194,81[illegible]	1,510,461
Error	24	669,758	678,042	622,845	657,716	1,345,070	2,125,653	1,066,781	731,868	2,039,959
TOTAL	38									

Table 55 (continued)

SOURCE	DF	W PR-45	W PR-46+	W PR-48	D PR-50	D PR-51	D PR-53	D PR-54	D PR-55	W PR-58
Blocks	2	2,342,050	12,471,683**	332,229	2,299,768	879,244	5,500,862	2,828,918	1,699,763	2,050,618
Treatments	12	962,192	766,466	1,161,392	2,219,175	2,145,956	2,832,587	1,640,010	2,095,241	10,167,817
N	1	4,891,003*	3,996,193	3,140,170	17,393,079**	15,675,197**	30,750,653**	17,598,685**	18,754,975**	115,622,868**
P	1	133,017	3,442	5,473,364*	52,709	157,265	332,446	131,896	161,647	94,236
N^2	1	2,250,283	247,949	26,417	2,421,228	3,780,019*	1,359,959	119,298	3,543,220*	4,208,558*
P^2	1	11,714	13,882	87,794	959,954	171,605	831,786	126,494	1,193	8,262
NP	1	2,356,146	23,180	371,992	937,126	27,064	5,011	71,611	1,077	14,969
Lack of Fit	7	272,020	701,850	690,994	695,143	850,332	711,186	233,162	382,968	294,987
Error	24	1,031,058	1,010,843	1,190,300	1,018,260	857,734	1,044,982	554,239	555,179	652,401
TOTAL	38									

SOURCE	DF	W PR-59	W PR-60	W PR-61	W PR-62	W PR-63
Blocks	2	3,126,129	314,924	13,278,083	44,719	621,217
Treatments	12	9,295,276	4,965,719	2,057,840	631,196	710,234
N	1	103,919,929**	41,766,404**	4,046,856	28,400	1,255,106
P	1	38,588	125,398	5,386,869*	733,611	784
N^2	1	1,296,981	11,687,767**	6,044,705*	261,136	1,681,019
P^2	1	513,833	391,765	726,837	1,219,336	30,216
NP	1	3,953,256*	310,638	683,751	1,671	3,060,054
Lack of Fit	7	260,103	758,094	1,115,009	761,457	356,518
Error	24	761,776	1,130,704	956,452	351,308	836,640
TOTAL	38					

+Residual Transfer Experiment

Table 6. Example showing calculations for confidence interval procedure for experiment B-22

Treatment Number	Observed Yields	Observed Deviations	Predicted Yields ($\hat{\hat{Y}}_i$) Experiment-specific Model 1	Uncertainty Factor $t_{.05}\ s_y\sqrt{x'Cx}$	Lower 95% Confidence Limit	Upper 95% Confidence Limit	Predicted Yields from data from other 30 sites ($\hat{Y}_{(-i)}$)	Does $\hat{Y}_{(-i)}$ Occur without Confidence Interval
1	1455	-2687	-2745	1.96 (453.2106)(0.8195)	-3473	-2017	-2275	Yes
2	1585	-2557	-2875	"	-3603	-2147	-2113	No
3	6229	2087	2303	"	1575	3031	1590	Yes
4	6451	2309	2376	"	1648	3104	1840	Yes
5	3130	-1012	-1039	1.96 (453.2106)(0.3706)	-1368	-710	-806	Yes
6	2803	-1339	-1076	"	-1405	-747	-719	No
7	5813	1671	1361	"	1032	1690	1023	No
8	6029	1887	1370	"	1041	1699	1130	Yes
9	4171	29	265	1.96 (453.2106)(0.4256)	-113	643	270	Yes
10	1081	-3061	-2870		-3429	-2311	-2041	No
11	6389	2247	2280	"	1721	2839	1868	Yes
12	4555	413	339	"	-220	898	14	Yes
13	4155	13	310	"	-249	869	220	Yes

Note: Model 6 was assumed for the $\hat{\hat{Y}}_{(-i)}$ predictions.

No. within confidence interval = 9 = $(\frac{9}{13}) \times 100 = 69.2\%$

Table 7 Mean grain yields of the leading five [1/] maize varieties of eight trials conducted at Isabela, Puerto Rico and Jaiba, MG, Brazil.

Variety/Source	Experiment/Season (Dry, Wet), Year Planted							
	PR-4/W76	PR-5/W76	PR-18/W77	PR-22/D77	B-2/W76	B-5/W76	B-14/D77	B-18/W77
	kg/ha[2/]							
X304C, Pioneer	9782	3962	8998	5856		7458		7738
X304B, Pionner	8957	3647	8184			7740		
X304A, Pioneer	8349		8818	5300		7680		
H638, Hawaii	8315							
X105A, Pioneer	8186					7032		
X306B, Pioneer		3388	7796	5654	8273	7442	4473	7523
QK 231, Australia		3264						
S 1973, Mexico		3234						
111C, Cargill			7520		9349		5182	490[illegible]
X5800, Pioneer				6559				
X4817, Pioneer				5209				
Maya X					8820		4122	
259, Agroceres					8800			
Phoenix 1110					8292		4417	7193
H 610, Hawaii							4518	5351

1/ In total, 30 selected varieties and hybrids were tested during 1976-78; only the top-ranked 5 in each trial are shown above.

2/ Mean grain yields of 3 or 4 replicates, adjusted to 15.5% moisture.

Table 8. Mean grain yields of the top 10 varieties included in unirrigated "Brazil National Maize Trials" conducted at Jaiba, MG, Brazil from 1977 to 1980.

Rank	1977		1978		1979		1980	
	Variety	Yield	Variety	Yield	Variety	Yield	Variety	Yield
		kg/ha[1/]		kg/ha		kg/ha		kg/ha
1	Cargill 111	7336	Dekalb 7601	6770	Dekalb B670	8135	Cargill 111S	8500
2	Contibrasil 3	7158	Ag 170	6620	Cargill 125	7856	Cargill 111X	7888
3	Cargill 111X	7139	Dekalb B670	6574	Cargill 111X	7829	Cargill 317	7355
4	Cargill 318	7128	Ag 162-5	6452	Cargill 111S	7019	Cargill 5005-M	6823
5	Cargill 319	7127	Maya XIV	5643	Dekalb 7601	6897	Cargill 121	6809
6	Cargill 111S	7059	Phoenix 1413	5535	Phoenix B	6959	Cargill 115	6799
7	Cargill 317	6948	Contimayz	5491	Dina 05	6874	Phoenix B	6423
8	HV-Gen 200	6824	Pioneer X4816	5490	Ag 401	6836	Ag 259	6218
9	Composto A	6772	Cargill 5005-M	5435	Conti-Exp-1	6793	Dekalb R670	5885
10	Cargill 5005-M	6725	GO 05	5329	Ag 162-5	6703	Pioneer 6874	4829

1/ Adjusted to 15.5% moisture grain, means of 4 replicates.

Table 9. Mean grain yields of the top 10 varieties included in unirrigated "Brazil National Precocious Maize Trials" conducted at Jaiba, MG, Brazil in 1979 and 1980.

	1979		1980	
Rank	Variety	Yield	Variety	Yield
		kg/ha[1/]		kg/ha
1	Agroceres 66A	7259	Agroceres 64A	4983
2	Pioneer 4816A	6378	Pioneer 6874	4399
3	Cargill 511	6365	Save 342	4301
4	Pioneer 4817	6040	Pioneer 6872	4267
5	Agroceres 773	5950	Dekalb E5601	4193
6	Pioneer 4816	5796	Pioneer 6875	4131
7	CMS 05	5893	Cargill 511	4059
8	Cargill 503	5675	Cargill 503	4041
9	Agroceres 64	5518	Cargill 513	4003
10	Cargill 508	5450	Agroceres 301	3965

1/ Adjusted to 15.5% moisture grain, means of 4 replicates.

Table 10. Mean grain yields of two INTSOY soybean variety trials conducted in 1976 and 1977 at Jaiba, MG, Brazil.

1976		1977	
Variety	Yield	Variety	Yield
	kg/ha		kg/ha
Davis	4473	Davis	3367
Bragg	4003	Essex	2884
Ransom	3815	Columbus	2845
Bossier	3513	B-1	2654
Forrest	3476	Forrest	2579
Columbus	3397	Calland	2527
Clark 63	3262	Improved Pelican	2384
Cobb	2941	Jupiter	2196
Cutler 71	2879	Ransom	2172
Calland	2766	Cobb	1933
Pickett 71	2698	Mitchell	1923
Woodworth	2655	Williams	1923
Hill	2641	Bossier	1898
Williams	2598	Bragg	1823
Improved Pelican	1178	Kahala	1787
Jupiter	153	Rillito	1734
Grand Mean	2903		2289
Coefficient of Variation (%)	19.2		47.6
5% LSD Variety Means	793.5		547.5

Table 11. Maize, Pioneer hybrid X304C, grain yields from three irrigation x nitrogen experiments (PR-24, 40 and 57) conducted at Isabela, Puerto Rico.

N	Planting Date	Irrigation, mm water/application[1]						Mean Yield	Grain/kg N
		0	4	8	12	16	20		
kg/ha		Grain yield, kg/ha[2]							kg
0	01-18-78[3]	2285	2119	3281	2002	1027	1224	1990	--
	12-14-78	4499	6205	6048	7689	7471	6548	6410	--
	12-18-79	3106	3499	3636	4092	2985	3330	3441	--
20	01-18-78	3208	2071	538	1727	2415	2023	1997	0.4
	12-14-78	5131	7019	6048	7446	6260	8173	6680	13.5
	12-18-79	3607	4406	3737	4213	3548	3638	3858	20.9
40	01-18-78	4776	3532	3307	4124	3192	4617	3925	53.8
	12-14-78	4525	5169	6996	6997	7101	8284	6512	2.6
	12-18-79	3981	5136	4623	4940	4315	4338	4556	27.9
80	01-18-78	5403	4931	5109	5522	5945	6095	5501	48.8
	12-14-78	5643	6309	7034	7290	7453	6085	6636	2.8
	12-18-79	4244	5916	6097	5742	5983	6173	5692	28.1
160	01-18-78	7815	9969	7980	6974	7997	8954	8282	43.7
	12-14-78	6915	6473	7194	6962	7557	9252	7392	6.1
	12-18-79	4894	6553	7569	7843	9160	7541	7260	23.9
320	--	--	--	--	--	--	--	--	--
	12-14-78	4694	7194	6439	8109	7973	8287	7116	2.2
	12-18-79	5236	6961	8394	8750	9201	8794	7889	13.9

1/ Water applications, 0-20 mm based on the entire plot surface area, were concentrated on the crop rows.
2/ Adjusted to 15.5% moisture grain.
3/ Experiment PR-24, through error, received 8% less N than indicated above, kg grain/kg N calculations account for this error.

Table 12. Maize grain yield-related parameters for a moisture stress x P level x plant density experiment (B-50) conducted at Jaiba, MG, Brazil.

Treatments (Periods of Stress)		Yield [1]	Count	Ear Wt.	Shelling rate	Time to 50% Tassel	Lodged Plants	Mature Plant Ht.	100-seed Wt.
		kg/ha	No.	g	%	days	%	cm	g
1st 30 Days		6058a [2]	32.7a	134a	83.3a	79.6b	9.8a	239b	34.3a
2nd 30 Days		3003b	27.1c	79b	79.9b	83.8a	2.8a	185c	30.4c
3rd 30 days		6287a	30.4ab	145a	83.5a	78.1b	9.1a	273a	33.6b
No Stress		6271a	31.6ab	147a	83.1a	78.7b	10.3a	269a	33.7ab
Subtreatments									
kg P/ha	Plants/ha								
60	55000	6139ab	33.8a	135ab	82.9a	79.6b	9.0b	243a	33.8a
40	55000	5343bc	33.8a	121bc	82.7a	90.1b	4.8b	236c	33.3ab
20	55000	5189bcd	31.0ab	125bc	83.0a	80.1b	7.4b	242ab	32.4b
0	55000	4285d	28.8bc	112c	80.9b	82.2a	2.5b	225c	31.8b
60	33000	4622cd	27.4c	147a	82.2a	79.1b	4.7b	250a	34.1a
60	85000	6850a	27.9bc	117c	82.8a	79.2b	19.8a	253a	32.7ab

1/ Values are means of 3 replicates; yields are adjusted to 15.5% moisture grain.

2/ Means within columns within treatments or subtreatments with the same letter are not significantly different at the 0.05 level by Duncan's Multiple Range Test.

Table 13. Dry matter (DM) production of 34-day old maize (X304C) grown in pots of Coto clay[1/] treated with and without complete fertilizer and with levels of lime.

Treatment		
No.	meq Ca/100 g soil	DM g/plant
1	0[2/]	0.48 d[3/]
2	0	4.37 c
3	.26	4.32 c
4	.39	4.51 c
5	.50	4.86 bc
6	1.00	5.47 abc
7	2.00	5.52 bc
8	2.60	5.42 abc
9	2.86	5.20 bc
10	3.0	5.52 abc
11	4.0	6.91 a
12	4.29	5.57 abc
13	5.0	6.16 ab
14	6.0	6.28 ab
15	7.00	5.84 abc
16	8.00	5.95 abc

1/ Soil from the Isabela secondary site 2 (Calero), ph 4 2 in H_2O.

2/ All treatments except no. 1 had a uniform application of complete fertilizer; treatment no. 1 received no fertilizer.

3/ DM values followed by the same letters are not significantly different at the .05 level of probability; means of four replications.

Table 14. Dry matter (DM) production above ground of 34-day old maize (X304C) plants grown in pots of Coto clay[1/] treated with various lime and micronutrient combinations.

Treatment No	Lime	Micronutrients	DM
	meq Ca/100 g soil		g/plant
1	0	Mg + Zn + B	5.03 bcd[2/]
2	0	Mg + Zn	4.58 bcd
3	0	Mg + B	3.85 cd
4	0	Zn + B	3.65 d
5	4	Mg + Zn + B	7.61 ab
6	4	Mg + Zn	7.17 abc
7	4	Mg + B	7.11 abc
8	4	Zn + B	8.91 a

1/ Soil from the Isabela secondary site 2 (Calero), pH 4.2 in H_2O.

2/ DM values followed by the same letters are not significantly different at the .05 level of probability. Means of four replications.

Table 15. Dry matter (DM) production of 28-day old maize (X304C) grown in pots of Coto clay[1/] treated with various levels of phosphorus fertilizer (TSP)

P Treatment	DM
kg/ha	g/plant
0	0.48 b[2/]
43	1.88 a
65	1.94 a
22	2.00 a
86	2.08 a
106	2.62 a

1/ Soil from the Isabela secondary site 2 (Calero), pH 4.2 in H_2O.

2/ DM values followed by the same letters are not significantly different at the .05 level of probability. Means of four replications.

Table 16. Dry matter (DM) production above ground of 28-day old maize (X304C) plants grown in pots of Coto clay treated with various combinations of lime and triple super phosphate (TSP)

Treatment			
No.	Lime	TSP	DM
	meq Ca/100g soil	g/pot[1/]	g/plant
1[2/]	0	0	1.05 gh[3/]
2	0	0	0.58 h
3	0	0.82	1.85 efgh
4	U	1.63	2.17 efg
5	0	4.08	3.30 de
6	2	0	1.16 fgh
7	2	0.82	2.56 ef
8	2	1.63	4.81 bc
9	2	4.08	5.99 ab
10	4	0	1.82 efgh
11	4	0.82	3.10 de
12	4	1.63	4.44 cd
13	4	4.08	7.47 a
14	6	0	2.32 efg
15	6	0.82	5.03 bc
16	6	1.63	5.37 bc
17	6	4.08	6.87 a

1/ Pots utilized were 15 cm in diameter filled to approximately 15 cm with soil from the Isabela secondary site 2 (Calero), pH 4.2 in H_2O.

2/ All treatments except no. 1 received a uniform application of N, K and micronutrients.

3/ DM values followed by the same letters are not significantly different at the .05 level of probability Means of four replications.

Table 17. Maize, Pioneer hybrid 306B, wet season grain yields and 30-day plant heights from a phosphorus placement and rate of application experiment (PR-14) conducted at Isabela, Puerto Rico, during April to August 1977.

Applied P		P, ppm in soil solution[1]			
Placement	% of bdcst.	.02	.03	.05	.09
		Yield, kg/ha[2]			
15 cm band	20	5539 c	5311	6276	5638 c
45 cm band	60	6096 bc	6745 abc	6897 abc	7516 ab
Broadcast	100	7183 abc	7525 ab	7241 abc	8338 a
Rill	100	6681 abc	6986 abc	7557 ab	6945 abc

1/ Amounts of P applied were 62, 98, 139 and 193 kg/ha to achieve .02, .03, .05 and .09 ppm of P in soil solution, respectively, for broadcast treatments. Actual kg/ha rates were proportionately less for band treatments.

2/ Values not followed by common letters are significantly different at the 5% level of probability. Values shown are means of three replications.

Table 18. Maize, X304C, grain yields from a tillage x plant spacing experiment (PR-56) conducted at Isabela, Puerto Rico, from December 1979 to April 1980.

In-row Spacing	Plants/ha	Tillage Treatment Conventional	No tillage	Mean
cm		Grain Yield, kg/ha[1/]		
20	66666	9273	9446	9360 a[2/]
23	57971	8623	9142	8883 a
27	49383	7770	8174	7972 b
Mean		8555 a	8921 a	8738

1/ Adjusted to 15.5% moisture; means of 3 replicates.

2/ Means in the same column or line followed by the same letters are not significantly different at the .05 level of probability.

Table 19. Yield data from a mulching experiment (B-70) with maize (X304C) conducted at Jaiba, MG, Brazil, from June to December 1980.

Levels of maize stover	Grain Yield	Mean Ear Wt.	Plant Count
kg/ha[1/]	kg/ha	g	(No./Plot)
0	657 c[2/]	33.3 c	49.0 a
1042	1100 bc	40.7 bc	51.0 a
2083	1280 bc	44.7 bc	51.7 a
4167	1076 bc	43.3 bc	49.0 a
6250	1046 bc	39.0 bc	50.3 a
8333	1108 bc	44.0 bc	49.7 a
10417	2017 ab	56.0 ab	53.0 a
12500	2544 a	72.7 a	52.0 a

1/ Adjusted to 15.5% moisture; means of 3 replications.

2/ Means with the same letter are not significantly different at the 0.05 level by Duncan's Multiple Range Test.

Table 20. Maize, Cargill hybrid 111, yield data from a wet season population density "wheel" experiment (B-15) planted November 1977 and harvested April 1978 at Jaiba, MG, Brazil. Each value represents the mean of four replications of 8-plant samples.

Circle 1/	Density plants/ha	Ears/ 8 plants	Ear Wt. g/ear	Grain Wt. g/8 plants	100-Seed Wt. g	Grain Yield kg/ha 2/
3	70,126	7.8	148	942	254	8349
4	63,467	9.5	123	951	253	7612
5	57,544	10.0	124	1030	262	7446
6	52,174	9.5	132	998	260	6596
7	47,304	9.3	136	1031	274	6163
8	42,889	11.0	140	1276	273	6869
9	38,886	11.8	130	1261	262	6186
10	35,257	12.0	140	1353	263	6017
11	31,967	12.8	146	1526	262	6146
12	28,983	13.0	142	1516	288	5529
13	26,279	14.8	143	1746	274	5794
14	23,826	15.0	131	1582	295	4765
15	21,603	14.8	146	1779	295	4843
16	19,586	14.8	157	1912	291	4702
17	17,758	15.5	173	2140	288	5241
18	16,101	14.8	168	2034	300	4130
19	14,598	16.0	169	2211	294	4063
20	13,236	18.5	158	2386	306	3986
21	12,001	17.3	151	2088	302	3162
22	10,881	17.0	160	2182	308	2986
23	9,865	16.3	167	2218	307	2763
24	8,945	17.5	166	2393	322	2704
25	8,109	18.0	168	2451	329	2511
26	7,353	19.5	164	2626	310	2428
27	6,667	17.0	172	2128	328	1784

1/ The innermost and outermost circles were discarded as borders.

2/ Adjusted to 15.5% moisture.

Table 21. Maize, Cargill 111, data means from a date of planting experiment (B-32) conducted at Jaiba, Brazil.

Planting date	Grain	Ears/plot	Ear Wt.	Shelling	Grain H_2O	Lodging
	kg/ha	no.	g	%	%	%
15 Oct 1978	6386 a[1/]	66 a	179 a	78.7 a	23.0 a	15.3 a
04 Nov 1978	5935 a	71 a	146 b	77.7 a	22.7 a	38.3 a
24 Nov 1978	5005 ab	72 a	129 c	75.8 a	22.6 a	30.7 a
14 Dec 1978	3982 b	72 a	102 d	75.6 a	22.3 a	13.3 a
03 Jan 1979	2098 c	60 a	58 e	76.1 a	14.2 b	71.0 b

1/ Means with the same letter are not significantly different at the 0.5 level by Duncan's Multiple Range Test.

Table 22. Crop yield and economic data for four planting cycles of an irrigated, intensive management multicrop experiment (400 m^2) conducted at Jaiba, MG, Brazil.

Crop/Variety	No. 20-M Rows	Planting/Harvest Dates	Yield: plot yield	Yield: kg/ha	Unit Value $ US	Total Value $ US
First Planting Cycle, Aug 78 - Feb 79						
Raddish, Redondo Verm. Precoce	2	Aug 18/78 - Sep-Oct/78	237 dz	--	0.125/dz	29.62
Onion, Red Creole	12	Aug 18/78 - Jan 4/79	29.2 kg	1622	0.83/kg	24.24
Carrots, Nantes Superior	7	Aug 18/78 - Jan 10/79	124.0 kg	11,857	0.42/kg	51.67
Garlic, local cultivar	6	Aug 21/78 - None harvested	(poor germination)		--	--
Dry Bean, Campesino	26	Sep 11/78 - Dec 28/78	20.6 kg	515	0.63 kg	12.88
Maize, 111C (Cargill)	27	Sep 18/78 - Feb 24 /79	230.6 kg	5765	6.25/60 kg	23.95
Total Value, 1st cycle						142.36
Second Planting Cycle, Apr-Sep 79						
Dry Bean, Carioca	26	Apr 10/79 - Jul 25/79	60.0 kg	1500	0.82/kg	49.20
Maize, 111C (Cargill)	14	Apr 25/79 - Sep 18/79	24.7 kg	617	0.19/kg	4.70
Squash, Abobora Menina	5	Apr 25/79 - Aug-Sep/79	186.6 kg	12440	0.42/kg	78.37
Cucumber	5	Apr 25/79 - none harvested	--	--	--	--
Squash, Zuchini	3	Apr 25/79 - none harvested	--	--	--	--
Total Value, 2nd cycle						132.27

Table 22 cont'd

Crop/Variety	No. 20-m Rows	Planting/Harvest Dates	Yield: plot yield	Yield: kg/ha	Unit Value $ US	Total Value $ US
Third Planting Cycle, Sep 79 - Jul 80						
Cassava	13	Sep 20/79 - Jul 3/80	954.3 kg	23,857.5	0.16/kg	152.69
Dry Beans, Carioca	26	Sep 22/79 - Dec 28/79	37.4 kg	935.0	0.95/kg	35.53
Peanut, Tatu	12	Jan 4/80 - None harvested	--	--	--	--
Total Value, 3rd Cycle						188.22
Fourth Planting Cycle, Jul 80 - Dec 80						
Onion, Early Yellow Globe	26	Jul 11/80 - Nov 19/80	466.3 kg	11,657.5	0.65/kg	303.10
Dry Bean, Black Rico 23	26	Jul 15/80 - Oct 25/80	49.3 kg	1,232.5	1.20/kg	59.16
Carrot, Nantes Superior	13	Aug 25/80 - Dec 29/80	458.6 kg	11,465.0	0.73/kg	334.78
Total Value, 4th Cycle						697.04
Total Value of all 4 cycles						1,159.88
Mean Value per planting cycle						289.97

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