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Assessment of Agrotechnology Transfer in a Network of Tropical Soil Families

Benchmark Soils Project
Progress Report 3
July 1979-September 1982

Benchmark Soils Project
Department of Agronomy and Soil Science
College of Tropical Agriculture and Human Resources
University of Hawaii

and

Department of Agronomy and Soils
College of Agricultural Sciences
University of Puerto Rico

On the cover:
The diversity of BSP's research activities converge on the central objective of demonstrating the use of soil classification to predict similar crop performance on similar soils which may be located in different parts of the world. The experiments illustrated on the cover are those of maize, fuelwood trees and vegetable crops -- test crops which were selected to demonstrate differences and similarities in crop performance in the agroproduction niches defined by the three soil families. The project also insures that in-country cooperators would benefit from the concepts being demonstrated by providing training in Soil Taxonomy and agrotechnology transfer.

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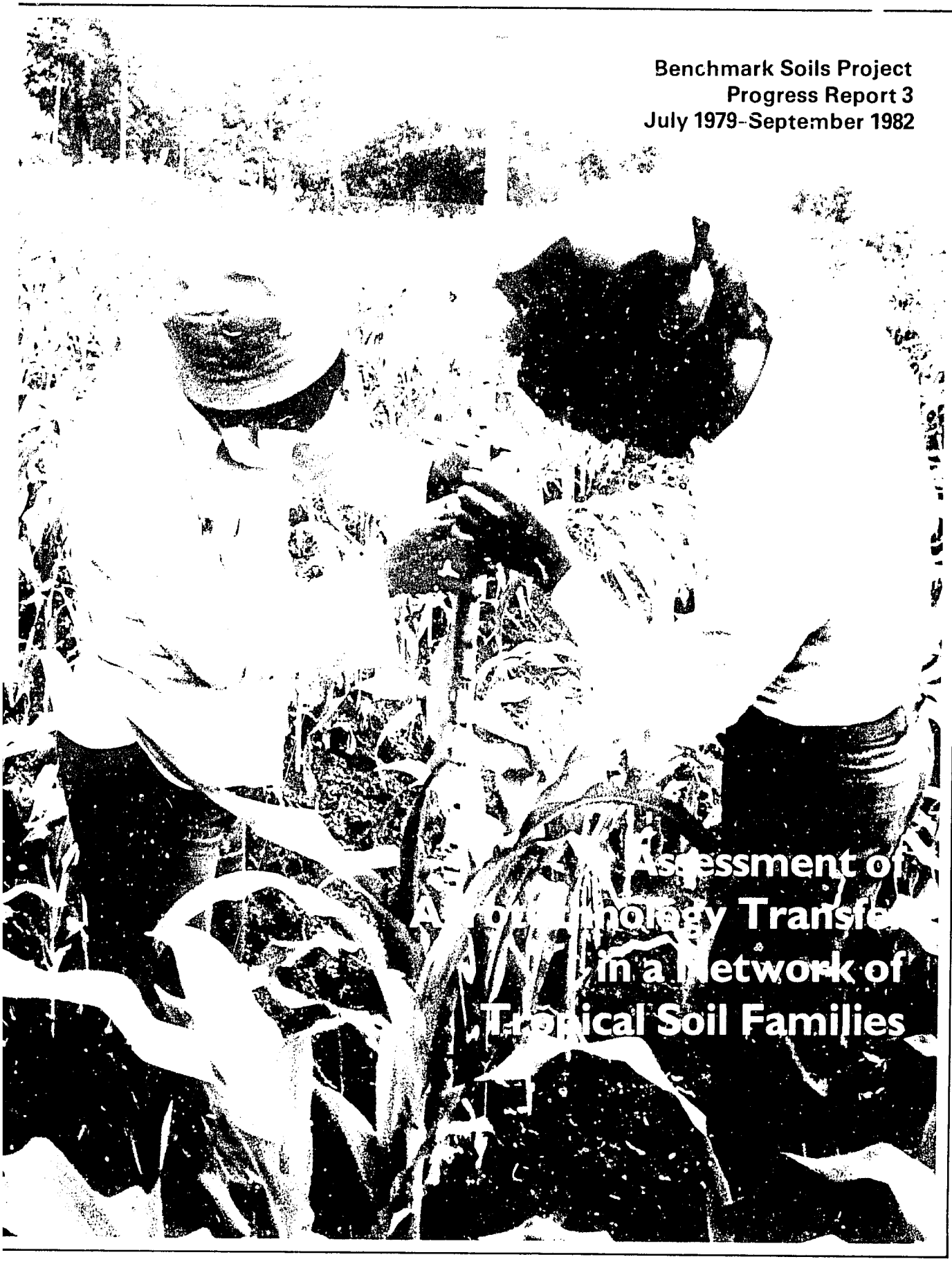

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Foreword

An uneven capacity to utilize technology creates a corresponding unevenness in the distribution of wealth among nations of the world. This unevenness is made prominent by the fact that the number of technically advanced countries diminishes with increasing proximity to the equator. To lessen this economic and technological gap, the industrialized countries of the north and south have joined forces with the developing countries of the intertropical region to create a network of international agricultural research centers to design and develop agricultural technology for the tropics. As a result of this combined effort, an immense quantity of agricultural technology is now being generated not only by the international centers but by the national agricultural research centers as well.

To achieve their goal of closing the economic and technological gap, the research centers must transfer their new discoveries to the largest number of clients with a minimum of error. Since faulty transfers of technology are as costly to the recipient as successful transfers are profitable, one aim of agricultural research should be to maximize successful transfer and minimize failures. The aim of the Benchmark Soils Project is to test principles and concepts that will enable people to do just that.

For example, the most frequently produced innovation is the seed of a new, high-performance cultivar of a food crop. But the performance of a plant that emerges from the seed is sensitive to the environment where it is planted, thus one must be sure that the environmental requirements of the technology match the environmental characteristics of the new location. Most transfers are made with incomplete knowledge of these factors so that success often depends on chance. Technology transfers based on trial and error are too slow and costly.

The Benchmark Soils Project employs principles and concepts contained in Soil Taxonomy to increase the success rate of technology transfer. Its premise is that a technology is more likely to succeed if it is transferred among locations that are environmentally similar. The criteria set forth in Soil Taxonomy enable specific, named kinds of agroenvironments to be identified.

This third Progress Report of the Benchmark Soils Project contains research results conducted on three named kinds of Benchmark agroenvironments. The aim is to increase the success rate of named kinds of crops to be matched and transferred to named kinds of agroenvironments.

Names play an important role in technology transfer because they allow crop requirements or land characteristics to be associated with identifiable objects. Also, names contribute to economy of thought and action.

For example, cassava *(Manihot esculenta)* has different requirements from potato *(Solanum tuberosum)*, and pigeonpea *(Caganus cajan)* has different requirements from soybean *(Glycine max)*. By the same token, a clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox differs in characteristics from a thixotropic, isothermic Hydric Dystrandept, and both differ from a clayey, kaolinitic, isohyperthermic Typic Paleudult. A subsistence farmer who cultivates clayey, kaolinitic, isohyperthermic Typic Paleudults frequently grows cassava but almost never potato. On the other hand, a farmer on thixotropic, isothermic Hydric Dystrandepts will cultivate potato instead of cassava. The farmer's choice is determined not so much by what he wishes to grow, but by the capacity of his land to accommodate the requirements of a crop.

Some crops such as maize have been bred for a wide range of environmental conditions, but each cultivar of the crop has a

limited sphere of transferability. There are maize cultivars that perform equally in the thixotropic, isothermic Hydric Dystrandepts and the clayey, kaolinitic, isohyperthermic Typic Paleudults, but would be recommended for one soil rather than the other. This would be the case for a cultivar susceptible to a disease that is prevalent in one soil environment and not in the other. This report contains several such examples.

It is also possible to link specific management practices to named kinds of soils. The amount and kind of fertilizers required to achieve optimum yields and the proper manner for applying them differs for different kinds of soil. The interpretation of soil tests for diagnostic purposes differ for different named kinds of soil.

The closing of the technology gap depends not only on technology development but on development of methods to transfer technology to the right places in a timely manner. A technology is appropriate only when it is used in its proper niche. This report illustrates how new cultivars and soil management practices can be transferred to new locations by relating their requirements to characteristics of named kinds of soil.

Crop response to phosphorus treatments were recorded in transfer experiments such as that in the thixotropic, isothermic Hydric Dystrandept near Naga City, Philippines. Soils of this family normally occur in the vicinity of volcanoes.

Highlights of Progress

A Network of Benchmark Soil Families

Three soil families from upland areas that have the potential to be productive under appropriate management practices were selected to test the hypothesis of agrotechnology transfer. Detailed soil surveys were conducted in nine countries, and a network of three soil families were established on 23 experimental sites in Brazil, Cameroon, Hawaii, Indonesia, the Philippines, and Puerto Rico.

- The network of Tropeptic Eutrustox is in the phase-down stage. All sites in Brazil and Puerto Rico were terminated in 1981. Two sites in Hawaii continue to be operational.
- The network of Typic Paleudults is completely operational with a total of seven sites covering three countries—Cameroon, Indonesia, and the Philippines. Data generation is continuing at all sites.
- The network of Hydric Dystrandepts continues to be operational; field operations have been terminated in three of the nine sites.

Successful Test of a Statistical Model for Agrotechnology Transfer

Statistical tests on the Hydric Dystrandepts were completed in 1981, indicating that the hypothesis of agrotechnology transfer from one location to another on the basis of the soil family is valid and that crop response can be predicted. The statistical test of the transfer model combines data of experiments from different countries and sites on one family and predicts the yield response of maize at another site of the same soil family.

- Tests of the model on the Hydric Dystrandepts were successful. Tests are being continued for the Typic Paleudults.
- The Project demonstrated that there is a similarity of response to phosphorus in soils that are widely separated but are within a common soil family.
- Phosphorus was required on Hydric Dystrandepts to achieve acceptable maize yields, and response to nitrogen was generally marked throughout the Hydric Dystrandept network, especially at the highest phosphorus rates.
- On the Tropeptic Eutrustox, the transfer experiments produced the highest yields to date: 12 metric tons/ha. Less phosphorus is required for acceptable maize yields on the Tropeptic Eutrustox than on the Hydric Dystrandepts.
- Yields on the Typic Paleudults were comparable to those of the Hydric Dystrandepts with marked response to nitrogen and phosphorus, especially on the Indonesia sites.
- Coded levels of phosphorus for each treatment in the experimental design continue to be determined by the modified Truog method.
- The amount of phosphorus fertilizer required to attain the coded levels was much greater in the Hydric Dystran-

depts. Rates of phosphorus fertilizer application for the Typic Paleudults and Tropeptic Eutrustox were comparable.

- Maize yield levels are highest in the warm, dry Tropeptic Eutrustox and lowest in the cool, moist Hydric Dystrandepts.

Soil Taxonomic Considerations and Interpretations

The nonstatistical approach to agrotechnology transfer through soil taxonomic considerations was expanded through a collaborative effort with scientists in the Hawaii Institute of Tropical Agriculture and Human Resources (HITAHR) and is compiled in this Progress Report. Below are examples of transferable information that can be made through soil classification, particularly Soil Taxonomy. Early indications demonstrate that the quantitative determinations for soil and environmental characteristics used in Soil Taxonomy lend themselves to evaluating criteria for land qualities for specific land use.

- Nitrogen-fixing tree species, mostly legumes that were planted in each of the three soil families, reflect soil family differences in their growth as early as six months after planting in the field.
- Erosivity, as expressed by the erosion index, was found to be similar among sites of the same soil family.
- Occurrence of certain pests and diseases are favored by certain environments which can be inferred from the soil family name. A typical example is downy mildew of corn which is prevalent in the warm and humid environment of the Typic Paleudults. This disease is rare in either the cool and wet or the warm and dry soil environments.
- A modified Truog extractant for soil phosphorus was successfully calibrated for all three soil families to establish the P treatments for maize, based on a critical level of extractable P which has a value of 25 ppm for this crop. Soil family differences occur in the amount of P required to reach this critical level.

Crop and Soil Management Information

Crop, soil, and weather data for transfer, management, and variety experiments were compiled and stored in the Benchmark Data Bank for application as the data bank system is expanded. Information on variety and management trials was available to local governments for in-country use.

- A total of 14 variety trials were conducted on primary sites of all three soil families.
- Residual fertilizer experiments continue to effectively demonstrate that phosphorus application is effective for several crops, and thus the net cost of fertilizer per crop is reduced (Hydric Dystrandepts) for soils of the three families.
- Initial results from placement studies show promise for developing simplified fertilizer application techniques to maximize return from small phosphorus applications on soils with high phosphorus fertilizer requirements for Hydric Dystrandepts and Typic Paleudults.
- The scope of management experiments was focused on the relationship of crop performance to soil and weather characteristics of each soil family. A series of cropping systems were designed to be installed in a number of sites.

A Framework for a Model Crop and Soil Data Bank

The crop and soil data bank was enlarged to include a weather data file. A combination of the three files is being systematized to provide a framework for the development of an interpretation data file. The crop file is being expanded to include crop modelling to develop further means to identify constraints to crop development in agroenvironments described by the soil family. The soil data file on characterization properties has been computerized and stored in a format similar to that of the Soil Conservation Service

A Network of Cooperating Countries and Agencies

The Project has had an important role in the growing network of communicating and cooperating research institutions focusing on the food problems of the tropical world.

- The Project continues to maintain cooperative agreements with five agencies/institutions and established linkages with three international agricultural research centers.
- Project personnel organized the Third and Fourth International Soil Classification Workshop in Syria and Rwanda, in April 1980 and June 1981, under a special grant from the U.S. Agency for International Development through SMSS.
- PCARRD (Philippine Council for Agriculture and Resources Research and Development), CSR (Center for Soil Research), IRA (Institut de la Recherche Agronomique), and cooperating agencies in the Philippines, Indonesia, and Cameroon convened Advisory Committees to provide guidance in the conduct of regional programs by the Project and to serve as a bridge between host-country scientists and planners.
- Project personnel collaborated with SMSS scientists in presenting the First Forum on Soil Taxonomy held in Fiji.
- The New Zealand Soil Bureau and the

Poster displays prepared for seminars and workshops are effective means of disseminating project concepts and accomplishments (Soils with Variable Charge Conference, New Zealand).

International Soil Science Society invited the Benchmark Soils Project to participate in an informative one-day symposium on project accomplishments and impact entitled Soils with Variable Charge.

Awareness and Utilization of Project Concepts

Dissemination of research results and the theories and implications of the Project, through participation in conferences and through publications, has stimulated interest in the Project and has served as a catalyst in the utilization of these concepts in various areas.

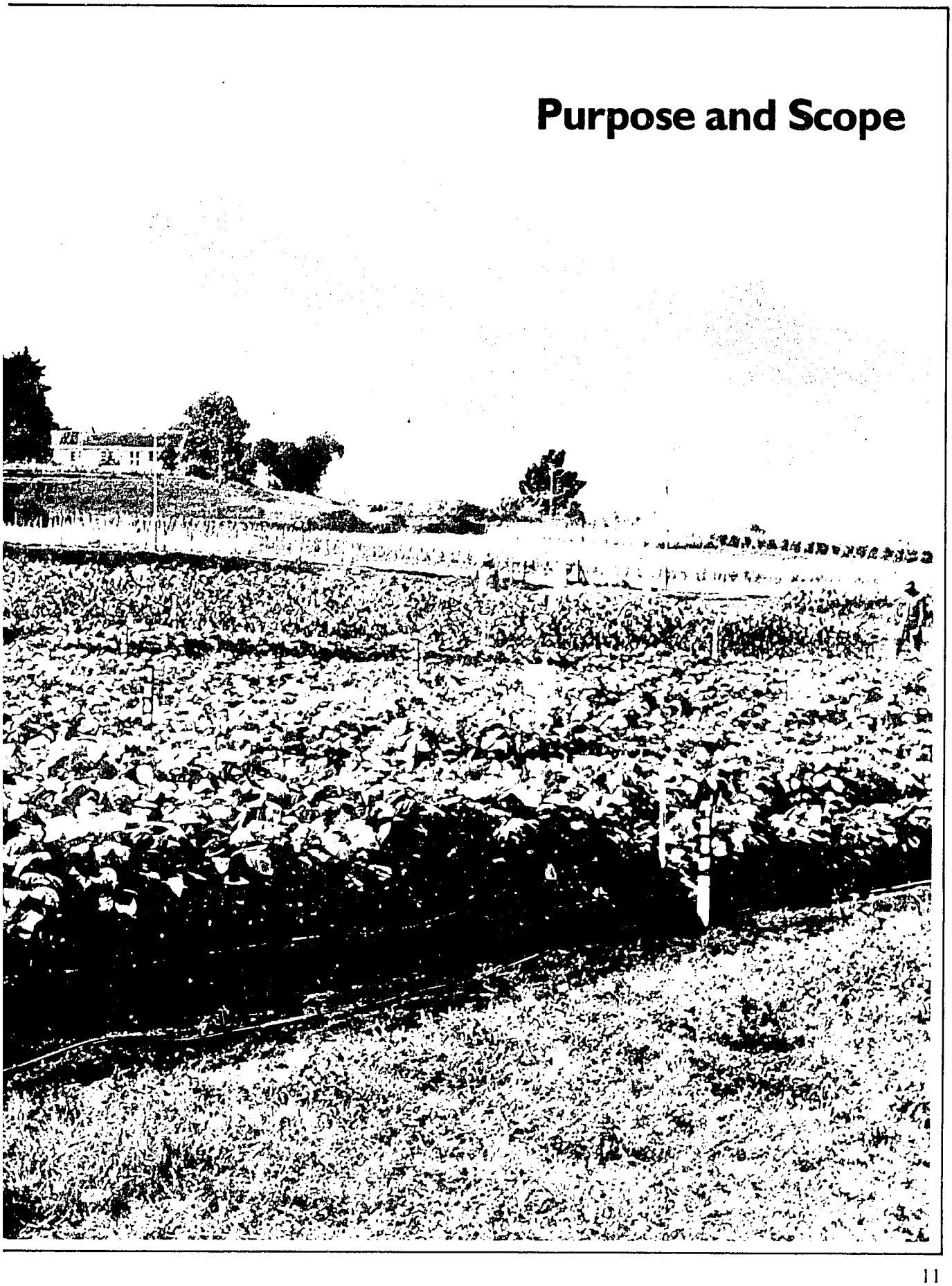
- The mailing list for Project publications now contains 1959 people from more than 80 countries. Expressions of interest have been received from a number of countries, including Haiti and Rwanda. The list is jointly used by the Soil Management Support Services (SMSS) program of SCS.
- A joint proposal for the classification of Philippine soils and the use of Soil Taxonomy for agrotechnology transfer was prepared by Philippine Project personnel and representatives from BSP-cooperating agencies, the Bureau of Soils, PCARRD (the Philippine Council for Agriculture and Resources Research and Development), and the University of the Philippines, Los Baños.
- The Benchmark Soils News continues to be the primary means of disseminating information related to Project concepts and activities. A total of 5 Technical Reports also have been published. In addition, numerous papers have been presented at conferences and workshops to both local and international audiences.

Training on Soil Taxonomy and Agrotechnology Transfer

Awareness of Project goals has been disseminated through the development of a training program on Soil Taxonomy and Agrotechnology Transfer.

- The immediate impact of the workshop was the support expressed by the Philippine government agencies for a coordinated plan for the participants to systematically classify soils at the experiment stations in each region according to Soil Taxonomy.
- Seminars on Agrotechnology Transfer were organized in both Indonesia and the Philippines in 1980 to convey concepts and experiences to local scientists and officers.
- A second training workshop on Soil Taxonomy was conducted in Indonesia in 1980. Participants of the first such workshop held in the Philippines met in 1980 to present studies and results of workshop-designed activities developed in 1979.
- Graduate students from both the Philippines and Indonesia received their graduate degrees in 1980 and 1981, respectively. Five additional students are expected to receive their degrees by the end of 1982 and 1983.

Purpose and Scope



General Background

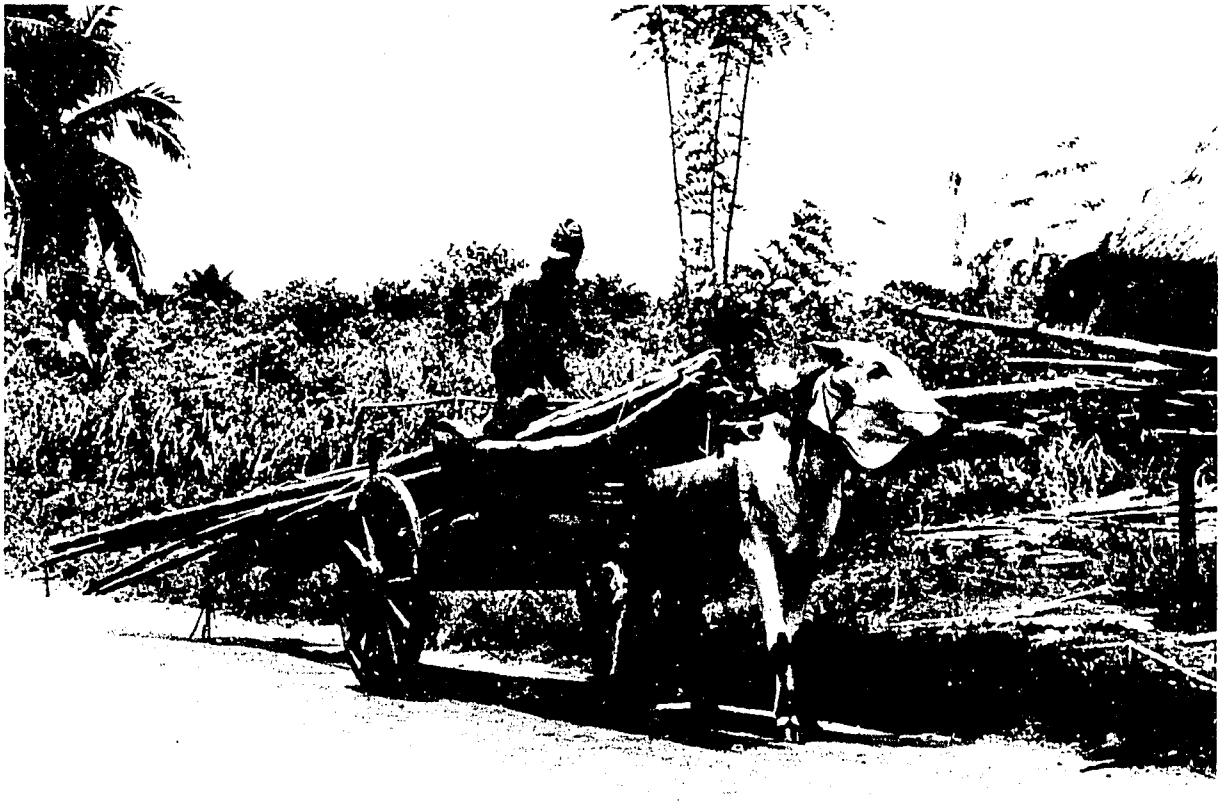
In May 1974 a contract was signed between the U.S. Agency for International Development (AID) and the University of Hawaii (UH) to initiate a project entitled "Crop Production and Land Capabilities of a Network of Tropical Soil Families." A companion contract (AID/Contract No. ta-C-1158) was signed with the University of Puerto Rico in December 1975. The projects are known more briefly and popularly as the Benchmark Soils Project (BSP). The purpose of the Project is to test an innovative approach to agrotechnology transfer designed to assist LDCs (less-developed countries) in appropriately utilizing their land resources for increased and better quality food production by bypassing three major constraints: scarcity of qualified research personnel; insufficient capital; and, above all, time needed to close the widening gap between agroproduction and food requirements. The traditional approach to agricultural research is extremely time-consuming, and farmers urgently need the basic information conducive to higher outputs; they cannot wait for local research to regenerate information that is already available to them via transfer.

The concept in question—"Can agrotechnology be transferred from one tropical region to another tropical region on the basis of Soil Taxonomy at the soil family level of classification?"—will have far greater effect on food production and its tempo than may seem possible at first glance. Its effect may well be profound. First, millions of dollars worth of research information produced by thousands of man-year efforts will be available for immediate tapping. Second, costs of site-specific trials all over the world will be reduced. Third, the overall process will be the formation of a worldwide network of expertise and a Soil and Crop Data Bank(s) to expedite and provide the needed information and communication for development. Fourth, the concept of agrotechnology transfer will be all-encompassing; it will include transfer of information on crops and cropping systems, water management practices, erosion control measures, suitability to new crops, and economies of crop production.

Project Objectives

The thrust of the Benchmark Soils Project is the acceleration and reduction of cost of agricultural planning and development in the less-developed countries through the process of agrotechnology transfer. This relates to AID's objective of expanding the information available on the management of tropical soils to increase food production in the tropics. The objectives are:

1. To determine scientifically the transferability of agroproduction technology among tropical and subtropical countries.
2. To assist tropical countries in assessing the potential of upland areas for intensive cropping and intensive soil management.
3. To demonstrate the value of soil and land classification in formulating agricultural development plans in selected areas.



Transfer of agrotechnology may not always involve transfer of material resources but may also be achieved by more efficient utilization of indigenous technology (Sumatra, Indonesia).

There are five major activities through which these objectives are being met:

1. Establish and complete the network of soils.
2. Establish, install, complete, and analyze transfer experiments.
3. Establish, install, complete, and analyze crop (variety) and soil management experiments.
4. Analyze information for soil interpretation and land evaluation.
5. Disseminate principles, concepts, and results.

The first activity was completed in 1980 and is described in the section on Establishment of a Network of Benchmark Soil Families, while the remaining four activities are being continued. The rationale, approach, and methodology developed in association with agronomic experiments to test the transfer hypothesis (Activity 2) can be found in publications produced by the Project. Progress Reports No. 1 and No. 2 are relevant as well as the following publications:

Cady, F. B., C. P. Y. Chan, C. L. Garver, J. A. Silva, and C. L. Wood. 1982. Quantitative evaluation of agrotechnology transfer: a methodology using maize response to phosphorus on Hydric Dystrandepts in the Benchmark Soils Project. BSP Tech. Rep. 6. College of Tropical Agr. and Human Resour., Univ. Hawaii. 31 pp.

Wood, C. L., and F. B. Cady. 1981. Intersite transfer of estimated response surfaces. Biometrics 37:1-10.

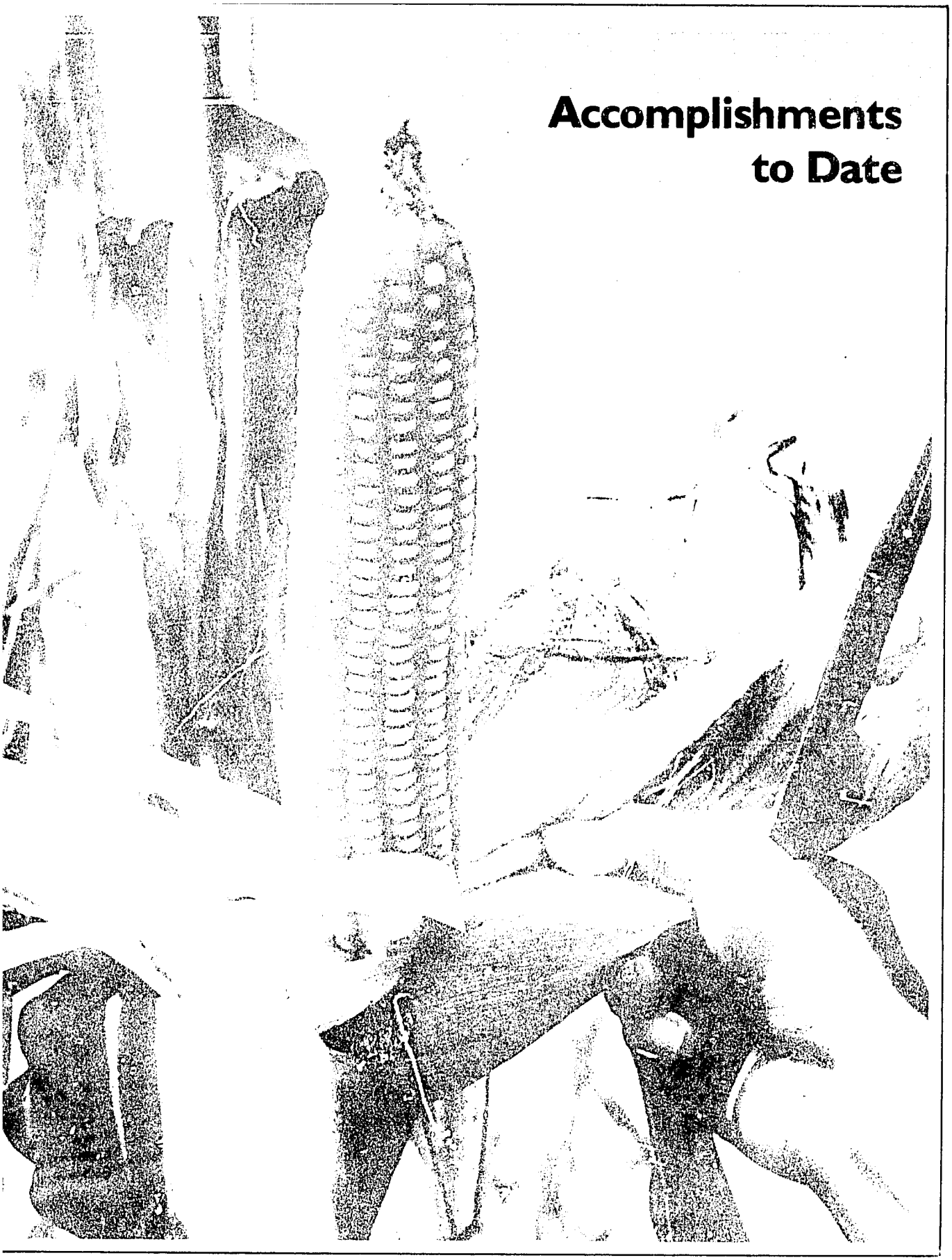
Silva, J. A. (ed.) 1981. Experimental designs for predicting crop productivity with environmental and economic inputs for agrotechnology transfer. Departmental Paper 49. Hawaii Institute of Tropical Agr. and Human Resour., Univ. Hawaii. 184 pp.

Beinroth, F. H., G. Uehara, J. A. Silva, R. W. Arnold, and F. B. Cady. 1980. Agrotechnology transfer in the tropics based on Soil Taxonomy. Advances in Agronomy 33:304-339.

Data generated for transfer experiments since the publication of Progress Report No. 2 are compiled in Appendix 1 and is used in the section on Quantitative Evaluation of the Concept of Agrotechnology Transfer.

Activities 3, 4, and 5 are related to much of the material presented in the Accomplishments to Date as well as in Other Accomplishments.

Accomplishments to Date



Establishment of a Network of Benchmark Soil Families

The soil family was selected as the basis for the transfer of agrotechnology because it stratifies the soils of the world into relatively narrow agroenvironments, integrating the environmental (climatic) information that is important to plant growth with the physical and chemical characteristics that affect soil response to management. The three soil families that were selected to test the hypothesis of agrotechnology transfer are:

- The thixotropic, isothermic Hydric Dystrandepts
- The clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox (This is the link between the Hawaii and Puerto Rico projects.)
- The clayey, kaolinitic, isohyperthermic Typic Paleudults

Establishing the network of soils in four countries and six locations in the tropics required, for each cooperating country, a combination of negotiation, soil survey and classification, and training. Agreements were negotiated with the cooperating country government agencies for use of the site and joint participation in the Project. For each cooperating country, a project leader was trained in Hawaii in the agronomic techniques to be followed and then assigned to head the country project on location. Table 1

Site selection required a detailed soil survey of likely areas for establishment of network sites, as in Cameroon.

Table 1. Soil family network of experimental sites.

Location	Site	Reference abbreviation	Type of site	Milestone[a] achieved
Soil Family A: thixotropic, isothermic Hydric Dystrandepts				
Hawaii	Niulii, Iole, North Kohala, Hawaii	IOLE	Primary	5
	Kukaiau, Honokaa, Hawaii	KUK	Secondary	5
	Niulii, Halawa, North Kohala, Hawaii	HAL	Secondary	6
Philippines	Philippine Union College, Panicuason, Naga City	PUC	Primary	5
	Palestina, Pili, Camarines Sur	PAL	Secondary	5
	Burabod, Calabanga, Camarines Sur	BUR	Secondary	5
Indonesia	ITKA, Cisarua, Java	ITKA	Primary	6
	PLP, Lembang, Java	PLP	Secondary	6
	Segunung, Cipanas, Java	LPH	Secondary	5
Soil Family B: clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox				
Puerto Rico	Isabela	ISA	Primary	6
	Isabela	ISA-2	Secondary	6
	Isabela	ISA-3	Secondary	6
Brazil	Paraná, Jaiba	PAR	Primary	6
	Bahia, Jaiba	BAH	Secondary	6
	Ceará, Jaiba	CEA	Secondary	6
Hawaii	Maunaloa, Molokai	MOL	Primary	5
	Waipio, Oahu	WAI	Secondary	5
Soil Family C: clayey, kaolinitic, isohyperthermic Typic Paleudults				
Philippines	Davao, Mindanao	BPI	Primary	5
Indonesia	Lampung, South Sumatra	NAK	Primary	5
	Lampung, South Sumatra	BUK	Secondary	5
	Lampung, South Sumatra	BPMD	Secondary	5
Cameroon	Barombi-Kang	CAM	Primary	5
	Southwest Province	BAK	Secondary	5

[a]Milestone: 1 = soil survey initiated; 2 = soil survey completed; 3 = agreements signed; 4 = site prepared and staffed; 5 = experiments underway; 6 = experiments completed.

shows the milestones achieved to date on the network; Table 2 shows the purpose and expected results of the types of experiments.

The eight sites on the Hydric Dystrandepts are fully operational. Continuing agreements with the cooperating agencies—PCARRD (Philippine Council for Agriculture and Resources Research and Development) in the Philippines and CSR (Center for Soil Research), formerly known as SRI (Soil Research Institute) in Indonesia, and with the Kohala Corporation and Davies Hamakua Sugar Company, formerly Honokaa Sugar Company, in Hawaii—are renewed periodically.

Two sites are being phased out. Activities at the ITKA (Institut Theologia Kegurnan Advent) site in Indonesia and the HAL (Halawa) site in Hawaii were gradually scaled down. Both sites were productive but have become expendable for both technical and fiscal reasons. All usable areas for transfer experiments have been exhausted and other existing sites of the same family were selected for continuing implementation of management experiments.

The two sites on the Tropeptic Eutrustox in Hawaii also continue to be fully operational. Lease agreements with Molokai Ranch, Inc., on the Island of Molokai for the MOL site and with Gentry Pacific on the Island of Oahu for the WAI (Waipio) site are renewed each year.

The seven sites on Typic Paleudults in Cameroon, Indonesia, and the Philippines are operational. Agreements covering activities at these sites are included as part of the overall agreements with DGRST (General Delegation for Scientific and Technical Research), CSR, and PCARRD, respectively.

Table 2. Experiments in the Benchmark Soils Project's three soil family networks.

Type	Purpose	Expected results
Transfer experiments	To test hypothesis of transferability of agrotechnology	Similar yield response on similar soil families
Variety experiments	To identify most responsive and best-adapted varieties for transfer experiments	Selection of best-adapted varieties
Management experiments	To test and develop soil management practices for a particular soil family	Management practices recommended for a region and a soil family

A memorandum of understanding with DGRST is the basic document covering a cooperative effort among IRA (Institut de la Recherche Agronomique), FAO-Soil Resources Project at Ekona, USAID/Yaounde, and the Project.

The two sites (CAM and BAK) at Barombi Kang and one (SOR) at Sorsogon (Philippines) were the final three experimental sites to be established during this second extension phase of the contract. One hectare at Barombi Kang's primary site, CAM, was planted with maize in early 1980 to determine the uniformity of the proposed area for the initial transfer experiment, and this first transfer experiment was planted in November 1980. Approximately 2 hectares of the secondary site, BAK, have been cleared of trees and undergrowth. The area designated for transfer experiments was planted with maize to determine its uniformity in 1981. The first transfer experiment was planted and harvested in early 1982. The irrigation system at the Barombi Kang station was installed for coffee and cacao more than 20 years ago. The Cameroon government provided funds for the installation of a new hydraulic ram and conveyance system at Barombi Kang. A reservoir is under construction and scheduled for completion by April 1982. The new system was built to provide irrigation for BSP and the perennial crops at Barombi Kang. The Benchmark Soils Project contributed funds for some of the labor and materials for the reservoir designed by engineers affiliated with SATA (Swiss Association for Technical Assistance).

Agencies in cooperating countries contribute to Project expenses; thus they actively support and participate in Project planning and development.

Site establishment was completed at the Sorsogon site with the installation of a conveyance system for irrigation. Support and cooperation were provided by the Bureau of Soils, PCARRD, and the lessor of the land, del Rosario Farms.

Fig. 1 shows the network of cooperating countries on the three soil families of the Benchmark Soils Project. Agencies in cooperating countries contribute to Project expenses; thus they actively support and participate in Project planning and development. These host-country cooperating agencies include:

- Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG), Brazil
- Office National de la Recherche Scientifique et Technique (ONAREST), Cameroon
- Philippine Council for Agriculture and Resources Research and Development (PCARRD), Philippines
- Center for Soil Research (CSR), Indonesia
- University of Hawaii (UH), U.S.A.
- University of Puerto Rico (UPR), Puerto Rico

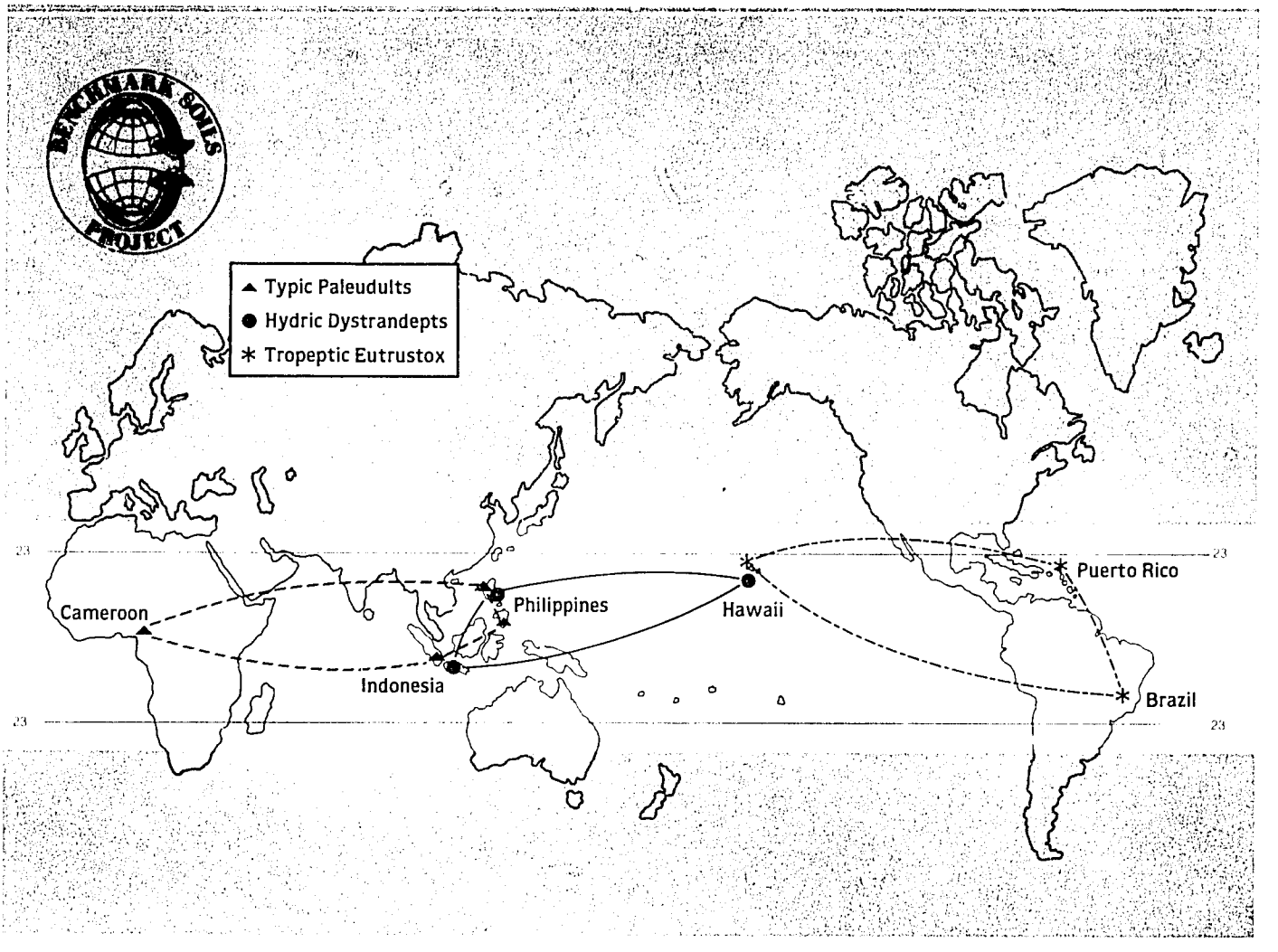


Fig. 1. The three soil family networks in the Benchmark Soils Project.

Executive Summary of the Final Report of the University of Puerto Rico's Benchmark Soils Project

To reiterate, 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 U.S. Agency for International Development (AID) as a companion project to a similar AID contract of the University of Hawaii. The UPR/BSP had a duration of seven years and terminated in December 1981. Both projects were closely coordinated and constituted an integrated joint endeavor of both universities.

The primary research objectives of the UPR/BSP 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.
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 less-developed countries (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 experiment 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 that 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 test crop. 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.

Test of the Transfer Hypothesis

Field data of the transfer experiments (UPR/BSP, 1981) were statistically evaluated with three different techniques developed under the auspices of the Benchmark Soils Project. They were the P-statistic, the confidence interval procedure, and the 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 (Wood and Cady, 1981) were also positive as shown in Fig. 2. If certain site variables are considered, the results indicate that 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.

Agronomic Accomplishments

The results of the agronomic research demonstrate the high productivity of Eutrustox with irrigation and moderate fertilizer inputs. Highest mean maize yields of more than 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.

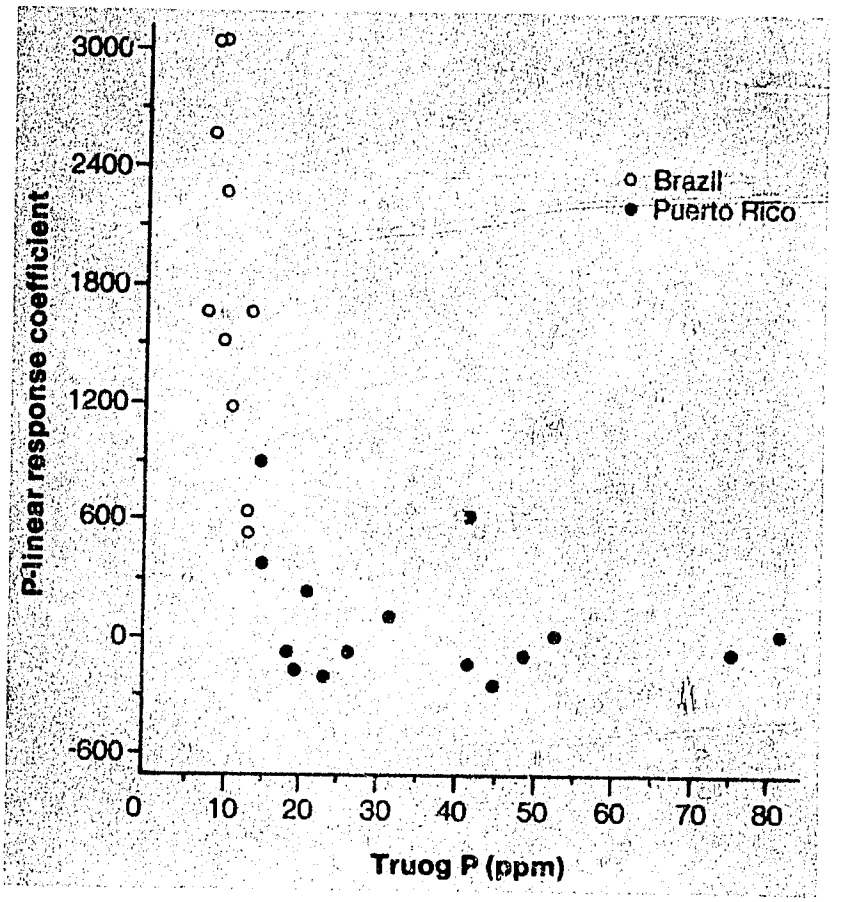
Hybrid 'X304C' was experimentally identified as a maize variety well adapted to the agroenvironment of Eutrustox. A maize composite population improvement study conducted with 88 varieties from all over the world, initiated by the UPR/BSP and now continued by EPAMIG, has produced promising changes in 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 also have been identified.

If certain site variables are considered, the results indicate that fertilizer response at a new site can be predicted on the basis of experiments conducted at other sites with the same soil family . . .

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

Fig. 2. Plot of relationship between the P-linear response coefficient and the Truog soil test P.



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 used effectively to conserve soil moisture and increase yields under rainfed conditions.

Dissemination and Impact

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 less-developed countries in producing the quality resource inventories that are the prerequisites for soil-based transfers of agrotechnology, to refine Soil Taxonomy, and to promote its application in the Third World. Thus SMSS is closely related to the BSP and facilitates possible follow-up activities.

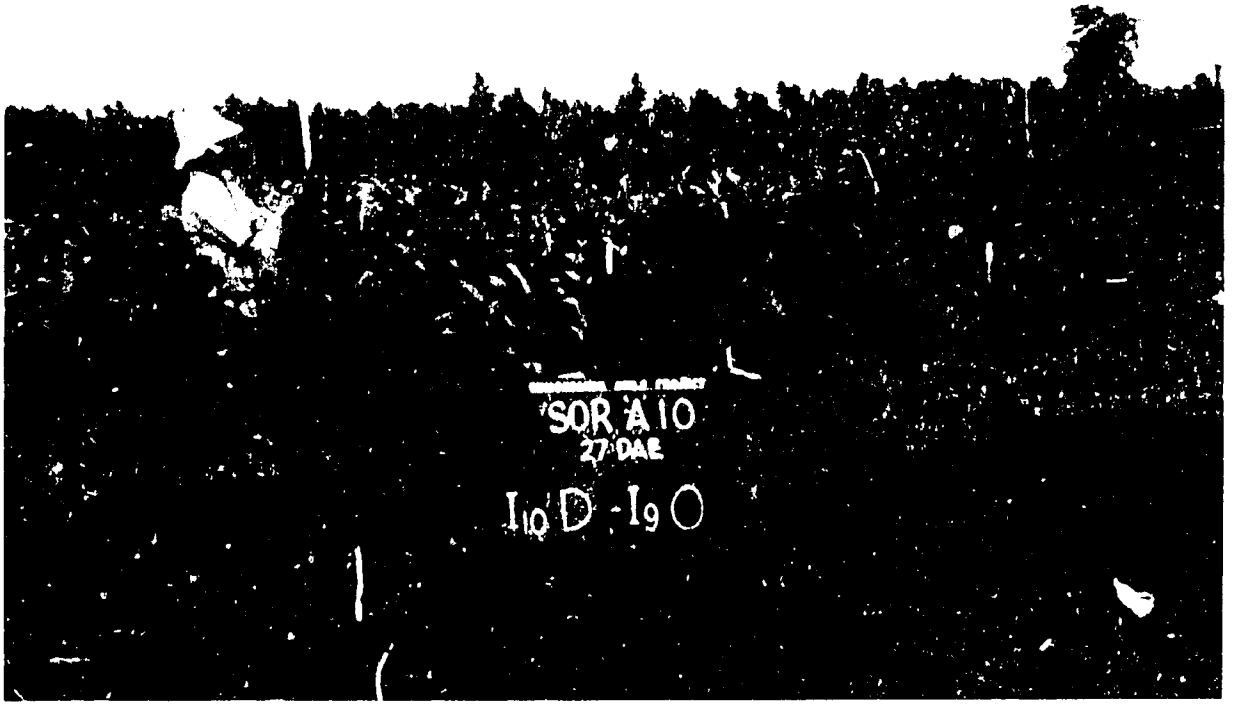
Planning meetings held at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the Food and Agriculture Organization (FAO) developed strategies for the implementation of the Benchmark Soils concepts and principles in a program of more comprehensive scope and wider geographical extent.

The primary impact of the BSP to date has been its ability to create an increased awareness and familiarity with the Project and its philosophy, to stimulate support activities, and to generate considerable momentum for the use of the Benchmark Soils concept for agrotechnology transfer.

Quantitative Evaluation of the Concept of Agrotechnology Transfer

The premise of the Benchmark Soils Project is that agrotechnology can be transferred from one similar ecological and environmental site to another. Sites that meet the taxonomic definition of the soil family of Soil Taxonomy are considered sufficiently similar to permit environmentally-sensitive technologies to be transferred among them. According to Soil Taxonomy, "the responses of comparable phases of all soils in a family are nearly enough the same to meet most of our needs for practical interpretation of such responses."

Although the desirability, and at times the implicit assumption, of transferring information on agricultural production requirements and recommended practices for specific crops in specific areas is widely recognized, to date there has been no means of "scientifically" assessing, for the purposes of prediction, whether the practices that are recommended for one set of sites will actually work at another "similar" site. Up to now, the time-



Maize response to phosphorus and nitrogen was recorded in transfer experiments in a Typic Paleudult network site in Sorsogon, Philippines.

consuming process of repetitive experimentation has been required as a test before specific practices have been implemented.

For a scientific and quantitative assessment of the transfer hypothesis, the experimental designers of the Benchmark Soils Project chose to study how a test crop (maize) would respond to a technology (an innovation, which presumes a *change* in technique or tools) in a number of widely separated locations.

This narrow definition of agrotechnology will let us *predict the response to a change in technology before that technology is applied.* This is statistical extrapolation—the inferring of an unknown from something that is known. The basic premise of our transfer model now becomes the prediction of *how much* increase in yield response can be expected from an application of a technology in a location where the technology has not been applied as determined by yield response in other locations of the same soil family. Thus, agrotechnology transfer is defined here as the extrapolation of a response-input relationship, estimated from known experimental situations to other similar agroenvironments.

. . . agrotechnology transfer is defined here as the extrapolation of a response-input relationship, estimated from known experimental situations to other similar agroenvironments.

This relationship has to be identified and estimated, and, before being used in practice, its worth evaluated quantitatively with experimental data. These data are obtained from a series of parallel-linked N × P experiments that are installed across the Project's three soil family networks using maize as the test crop. Crop yield, soil, and climatic data have been recorded for all experiments and the data subjected to statistical analysis.

Previous reports have developed the basic criterion used in assessing "goodness" of transfer predictions, which can be summarized as follows. Yields at new or "nonexperimental" sites have to be measured and compared with the yield predicted from the transfer model estimated from experimental sites. More specifically, it seems reasonable to judge the transfer process satisfactory if the predictions based on the experimental sites are close to predictions based on the observed yields at nonexperimental sites. Since plots have to be established at the new site, all the sites, old and new, are actually "experimental" sites. Then with a total of k experimental sites, we would set up a systematic series of calculations for evaluating the transfer conjecture with each site in turn assuming the role of a "nonexperimental" site. Briefly, the sequence of steps for a quantitative transfer evaluation includes:

1. Calculation of a site-specific prediction equation for each of the k sites based only on the yield data for that site. The differences between the site-specific predicted yields and the observed yields are called *site-specific residuals.*
2. Identification of the general nature of the transfer model. The simplest model would include the same components as the site-specific prediction equation of the first step. More complex transfer models incorporate uncontrolled site-variable information.
3. Estimation of the selected transfer model for each set of $(k - 1)$ sites.
4. Prediction of yields for each plot at one site using the transfer model estimated in Step 3 from the data of the other $(k - 1)$ sites. The differences between the transfer predicted yield and the observed yields are called *transfer residuals* and are calculated for each site.
5. Calculation of the ratio of the transfer residual sum of squares to the site-specific residual sum of squares where both sums of squares are added over the k sites. This specific criterion is called the *prediction* or *transfer statistic (P).*

Transfer Analysis Using 27 Hydric Dystrandept Sites

Evidence for transfer of maize response to phosphorus fertilization from one season to another season on a site, or from one site to another site within the Hydric Dystrandept soil family, has been obtained for several years. A summary of this evaluation using data from 27 sites is presented below (Table 3). Data are from sites in Indonesia, Hawaii, and the Philippines.

The transfer of applied phosphorus (P) response is evaluated separately from the applied nitrogen (N) response for two reasons: (1) P is the the most important controlled variable in these experiments; and (2) the analysis and graphics are easier to understand with one controlled input variable. Assuming that the PN interaction for the range of P and N utilized in a set of experiments is not important, then the P response can be analyzed separately by adjusting the plot of yields to remove the variability known to be due to the N factor.

The transfer of site average yields is of general interest, but required a relatively complex function of several uncontrolled variables. In addition, individual site means are not part of the consideration for determining the economic optimal level of phosphorus application. Consequently, in this transfer evaluation emphasis centers on the P-response portion of the relationship between yield and applied phosphorus.

The simplest transfer model (Model 1) used

Table 3. Within-site and transfer statistics for 27 Hydric Dystrandept sites.

Site	Within-site ordinary residual sum of squares (x10^3)	Transfer residual sum of squares (x10^3)		Average absolute differences between transfer predictions and within-site predictions (kg/ha)	
		Model 1	Model 2	Model 1	Model 2
IOLE-E-10	7,049	7,915	8,263	109	134
HAL-B-21	17,062	20,435	17,695	214	95
HAL-B-22	13,264	16,579	13,830	221	90
HAL-D-12	20,226	21,317	21,066	128	109
PUC-K-10	5,869	17,728	8,492	406	189
PUC-R-10	13,052	45,432	14,641	696	153
PUC-S-10	10,325	59,157	13,521	853	219
PAL-E-10	6,590	74,161	7,003	1009	79
PAL-F-10	8,379	30,249	9,692	574	136
BUR-B-10	25,055	50,172	30,069	598	275
BUR-D-10	12,677	20,523	13,947	343	136
PLP-G-10	29,893	33,072	32,324	214	191
LPH-A-16	16,240	20,004	17,047	236	110
LPH-D-20	7,947	8,924	8,108	120	48
LPH-E-10	17,880	17,950	17,964	32	35
LPH-E-12	19,563	20,555	20,114	116	87
LPH-G-10	25,800	30,685	27,185	232	122
LPH-G-11	41,424	47,119	42,522	253	111
ITKA-C-10	16,384	20,416	17,718	211	120
ITKA-C-11	32,090	34,542	32,809	166	86
ITKA-C-12	21,605	28,105	21,914	268	58
ITKA-D-10	19,867	31,670	22,155	355	156
ITKA-D-11	53,490	59,881	53,695	267	47
ITKA-E-10	18,445	21,518	19,165	185	88
ITKA-E-11	26,330	36,351	27,428	335	107
ITKA-K-12	24,638	28,071	24,640	227	5
ITKA-K-13	9,607	15,365	10,001	301	74
Total	520,751	818,196	553,009		
P Statistic		1.57	1.06		
Average				321	113
Range				32-1009	5-275

for P response includes the P linear and P quadratic terms—i.e., P and P^2. The differences between the within-site ordinary residual sum of squares and the Model 1 transfer sum of squares for each of the 27 Hydric Dystrandept sites is shown in Table 3. The transfer statistic, the ratio of the sum of squared transfer residuals to the sum of squared site-specific residuals, also shown in the same table, is associated with a very small probability level of occurring on chance alone. Therefore, this transfer model is not adequate.

Study of the uncontrolled variables that interact with response reveals that preplant soil phosphorus as measured by the modified Truog soil test (0.02N H_2SO_4 + 0.3% $(NH_4)_2SO_4$) is closely related to the magnitude of the P response. Therefore, this relationship was included as part of the augmented transfer model (Model 2) and the resultant transfer sums of squares are shown in Table 3. The probability level associated with the transfer statistic value of 1.08 is very likely to occur on chance alone, roughly one in two. This indicates that the predicted responses do not differ from the actual responses obtained in an experiment conducted at the site.

Fig. 3 and 4, PUC-S-10 and LPH-E-10, which are representative of the 27 sites used in the analysis, summarize graphically the transfer evaluation by showing the closeness of predicted values, estimated from the two transfer models, with the within-site predictions. In PUC-S-10 the transfer prediction curve estimated from the transfer model with Modified Truog information is closer to the site-specific prediction curve than the transfer prediction curve without Truog information. In LPH-E-10, curves from both transfer prediction models are close to the site-specific prediction curve. For the 27 sites in general, the dashed prediction curve, estimated from the transfer model with modified Truog information, is sufficiently close to the prediction curve obtained from site-specific experimentation so that we could use the transfer prediction in practice even if an experiment had not been available at the site. The average of the absolute values of differences between the dashed prediction curves of each transfer

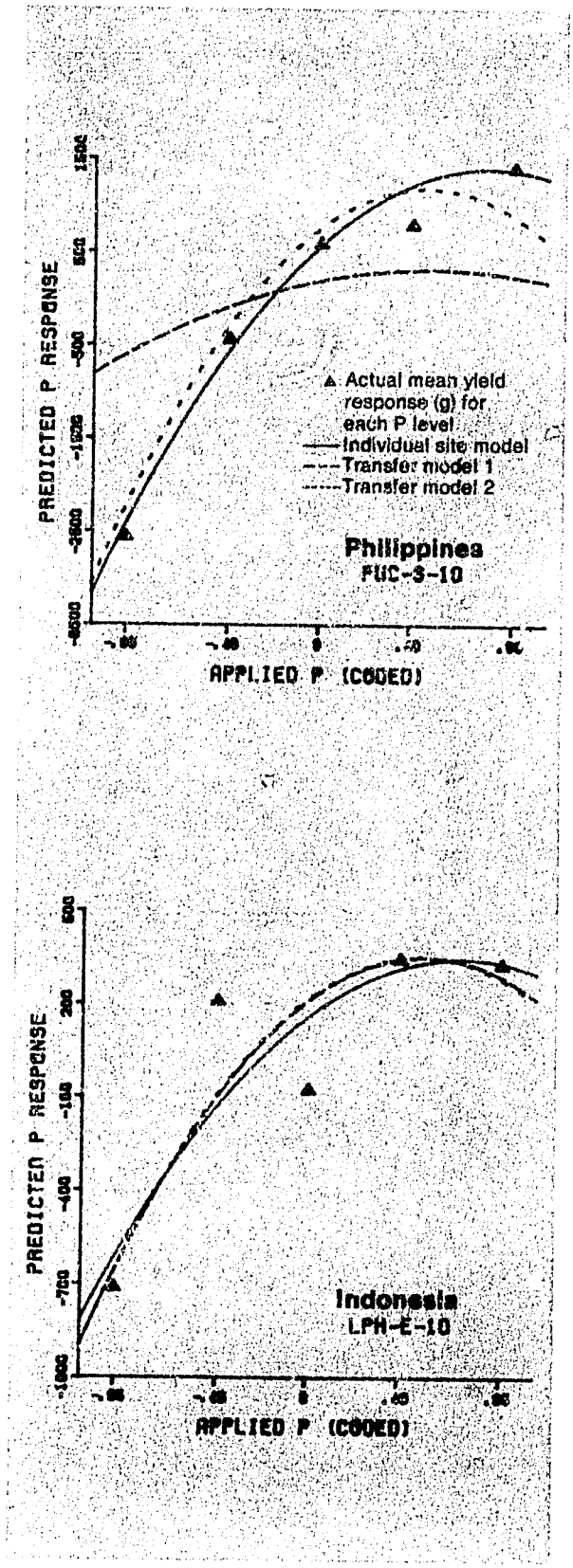


Fig. 3–4. The actual maize yield response obtained for the range of applied P in two of the 27 experiments on the Hydric Dystrandept sites is compared with predicted yield responses expressed as deviations from the mean of the experiment in kg/ha.

model and the solid within-site prediction curves are given in the last two columns of Table 3. On the average, the differences of both transfer models are not large enough to be of practical importance, although the smaller range of values in the last column would be a deciding factor for predicting with transfer Model 2, which includes a measure of the soil-P status of the site as determined by the modified Truog test. (A detailed discussion of this analysis is presented in BSP Technical Report 6, 1982.)

Transfer Analysis Using 12 Typic Paleudult Sites

A first approximation of testing the transfer hypothesis with data generated from the Typic Paleudult sites has been made and a summary is presented here. The approach followed is similar to that described above for the Hydric Dystrandept sites. However, the response to both N and P are included in this analysis because there were significant interactions between N and P. Data are from experiments in Indonesia and the Philippines.

The simplest transfer model (Model 1) for predicting maize response to P and N application included the same components as the site-specific model; that is, two terms for P response (P and P^2), two terms for N response (N and N^2), and one term for the interaction between P and N (PN). The mean yield for each experiment is subtracted from the plot yields as described for the Hydric Dystrandept.

The transfer residuals are calculated for each experiment as described previously (Step 4) and the ratio of the transfer residual sum of squares to the site-specific sum of squares (Step 5) summarizes the transfer analysis results as shown in Table 4. The probability of observing a value as large or larger than 1.33 on chance alone is less than 0.005, which indicates that the yield responses predicted with Model 1 are significantly different from the site-specific yield responses.

An augmented transfer model was developed that included the site-variable information, extractable soil phosphorus by the modified Truog method, soil nitrogen (an indirect measure was used and is explained in the 1980–81 Annual Report), temperature, and season (wet or dry). Thus Model 2 included the same five terms of Model 1 plus seven interaction terms, including applied phosphorus with soil phosphorus and weather

Table 4. Site-specific and transfer statistics for 12 Typic Paleudult sites.

Site	Site-Specific residual sum of squares ($x10^3$)	Transfer residual sum of squares ($x10^3$)		Average absolute differences between transfer predictions and site-specific predictions (kg/ha)	
		Model 1	Model 2	Model 1	Model 2
SOR-A	5,509	13,815	7,350	349	157
NAK-A	12,795	13,991	16,141	119	192
NAK-D	33,562	41,062	36,079	294	162
NAK-J	11,507	17,932	14,257	276	179
NAK-L	53,903	60,555	61,796	289	311
BPMD-A	33,166	36,063	35,386	174	161
BPMD-C	17,413	21,750	20,004	250	187
BPMD-D	25,207	31,742	26,364	329	138
BUK-A	15,899	37,166	21,986	557	308
BUK-C	11,607	24,525	16,924	460	283
BUK-D	18,085	25,239	20,542	338	210
BUK-E	24,487	26,493	27,072	159	206
Total	263,140	350,339	308,908		
P Statistic		1.33	1.15	300	208
Range				119-557	138-311

variables, and applied nitrogen with soil nitrogen. The transfer sums of squares are given in Table 4 (under Model 2) and may be compared with the site-specific residual sums of squares. The transfer statistic value of 1.15 for Model 2 indicates a value of 1.15 or larger on chance alone is 0.33; that is, a P value of 1.15 or larger would occur one out of three times on chance alone. These odds indicate that the transfer predictions are acceptably close to the actual responses obtained in an experiment conducted at the specific site.

Data gathered from the three soil families to date generally support the hypothesis that maize response to applied P can be transferred among sites of the same soil family.

The absolute differences between transfer predictions and site-specific predictions are reported in the last two columns of Table 4. In units of kg/ha, the differences are smaller for Model 2, and the magnitude of the individual experiment differences is sufficiently small in general so that we could use the transfer predictions in practice even if a site-specific experiment had not been carried out. Even though the average difference between the two transfer models is less than 100 kg/ha, transfer Model 2 is preferred for its smaller range of 173 kg/ha. Transfer Model 1 has a larger range (438) and also has a maximum difference of 557, compared with 311 for transfer Model 2.

Typic Paleudult Prediction from Hydric Dystrandept Transfer Model

A preliminary evaluation of the soil family specificity of the transfer equation was made using the Model 2 transfer equation developed for the Hydric Dystrandept soil family to predict the yield response to P in the Typic Paleudult experiments discussed in the previous section. The only information needed from each Typic Paleudult site for the transfer predictions is an extractable soil P test value. The maize responses for five levels of P fertilization in these 12 experiments were predicted and the absolute differences between transfer predictions based on the Hydric Dystrandept experiments and the site-specific prediction based on an experiment carried out at each of the Typic Paleudult sites was calculated. In general, the Hydric Dystrandept transfer model underestimates the site-specific predictions for the two lowest applied rates and overestimates for the two highest rates. The overall average absolute difference of 422 kg/ha is approximately four times larger than the value of 113 kg/ha for prediction of Hydric Dystrandept sites, indicating that the Hydric Dystrandept transfer model does not predict nearly as well for the Typic Paleudults as for the sites within the soil family for which it was developed.

Conclusions

Data gathered from the three soil families to date generally support the hypothesis that maize response to applied P can be transferred among sites of the same soil family. The results with the Hydric Dystrandepts indicate that response to P fertilizer applications can be predicted within about 110 kg/ha if a measure of soil P is included in the transfer model. In addition, the transfer statistic indicated that the predicted responses do not differ significantly from the actual responses obtained in an experiment conducted at the site. In the case of the preliminary analysis of data from the Typic Paleudults, the predicted responses were acceptably close to the actual responses obtained at the site, although the differences between the predicted and actual responses were higher than those found for the Hydric Dystrandepts—i.e., 208 vs. 110 kg/ha. The transfer equation for the Typic Paleudults included measures of soil N, temperature, and season in addition to soil P. An attempt to use the Hydric Dystrandept transfer equation to predict response for the Typic Paleudults indicated that this could not be done as well as when it was used for members of the Hydric Dystrandept soil family.

A major accomplishment of the Benchmark Soils Project has been the development

of a data analysis methodology for the quantitative evaluation of agrotechnology transfer. Within the Project, yield response to applied fertility was the crop variable transferred from experimental sites to new sites. Fortunately, the methodology developed by the BSP staff is general enough to be adapted by others in evaluating the utility of predictions based on a calculated model. Thus the data analysis procedures can be used for general problems of matching crop requirements, as reflected by measured crop characteristics, with controlled agrotechnology and uncontrolled environmental factors.

Simulation of Nitrogen Response in Hydric Dystrandepts

The U.S. Dept. of Agriculture/Agricultural Research Service Crop Systems Evaluation Unit (CSEU) at Temple, Texas, is developing a maize growth simulation model sensitive to climate, soil nitrogen and phosphorus fertility, soil physical properties, and genotype. The transfer experiments conducted by the Benchmark Soils Project provide valuable data sets for testing the accuracy of the model under tropical conditions. The model, when fully developed and adjusted for differences among soil families and maize genotypes, will provide a valuable tool in technology transfer. This report summarizes the simulated effects of nitrogen fertilizer rates on maize growth and yield on Hydric Dystrandepts in Hawaii. Future work could include simulation of the effects of nitrogen and phosphorus fertilizer rates on maize growth on Hydric Dystrandepts, Tropeptic Eutrustox, and Typic Paleudults in Hawaii, the Philippines, Indonesia, and Cameroon.

Model Calibration

Maize genotypes differ in many ways, including sensitivity to day length, thermal time (growing degree days) needed to complete various stages of growth, and potential kernel number per ear. The CSEU maize model contains several genotype-specific variables that quantify this variability. These variables were adjusted until reasonable agreement between actual and observed dates of silking and kernel numbers were obtained in the (+.85, +.85) treatment. The (+.85, +.85) treatment refers to the highest nitrogen and phosphorus treatment in the experiment.

Under normal conditions three sources of nitrogen are available to crops: residual mineral nitrogen in the soil profile prior to fertilization, fertilizer nitrogen, and organic nitrogen, which mineralizes during the growth of the crop. The relative sizes of these sources are affected by the rate and timing of fertilizer application, the previous cultural practices, and the rate of mineralization of the stable organic matter of the soil. No direct measurements of initial mineral nitrogen concentrations throughout the soil profile or rates of nitrogen mineralization were available. Initial soil nitrate concentrations and

the rate constant for mineralization of organic nitrogen were adjusted until the model accurately simulated kernel number in the (+.85, +.85) treatment. In general, this required that the initial nitrate concentration in the top 30 cm of the profile range between 5 and 10 ppm and that of the subsoil range between 1 and 5 ppm.

The model, when fully developed and adjusted for differences among soil families and maize genotypes, will provide a valuable tool in technology transfer.

Actual rates and dates of nitrogen fertilization were used in simulations. Actual weather data were used, and irrigation was assumed to occur whenever a soil layer dried to the lower limit of extractable soil water.

Soil properties such as percent organic carbon, total nitrogen, and bulk density were identical at all sites and were taken from Benchmark Soils Project publications and Soil Survey information.

High Nitrogen Treatments

Present in Table 5 are the actual and simulated dates of silking, kernel weight, kernel number, and grain yield of the (+.85, +.85) treatments in nine experiments conducted on Hydric Dystrandepts. Two experiments (Kukaiau A-22 and Iole F-10) that suffered wind damage (lodging) were not included because the effects of wind damage cannot be simulated with the CSEU model.

In general, accurate estimates of silking date, yield components, and grain yield in the (+.85, +.85) treatments using the model could not be determined. One experiment, Halawa D-12, had very low actual kernel weight combined with near normal kernel number. The model did not accurately simulate the low kernel weight, suggesting that disease or insect damage may have occurred during the grain filling period of this experiment.

Low Nitrogen Treatments

Shown in Table 6 are the actual and simulated kernel weight, kernel number, and grain yield of the (+.85, −.85) treatments in the same experiments. In general, both kernel weight and kernel number were reduced by nitrogen deficiency. One experiment, Halawa B-22, had an abnormally low kernel number. This may have been due to barrenness induced by nitrogen deficiency.

The model overestimated grain yield in the (+.85, −.85) treatment of all Halawa and Iole experiments; however, it underestimated grain yields in three of four Kukaiau experiments. This suggests that the initial soil conditions differed among sites. More accurate estimates of soil organic matter total nitrogen might reduce these errors.

Table 5. Actual and simulated silking dates and yield components of (+.85, +.85) treatments in experiments on Hydric Dystrandepts.

Experiment	Silking (days after planting)		Kernal weight (g)		Kernel number (kernel/m²)		Grain yield (kg/ha)	
	Actual	Simulated	Actual	Simulated	Actual	Simulated	Actual	Simulated
HAL B-21	65	75	.39	.39	2095	2047	8169	8010
HAL B-22	--	75	.40	.40	2157	2118	8629	8516
HAL D-12	92	87	.24	.40	2440	2068	5857	8283
KUK A-21	63	69	.37	.35	2122	2038	7852	7092
KUK C-11	76	74	.42	.43	2088	2063	8768	8929
KUK C-12	66	72	.44	.36	2105	2073	9262	7587
KUK D-12	85	71	.38	.42	2323	2029	8823	8531
IOLE E-10	71	79	.42	.41	1829	2062	7768	8463
IOLE I-10	87	84	.34	.40	1941	2073	6600	8234

Table 6. Actual and simulated yield components of (+.85, −.85) treatments in experiments on Hydric Dystrandepts.

Experiment	Kernel weight (g)		Kernel number (kernels/m²)		Grain yield (kg/ha)	
	Actual	Simulated	Actual	Simulated	Actual	Simulated
HAL B-21	.37	.39	1348	1527	4971	5913
HAL B-22	.35	.30	848	1325	2967	3979
HAL D-12	.23	.38	1543	1359	3550	5216
KUK A-12	.39	.28	1790	1737	6982	4926
KUK C-11	.36	.41	2044	1640	7358	6704
KUK C-12	.40	.35	1812	1698	7249	5902
KUK D-12	.36	.42	1541	1659	5546	6976
IOLE E-10	.40	.41	1566	1630	6263	6642
IOLE I-10	.29	.32	1127	1470	3268	4762

Yield Response Curves

Given in Fig. 5 are actual and simulated yield response curves for the (+.85, −.85); (+.40, −.40); (0, 0); (+.40, +.40); and (+.85, +.85) treatments of all experiments except Halawa D-12. In most experiments, the actual and simulated yield response curves were similar, though simulated yields were consistently too low in Kukaiau C-12 and too high in Iole I-10.

Crop growth simulation models cannot presently simulate all the processes affecting crop growth. For example, the CSEU model does not simulate the effects of wind, insect, or disease damage. It does not currently simulate denitrification, nitrification, phosphorus, potassium, or sulfur deficiencies. However, in experiments in which these factors are controlled and accurate weather and soil information are available, the CSEU maize model can produce accurate yield response curves.

Future Plans

The Crop Systems Evaluation Unit maize model can be used to simulate nitrogen response in transfer experiments in all Benchmark Soils Project transfer experiments. In addition, the CSEU soil phosphorus simulation model will be operational in 1983, and simulation of phosphorus fertilizer response curves in BSP experiments will be possible.

Nitrogen and phosphorus mineralization and phosphorus sorption and availability vary widely among soil families studied by the BSP. This variation must be taken into account by any crop growth simulation model. Close collaboration of CSEU and BSP scientists and collaborators around the world will be needed to produce a single crop growth simulation model capable of predicting yield response to N and P fertilizer in different soil families.

This is a contribution of C. Allan Jones, Plant Physiologist, Grassland, Soil and Water Research Laboratory, Southern Region, USDA, Temple, Texas.

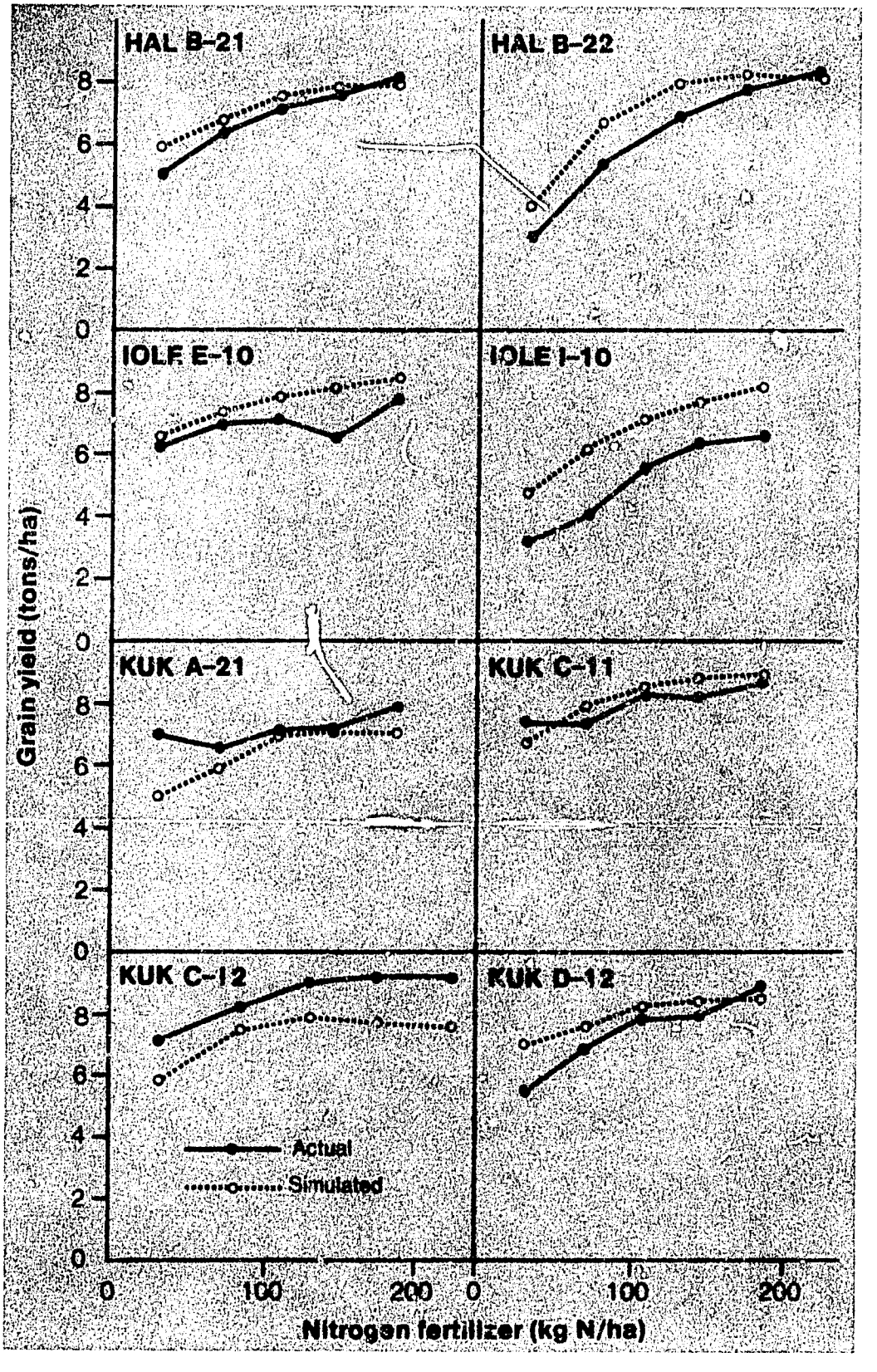


Fig. 5. The effects of nitrogen fertilizer rate on grain yields in eight Benchmark Soils Project experiments on Hydric Dystrandepts.

Demonstration of Soil Taxonomic Considerations: Cropping Systems Research

In an earlier report (Progress Report 2, 1979), the effect of land qualities and management inputs on crop performance was described subjectively on the basis of experience embodied in the nomenclature of Soil Taxonomy. To demonstrate the utility of soil taxonomic considerations for agricultural planning and development, Benchmark Soils Project personnel were involved in several activities related to this purpose. One activity that evolved from interaction with Jerry L. McIntosh, Cropping Systems Agronomist of the Cooperative IRRI/CRIA (International Rice Research Institute/Central Research Institute for Agriculture) program in Indonesia; Luis Manrique, CIP (Centro Internacional de la Papa) Agronomist, and agricultural scientists in the CTAHR (University of Hawaii College of Tropical Agriculture and Human Resources) was the development of a soil family-based cropping system experiment.

Each set of crops was selected for a particular season in a soil family by matching crop requirements to soil characteristics.

The goals of cropping systems research activities in the developing countries are part of a self-sustaining strategy to make food and energy available to small, subsistence farmers. The strategy is aimed at meeting the needs of food and energy for human sustenance at relatively low cost. Much research effort at IARCs (International Agricultural Research Centers) and NARCs (National Agricultural Research Centers) is now geared toward using multiple crops to optimize land productivity.

To unify the Project's efforts in the area of management experiments, a cropping systems research program was implemented throughout the three soil family networks with the objectives of obtaining information on crop productivity and soil management of these Benchmark Soils and gathering additional data to strengthen the hypothesis of agrotechnology transfer based on the soil family. The Project is not developing cropping systems

technology. It will be utilizing its concept of a sequence of planting as they relate to the soil family characterization.

The design of the cropping systems research involves the matching of crop requirements to agroenvironments. Since the climatic requirements of many crops are well established and temperature and moisture regimes are stratified at the family taxonomic level, it should be possible to select crops suitable for a particular family. Moreover, with additional knowledge of the seasonal variations in climate, it should be possible to select a sequence of crops to be grown throughout the year. The selection of the proper sequence of crops is an important step in realizing the production potential of a particular environmental niche, and there is sufficient reason to expect that the performance of cropping sequences should be similar throughout a network of similar soils.

The development of the cropping systems research program evolved from the collaborative activities with Jerry McIntosh, IRRI/CRIA Cropping Systems Agronomist, during his study leave in Hawaii. At the BSP workshop entitled A Multidisciplinary Approach to Agrotechnology Transfer (*see* Annual Report, 1979-80), ideas were presented on how to integrate experiments from the various disciplines into one cropping system experiment to provide a maximum amount of information with a minimum of additional financial or manpower inputs. Guidelines for the implementation of the experiment at several of the Project sites were developed in December 1980.

Cropping patterns designed for one soil family were also planted in one or two other soil families . . .

The cropping pattern selected for each soil family (*see* Table 7) consists of three cycles, with the first cycle generally starting at the onset of the rainy or cooler season. The seasonal characteristics of each cycle are described in Table 7.

The rationale for the selection of the patterns for each soil family is as follows:

Performance of vegetable crops was excellent on the Hydric Dystrandepts relative to the other two soil families. Evidence of this performance is shown at the Kukaiau site in Hawaii.

Table 7. Cropping system designs to test production of the three soil families of the Benchmark Soils Project.

Soil family	Location	Cropping pattern 1st cycle	2nd cycle	3rd cycle	Long-term side crop
Hydric Dystrandept, thixotropic, isothermic (HD)	Hawaii Philippines Indonesia	*Root Crop* Irish potato *Vegetable Crops* cabbage/carrot/ bush beans	*Vegetable Crops* mustard cabbage/ green corn/ bush beens	*Grain Crop* (protein) soybean, peanut	Taro
Typic Paleudults, clayey, kaolinitic, isohyperthermic (TP)	Cameroon Indonesia Philippines	*Grain Crop* upland rice, maize	*Grain Crop* (protein) soybean, peanut	*Grain Crop* (protein, drought-tolerant) cowpea, mung bean	Cassava
Tropeptic Eutrustox, clayey, kaolinitic, isohyperthermic (TE)	Hawaii	*Root Crop* Irish potato	*Grain Crop* (protein) soybean	*Grain Crop* (starch) maize	Cassava/ Pigeonpea Taro
Seasonal characteristics of each cycle		Generally wet and cool	Still wet for HD but wetness is tapering off with TP and TE. Supplementary irrigation already required for TP but a must for TE.	Dry toward crop harvest; drought condition imminent for TP and TE. Irrigation required for TE but supplementary for TP.	
Month scale [a]		0	4	8	12

[a] The start of the rainy season, which may differ from site to site, is designated as 0, and the end of the third cycle is 12 on the month scale.

Hydric Dystrandepts Pattern

The Hydric Dystrandepts pattern is Irish potato (var. 'Kennebec') and vegetable crops, followed by vegetable crops, then followed by a grain crop. A long-term crop, such as taro or cassava. is planted on wide rows for additional production. Because of the cool isothermic temperature and udic moisture regime of this soil family, Irish potato and vegetable crops are the preferred crops. Green corn was selected for the warm period in view of BSP's success with field corn in the transfer experiments during the dry season.

Typic Paleudults Pattern

The Typic Paleudults pattern is upland rice and maize followed by soybeans, then followed by cowpea. These crops were selected in relation to the isohyperthermic temperature and udic moisture regimes. Rice is the main crop during the first cycle and is planted during the start of the rainy season along with maize. When maize starts to silk, cassava is planted in sufficiently wide rows to permit an intercrop for the succeeding taro cycle. A grain crop like soybean was selected for the second cycle. which is the start of the dry season. Cowpea was designated for the third cycle because of its tolerance to droughty conditions. Fig. 6 shows the relationship of a particularly designed pattern with rainfall and temperature.

Tropeptic Eutrustox Pattern

Irish potato followed by soybeans and then by maize were selected to match crop require-

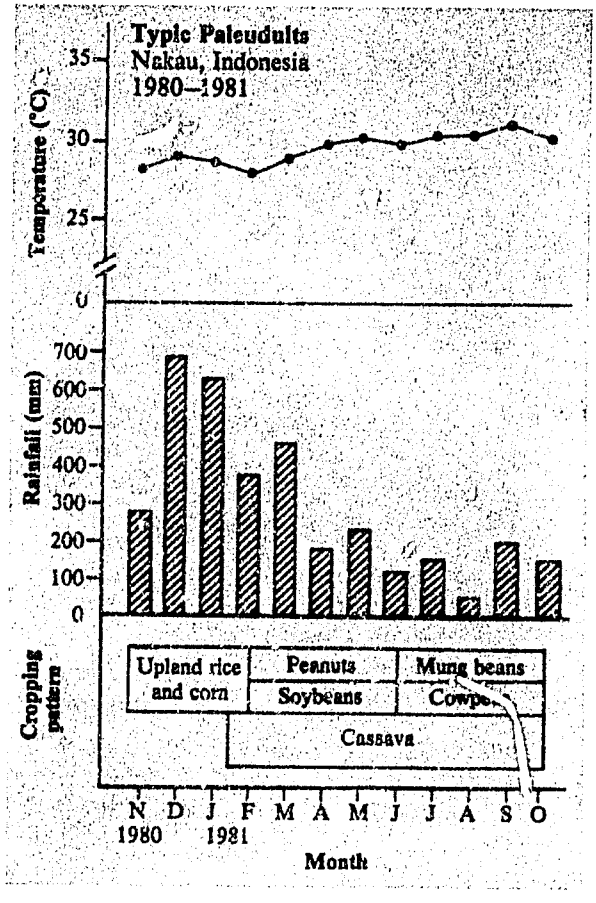


Fig. 6. Cropping patterns for each soil family were designed to maximize efficient use of available water and temperature.

ments with the isohyperthermic temperature and ustic moisture regimes of the Tropeptic Eutrustox. The wet season at the Waipio site (Hawaii) starts in November/December. Low night temperatures also have been recorded by Manrique (unpublished data) during this period and are conducive to tuberization in Irish potato (var. 'Kennebec'). Successful potato production was already demonstrated at this site under similar conditions as noted earlier in this report. Therefore, a cropping pattern that includes Irish potato on these soils appeared appropriate. The recommended crops after potato were soybeans, followed by maize. Maize production coincides with the warmer periods of higher solar radiation. It is in this period that the highest yield of corn was obtained on a transfer experiment. Pigeonpea, along with taro and cassava, are to be planted during the first cycle as side crops. Pigeonpea is particularly noted as a drought-tolerant legume and requires about the same period for maturity as taro and cassava.

Comparison of Patterns

Both irrigated and nonirrigated conditions were imposed on experiments grown in both udic and ustic moisture regimes while soil nutrients were optimized. The first crop cycle for each soil family was planted at the start of the rainy season. Cropping patterns designed for one soil family also were planted in one or two other soil families for the purpose of rating crop performances under different environments. The cumulative performance of a crop or set of crops in a cropping sequence will be used to assess the relative production potential of each soil family of the BSP network. Such production ratings may be useful to agricultural scientists and planners in providing information on alternative crops in agricultural land use planning without having to conduct costly field research.

Certain trends already are apparent from results obtained to date from sites located in Java and Sumatra, Indonesia (Hydric Dystrandepts and Typic Paleudults); Hawaii (Hydric Dystrandepts and Tropeptic Eutrustox); the Philippines (Hydric Dystrandepts and Typic Paleudults); and Cameroon (Typic Paleudults).

In the warm and dry environment of the Tropeptic Eutrustox, for example, irrigation increased the yield of cassava and pigeonpea by about three to four times. Soybean crops did not reflect the treatment effects of either inoculum or fertilizer treatments when water was limiting.

In the warm and humid environments of the Typic Paleudults, the Irish potato was a complete failure. However, potatoes were grown with relative success in both the isothermic Hydric Dystrandepts in Hawaii and Indonesia and isohyperthermic Tropeptic Eutrustox in Hawaii Apparently, the two months of cooler weather in the wet period were conducive to potato production in the latter environment.

Taro, carrots, sweet potatoes, and corn appear to have a wide latitude of adaptation and can be grown in all of the three soil families. Vegetables such as head cabbage, bush beans, chinese cabbage, and even peanuts appear to perform more vigorously in the cooler Dystrandepts.

Potato performance was very poor, as expected, in the warm and humid environment of the isohyperthermic Typic Paleudults of both Sumatra, Indonesia **(top)** and Mindanao, the Philippines **(bottom)**.

Performance of Nitrogen-Fixing Trees in Three Benchmark Environments

The Benchmark Soils Project is participating in a study of nitrogen-fixing trees (NFTs) being carried out by Dr. J. L. Brewbaker of the Department of Horticulture, College of Tropical Agriculture and Human Resources, University of Hawaii. In this study, experiments which include several species of nitrogen-fixing trees are established in various countries to determine the adaptability of species to different environments and to study the genotype × environment interactions of the species. In the Benchmark Soils Project experiments, 16 species of NFTs were planted in four locations in three soil families in three countries. The purpose of this experiment was to assess species × soil family (genotype × environment) interactions of perennials in three Benchmark environments and to obtain information with which to match specific tree requirements to land characteristics.

. . . trees are excellent indicators of the capacity of the soil family to stratify agroenvironments into narrow agroproduction niches.

Unlike annuals that complete their life cycles in a few months, trees integrate conditions of soil and climate over several years. Therefore, trees are excellent indicators of the capacity of the soil family to stratify agroenvironments into narrow agroproduction niches. Fast-growing NFTs not only serve as fuelwood, but as sources of lumber and forage, and as a means to improve soil conditions and protect soils from erosion. They also can serve as shade trees, boundary markers, windbreaks, and ornamentals. Since trees are cultivated for multiple uses, it is helpful to know the relationship between tree performance and land characteristics.

Three-month-old seedlings, germinated and nurtured in dibble tubes, were transplanted in the field without benefit of chemical fertilizers. All leguminous trees were inoculated with appropriate strains of Rhizobium obtained from the University of Hawaii Nif-TAL Project (Nitrogen Fixation by Tropical Agricultural Legumes).

Growth of *Leucaena leucocephala* reflect the cool, moist agroenvironment of the Hydric Dystrandept in Hawaii **(top)** and the warm, moist agroenvironment of the Typic Paleudults in both Indonesia **(center)** and Cameroon **(bottom)**.

Sixteen tree species were selected, mostly legumes. Five of these species were replicated four times in 4-m × 7-m plots. The names of the tree species are listed in Table 8.

Five months after planting, the seedlings began to show striking differences in growth. In the moist and cool environment of the thixotropic, isothermic Hydric Dystrandept site (Iole) on the Island of Hawaii, only two of the 16 tree species had shown any significant growth. The two were *Acacia mearnsii* and *Eucalyptus saligna*. In contrast, 14 species planted in the warm and dry environment of the clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox site (Waipio) located on the Island of Oahu had grown vigorously. Both sites were planted at nearly the same time during the wet season so soil moisture would not be limiting during the seedling establishment stage.

Both of the soil families have inherent differences in soil fertility, which could partly explain the differences in tree growth. Leguminous trees generally require high amounts of calcium for optimum growth. Calcium is an important element in nodulation. The soil at the Iole site had an acid pH and was low in calcium. Phosphorus levels, determined by modified Truog, were in excess of 30 ppm P. In comparison, the Waipio site had a slightly acid pH, but calcium was high. The phosphorus level was also high, measuring nearly 25 ppm. The soil fertility conditions in the latter, coupled with a relatively warmer soil temperature, had certainly favored the rapid growth of the NFTs. The influence of the soil moisture regimes should become apparent as the dry season is approached.

In Nakau, Indonesia, and Davao City, the Philippines, growth differences of the trees planted in the Typic Paleudult sites were already apparent as early as two months after planting. The Nakau site was in a warm and wet environment, with soils of acid pH, low native fertility, and especially low phosphorus levels of 5 to 10 ppm P by modified Truog.

Five months after planting, the seedlings began to show striking differences in growth.

The Davao site, also with a warm and wet environment, had a slightly acid pH, low-to-moderate native fertility and low-to-moderate soil P. At six months all trees were growing vigorously and most of the trees had outgrown those that were planted in the Waipio and Iole sites. Tree heights at six months after planting are summarized in Fig. 7 and Table 9 for the four sites. Davao appears to have had the most favorable environment for the rapid growth of these trees.

These experiments illustrate the importance of matching the environmental requirements of crops to the environmental characteristics of land. Mismatches between crop requirements and land characteristics are a major cause of failures in agrotechnology transfer. The use of the soil family is one way to minimize mismatches and accelerate the flow of agricultural innovations among widely separated locations.

Table 8. Tree species in the NFT trials.

Replicated entries:	Unreplicated entries
Acacia auriculiformis	*Acacia mangium*
Calliandra calothyrsus	*Acacia mearnsii*
Leucaena diversifolia	*Acrocarpus fraxinifolius*
Leucaena leucocephala	*Albizia falcataria*
Sesbania grandiflora	*Casuarina equisitifolia*
	Dalbergia sissoo
	Enterolobium cyclocarpum
	Eucalyptus saligna
	Gliricidia sepium
	Mimosa scabrella
	A local species

This is a collaborative effort between Benchmark Soils Project and James L. Brewbaker, Professor of Horticulture, College of Tropical Agriculture and Human Resources, University of Hawaii.

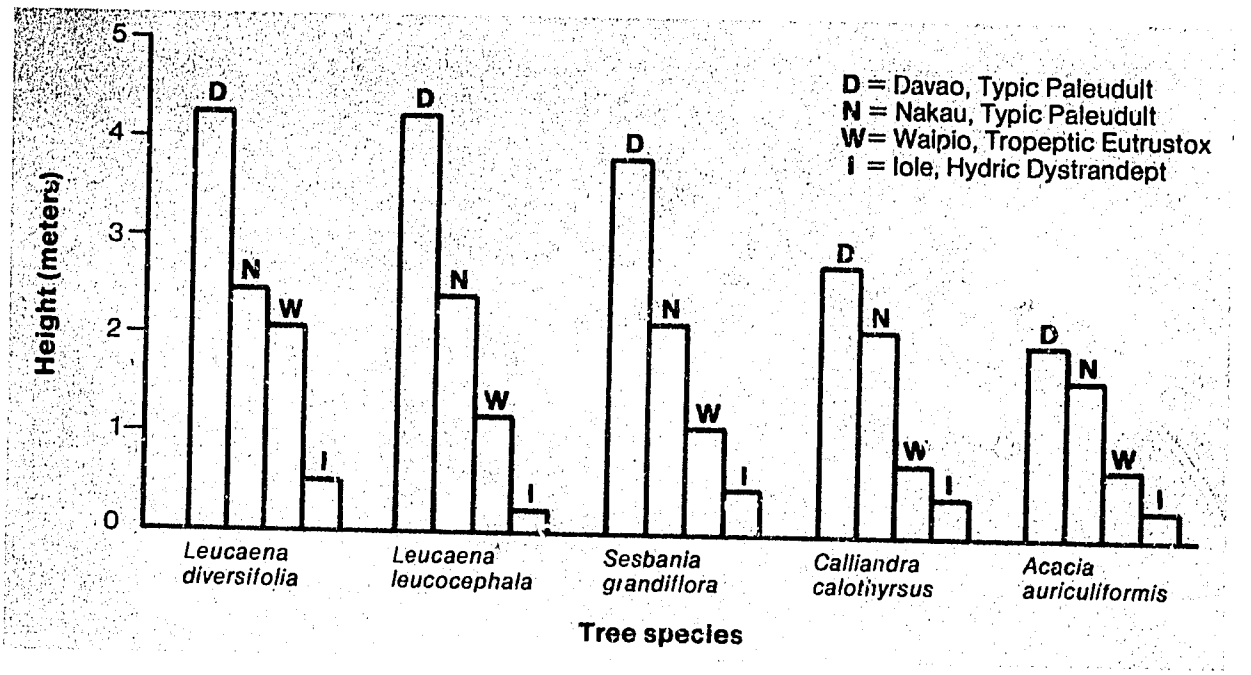


Fig. 7. Average height of five NFT species in replicated experiments, at six months after planting.

Table 9. Tallest trees at each site at six months after planting.

Sites			
Davao (Typic Paleudult)	**Nakau (Typic Paleudult)**	**Waipio (Tropeptic Eutrustox)**	**Iole (Hydric Dystrandept)**
Leucaena diversifolia	*Albizia falcataria* (2.73 m)	*Leucaena diversifolia*	*Acacia mearnsii* (1.29 m)
Leucaena leucocephala	*Leucaena diversifolia*	*Albizia falcataria* (1.58 m)	*Eucalyptus saligna* (0.72 m)

Evaluation of Phosphorus Fertilizer Materials and Placement Effects on Two Benchmark Soils

There are two possible strategies for improving the economic attractiveness of P fertilization on P-deficient soils in the tropics such as those of the Benchmark network:

1. Using other P sources, such as phosphate rock for direct application, in place of acidulated phosphates, particularly where indigenous rock sources occur; and
2. Using restricted placement of soluble phosphate fertilizers to maximize the return from low rates of applied P where financial constraints limit fertilizer use by farmers.

To evaluate these strategies on selected sites of the Benchmark experimental network, a collaborative research project between the University of Hawaii/Benchmark Soils Project and the International Fertilizer Development Center (IFDC), Muscle Shoals, Alabama, was initiated in early 1979. Field experiments were conducted on P-sources and P-placement at the PUC Hydric Dystrandept (HD) site in the Philippines and the Nakau Typic Paleudult (TP) site in Indonesia. Crop yield results over three seasons are shown for the P-source experiments in Fig. 8 and the P-placement experiments in Fig. 9.

P-Source Experiments

The experiments compared crop response to one highly reactive (North Carolina, NCf) and one moderately reactive (Central Florida, CFf) phosphate rock. These two sources were in finely ground form.

Since the dusty nature of finely ground phosphate rocks hinders transport and handling, IFDC developed the minigranulation process. Minigranular North Carolina rock (NCm) was also included in this study to determine if minigranulation reduces agronomic effectiveness. Because partial acidulation of phosphate rock of low reactivity has been shown to increase effectiveness, partially acidulated Central Florida rock in a minigranular form (CFpam) was also tested in this study.

Comparing the results for the two soil sites in the first season, a large difference between

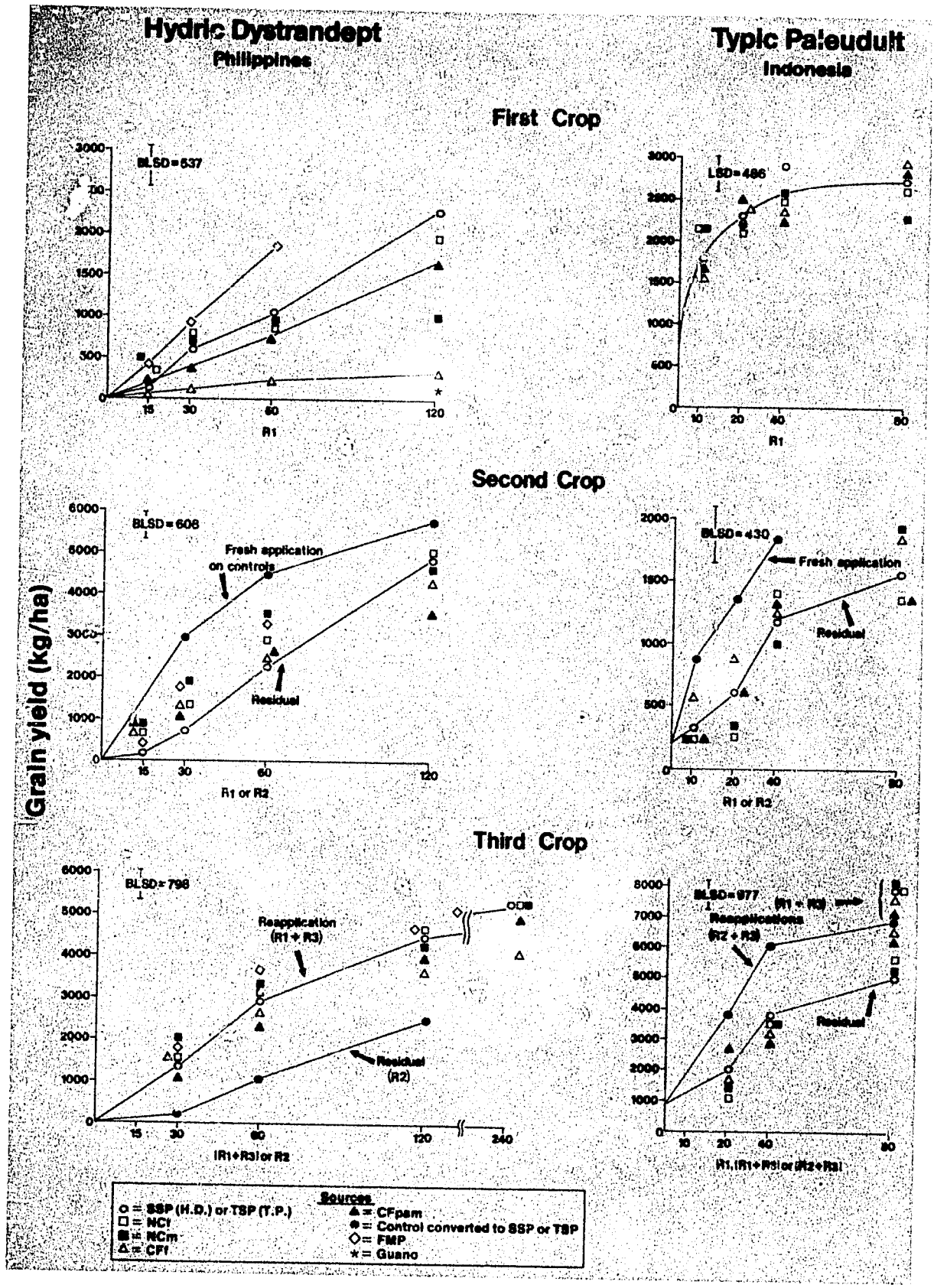


Fig. 8. Yield response for P-source experiments. Yield is maize grain except for TP second crop (soybean grain). P rate variables (R1, R2, and R3) are rates applied at first, second, and third plantings, respectively, in kg P/ha.

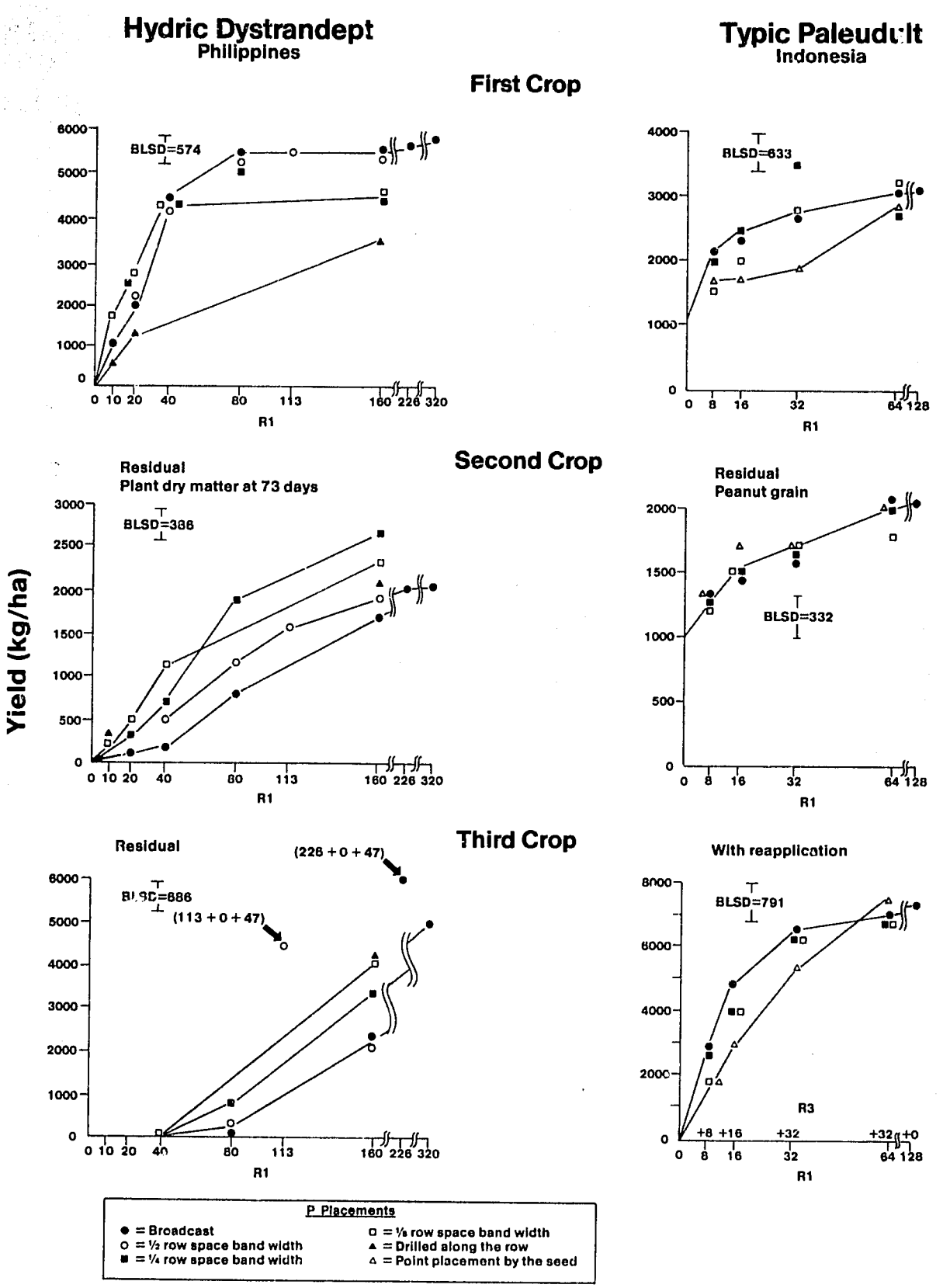


Fig. 9. Yield response for P-placement experiments. Yield is maize grain except as noted for second crop. P rate variables R1 and R3 are rates applied at planting of the first and third crops, respectively, in kg P/ha. P fertilizers were nongranular SSP for Hydric Dystrandept and granular TSP for Tropeptic Eutrustox.

sources was seen on the HD, while no significant differences were seen between sources on the TP. The yield differences on the HD were exaggerated due to insect and typhoon damage around the time of tasseling. This had a much greater effect on the grain yield of the late tasseling treatments, particularly the Central Florida rock. However, differences between sources in height at tasseling (before the severe stresses occurred) indicated that differences in grain yield would have occurred even in the absence of the stress conditions.

In the second season, fresh applications of superphosphate were made on former control plots on both sites and the other treatments were left as residuals. On the HD site, the fresh application showed that a normal response curve can be obtained over the P rate range in the absence of extreme insect and weather stress. Also, significant differences between sources can be seen in the residual effects on the HD. In comparison, on the TP site where soybeans were planted no significant differences were seen in the residual crop between source treatments.

Over these first two seasons two general comparisons can be made between the two soils: (1) the Hydric Dystrandept had a lower native level of P, since with no P application no yield was produced and (2) the Hydric Dystrandept had a higher P requirement than the Typic Paleudult since plateau yield was reached between 60 and 120 kg P/ha in the HD, whereas a plateau was reached between 30 and 60 kg P/ha in the TP. The higher P requirement evidenced by the HD made reapplication necessary at all rates for the third season, whereas for the TP reapplication of all sources was made only on the 10 kg P/ha plots on which 70 kg P/ha were applied to permit comparison with the residual 80 kg P/ha treatments.

The third season yield results again showed no significant differences between sources on the TP, even for the reapplication of 70 kg P/ha, at yield levels approaching 8,000 kg/ha. In comparison, significant differences were seen for the reapplication on the HD.

In summary, these results indicate that the Typic Paleudult is well-suited for direct application of phosphate rocks of moderate and possibly lower reactivity, whereas the Hydric Dystrandept requires phosphate rocks of high reactivity to obtain high yields comparable to those of superphosphate.

P Placement

In the placement experiments, the treatments compared ranged from placement by-the-seed, as the most restricted placement, to incorporated broadcast application, as the most extensive placement. (*See* Fig. 9 caption.)

On the HD, which has a high P requirement by virtue of its mineralogy, the results observed over three seasons (first crop plus two residual crops) confirm C. T. de Wit's (1953)[1] relationships—i.e., on the ascending part of the response curve, restricted band placement gives higher yields than broadcast; whereas, at rates reaching a yield plateau, broadcast treatments give superior yields. These results suggest the importance of developing fertilizer application methods that maximize returns from small P applications on soils with high P fertilizer requirements.

On the TP, very little differences between placement were observed over three seasons. The one significant effect observed in the crops that received new applications of TSP (first and third crops) was the inferiority of the most restricted placement (by-the-seed) at low and intermediate rates.

For both the Typic Paleudult and the Hydric Dystrandept, the inferiority of the most restricted placement when the P is freshly applied suggests the importance of spatial availability in addition to chemical availability in determining plant response to phosphorus.

[1] de Wit, C. T. 1953. A physical theory placement of fertilizers. Verslagen van Landbouwkundige Onderzoekungen 59:4.

Plant Pests in Benchmark Environments

Several years of growing crops under standardized, well-monitored situations in contrasting environments have made it evident to the Benchmark Soils Project field staff that the soil family not only stratifies agroenvironments according to crop production potential but according to occurrences of plant pests as well.

Before the first field experiment was installed in 1974, the Project staff was warned by consultants that the devastating fungal disease, downy mildew (*Sclerospora maydis* [Rac] Butler), would render maize unsuitable as a test crop. However, it turned out that the first soil family network established by the Project in Indonesia and the Philippines occurs in environments that do not permit the downy mildew organism to flourish. This was the thixotropic, *isothermic* family of Hydric Dystrandepts. We now know that downy mildew is not a problem in *isothermic* (soil temperature regime between 15-22°C) environments. On the other hand, in the second network of sites established in the clayey, kaolinitic, *isohyperthermic* family of Typic Pale*ud*ults, this disease was a serious pest. The isohyperthermic (greater than 22°C soil temperature regime) and *ud*ic *(ud* = h*u*mi*d)* moisture regime favored this organism.

. . . the soil family not only stratifies agroenvironments according to crop production potential but according to occurrences of plant pests as well.

The principles and concepts of the Benchmark Soils Project are clearly illustrated by this example. The lesson learned about downy mildew enables us to transfer this knowledge not only to soil belonging to these families but to virtually all tropical soils. We can now state with some degree of confidence that downy mildew will not be a serious problem in any soil with an isothermic or cooler temperature regime, but is a potential problem in environments with isohyperthermic (warm) and udic or wetter (humid) moisture regimes.

A major innovation of Soil Taxonomy is

that the differentiating characteristics employed to classify soil environments are retained in the taxa for utilitarian purposes. The ideas of John Stuart Mill, the English utilitarian philosopher, had a great influence on the shaping of Soil Taxonomy. He said "the name as a word (or set of words) serves as a double mark to recall to ourselves the likeness of a former thought or object and a sign to make it known to others." In a sense, the Project staff is rediscovering what has long been known to plant pathologists. What is new is that we are now able to relate what is known to pathologists to named kinds of soil environments. It is knowing these kinds of relationships that enable people to transfer knowledge and experience among widely separated locations in the tropics.

Since 1978, the BSP field staff has been monitoring the Hawaii sites of two soil families for diseases, insects, and weeds in the maize transfer experiments. Incidence and severity ratings of pests for the four Hawaii sites are presented in Tables 10 and 11. A severity rating of 0 was given to the pests that were present at the site but were of minor importance, and a + rating to pests that posed as a major threat to the crop and could cause appreciable losses in grain yields.

The Molokai (MOL) and Waipio (WAI) sites of the Tropeptic Eutrustox network are respectively located on the Islands of Molokai and Oahu, while the two sites of the Hydric Dystrandepts, Iole and Kukaiau (KUK), are on the Island of Hawaii. While the geographical remoteness of the Hawaiian Islands, as well as an agricultural quarantine program, have prevented the introduction of

Table 10. Maize disease incidence and severity for two soil families in Hawaii.

Disease (Sci. name)	Soil family: Tropeptic Eutrustox		Hydric Dystrandepts	
	MOL	WAI	IOLE	KUK
Common smut (Ustilago *maydis* [DC] Cda.)	0	0	—	—
Ear rots *(Gibberella roseum* F. Sp. *cerealis* [Cke.] Snyd and Hans) *(Fusarium moniliforme* Sheld) *(Penicillum oxalicum* Currie and Thom)	0	0	+	+
Common maize rust *(Puccinia sorghi* Schw.)	0	+	0	0
Northern leaf blight *(Helminthosporium turcium* Pass.)	+	0	+	+
Maize dwarf mosaic virus	0	0	0	0

Key: — = not observed at site
0 = disease of minor importance
+ = disease may cause appreciable crop losses

Table 11. Maize insect incidence and severity in three soil families.

Insect (Sci. name)	Soil family: Tropeptic Eutrustox		Hydric Dystrandepts	
	MOL	WAI	IOLE	KUK
Corn planthopper *(Peregrinus maidis* Fitch)	+	+	0	—
Red spider mite *(Tetranychus cinnabarinus* Boisduval) *(Tetranychus tumidus* Banks)	+	+	—	—
Grasshopper *(Euconocephalus nasutus* [Thunberg])	0	0	—	—
Fire ant *(Solenopsis geminata* [fabricius])	0	0	—	—
Chinese rose beetle *(Adoretus sinicus* Burmeister)	+	+	0	0
Cutworm *(Agrotis sp.)*	0	0	+	+
Aphid *(Rhopalosiphum maidis* Fitch)	0	0	0	0
Corn earworm *(Heliothis sea* Boddie)	0	0	0	0

Key: — = not observed at site
0 = insect of minor importance
+ = insect may cause appreciable crop losses

some maize pests, such as the destructive downy mildew disease, into the Islands, other maize pests commonly found throughout the tropics have made their way to Hawaii and now are distributed on all the Islands. The survey, however, shows that the occurrence and/or seriousness of infection of these pests, whether insect, disease, or weed, are generally stratified according to the agroenvironment defined in the soil family name.

Diseases

Maize diseases recognized in Hawaii were found in both soil families, with the severity of the disease attacks generally greater in the cool, moist environment of the Hydric Dystrandepts. Common smut [*Ustilago maydis* (DC) Cda.], which favors dry conditions and temperatures between 26 and 34°C, was observed only in the warm and dry environment of the Tropeptic Eutrustox sites.

Disease ratings for sites within a soil family were the same for the Hydric Dystrandept network and very similar for the Tropeptic Eutrustox network. The only differences between the Molokai and Waipio sites were the severity ratings for common maize rust (*Puccinia sorghi* Schw.) and northern leaf blight (*Helminthosporium turcicum* Pass.).

Outbreaks of rust at the Waipio site usually occurred during the dry season months when calm to moderate winds, high relative humidities, and warm temperatures prevailed. The high wind speeds of Molokai, a characteristic of that site, may have been a deterring factor to rust infection since this disease was observed only after wildcane windbreaks were established.

Rust infestations which are enhanced by cool temperatures (16 to 23°C) and high relative humidities were not a problem in the Hydric Dystrandept sites because the maize variety 'H610' used in the transfer experiment was rust-resistant.

In Hawaii the wet season months of November through March are characterized by a marked increase in rainfall and cooler air temperatures. This seasonal variation in weather has had a pronounced effect on the incidence of disease infection at sites of both soil families. For example, outbreaks of

Corn earworm (*Heliothis zea* Boddie) is a destructive pest common to all sites of the three soil family networks. A mature larva exits from the ear **(top)** where it developed over a period of 4-6 weeks

northern leaf blight disease, which is promoted by moderate temperatures (18 to 27°C) and heavy dews and retarded by dry weather, were more common during the winter months at the Tropeptic Eutrustox sites. On the contrary, blight infestations at the Hydric Dystrandept sites were less severe during the rainy season because the much cooler air temperatures were less than optimal. Ear rots were a major problem in the Hydric Dystrandept sites and infections were especially severe during the wet season when *Gibberalla roseum* F. Sp. *cerealis* (Cke.) Snyd. and Hans., which thrives in cool, wet weather, infested a high percentage of the ears.

Insects

The difference in insect pest occurrences between the two soil families is very evident in Table 11. The corn planthopper (*Peregrinus maidis* Fitch) is found on all the major Islands of Hawaii at low elevations and its habitat range does not usually extend into the isothermic sites of Iole and Kukaiau, which are located at moderate elevations of approximately 500 meters. Sightings of planthoppers at Iole have occurred only twice during unusually dry periods of summer. Red spider mites (*Tetranychus cinnabarinus* Boisduval and *T. tumidus* Banks) thrive in hot and dry weather conditions like that found at the Eutrustox sites. Mites were usually seasonal at these sites with few infestations during the cooler months of the wet season. The grasshopper (*Euconocephalus nasutus* [Thunberg]) probably prefers habitats of low elevations, and the fire ant's (*Solenopsis geminata* [fabricius]) nesting range probably excludes the cool and constantly wet soil environment of the Hydric Dystrandept sites.

The difference in insect pest occurrences between the two soil familes is very evident . . .

The Chinese rose beetle (*Adoretus sinicus* Burmeister) was potentially very destructive at the Eutrustox sites, but was found to be more common at Waipio than at Molokai. Beetle population numbers were not as high at the Dystrandept sites, probably due to the cool environment. The cutworm *(Agrotis sp.),* a major problem in the experimental corn plots, appeared to favor the cool and moist soils of the Hydric Dystrandepts.

Weeds

A pre-emergence application of Lasso (Alachlor) and Aatrex (Atrazine) was applied on all maize transfer experiments in Hawaii. This herbicide combination usually gave adequate, broad-spectrum control of weeds for the first three months, after which time weeds began to infest the fields as the canopy opened up. In Table 12 the persistent weeds

Table 12. List of weeds in maize plots of two soil families in Hawaii.

Soil family of Tropeptic Eutrustox	Soil family of Hydric Dystrandepts	Common to both families
Convolvulus arvensis L.	*Ageratum conyzoides* L.	*Bidens pilosa* L.
Amaranthus spinosus L.	*Erechtites hieracifolia* (L.) Raf	*Emilia sonchi folia* L.
Momordica charantia var. pavel Crantz	*Kyllinga brevifolia* Rottb.	*Sonchus oleraceus* L.
Cyperus rotundus L.	*Cyperus hypochlorus* Hilleb	*Digitaria sanguinalis* (L.) Scop.
Cenchrus echinatus L.	*Setaria glauca* (L.) Beaur.	
Chloris barbata Swartz		

are listed as they are found in the different soil families.

In retrospect, it is not surprising to find that weeds and soil families go together since vegetative zones usually follow climatic zones. Weeds listed under the soil family of Tropeptic Eutrustox prefer dry habitats, whereas those listed under the soil family of Hydric Dystrandepts prefer moist habitats. *Bidens pilosa* L., *Emilia sonchifolia* L., *Digitaria sanguinalis* (L.) Scop., and *Sonchus oleraceus* L. have wide ecological adaptations and were found in both soil families.

Hawaii's experience clearly shows that maize pest problems are indeed stratified by agroenvironments defined at the soil family level. A final report is being prepared on maize pests in the Project's three-soil-family network that would link together Cameroon, Indonesia, the Philippines, and Hawaii.

Soil Tests for Phosphorus

The modified Truog extractant, 0.025N H_2SO_4 + 0.38% $(NH_4)_2SO_4$, was calibrated to establish P treatments in three soil families. A modification of Bray-I was also calibrated for this purpose but was successful only in establishing the P treatments in the Hydric Dystrandepts. The P treatment levels were then used to establish yield response curves.

The calibration technique was developed by first establishing a critical P level for the crop through field experiments, then determining its correspondence to extractable P in order to determine the amount to be used in future applications. This critical level was fixed for a given crop but actual amounts of P to reach this level were different for each soil family (Table 13). In this report, the critical level is defined as the maximum extractable P at which point no response to applied P is expected. Since the critical level determines the limit above which there is no response to P, one can readily assess the need to apply P by examining the extraction curve. For example, Benchmark Soils Project sites with a long history of animal manure and rock phosphate application that showed extractable P near or above the critical level show no response to applied P.

The modified Truog extractant . . . was calibrated to establish P treatments in three soil families.

Table 13. Amounts of P to reach the critical level of maize for modified Truog and Bray-I (1:30).

	Y_m					
	Hydric Dystrandept		Typic Paleudult		Tropeptic Eustrustrox	
Critical Level, X_m	*Block*	*P µg/g*	*Block*	*P µg/g*	*Block*	*P µg/g*
Modified Truog (25 ppm)	BUR-B	218	NAK-A	65	MOL-M	52
	PAL-E	206	BPMD-A	75	MOL-N	56
	PUC-R	204	BUK-A	55	WAI-A	-41
	LPH-E	-9	SOR-A	88	WAI-B	-45
			BPY-F	13		
Bray-I (1:30) (9 ppm)	BUR-B	194				
	PAL-E	262				
	PUC-R	268				

The critical level for maize which was successfully used to determine P treatments has a value of 7 to 9 ppm for Bray-I (1:30) and 22 to 25 ppm for the modified Truog method. Using these critical levels for each method, calculated P treatments in all Hydric Dystrandept sites were nearly identical (*see* Table 13). Maize planted on soils showing initial P which were close to or greater than the critical levels did not respond to added P. Examples of extraction curves for both methods are shown in Fig. 10.

The critical level for each experimental block is indicated by a vertical line and designated as X_m. For this critical level there corresponds a value of P-added designated as Y_m which is the actual amount of P to reach the critical level of extractable P. A single critical value of 25 ppm for the modified Truog method was used to calculate P treatments in all three soil families and experimental blocks with modified Truog levels below this critical level consistently showed response to applied P. The critical level of 9 ppm for Bray-I resulted in similar maize responses to applied P as the 25 ppm level obtained with the modified Truog method. This was only true in the Hydric Dystrandepts. The Bray-I method was not satisfactory for the Typic Paleudult and Tropeptic Eutrustox.

The calibration technique was developed by . . . establishing a critical P level for the crop . . . which is defined as the maximum extractable P at which point no response to applied P is expected.

The existence of a single critical Truog soil P value for three Benchmark soils suggests that this method may have wide application in other similar kinds of soils. The critical value used in conjunction with an extraction curve enables the user to ascertain whether a soil is adequately supplied with P, and if not, how much is needed to reach the critical level. The procedure is simple and inexpensive.

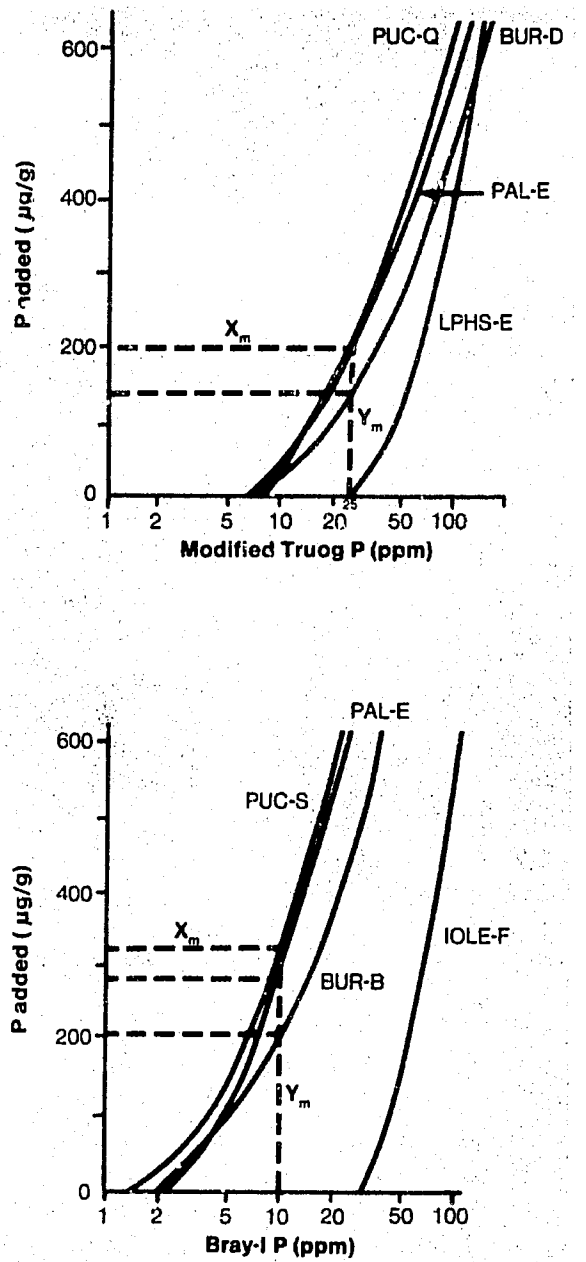


Fig. 10. Extraction curves of Hydric Dystrandept soils from the Philippines (PUC, BUR, PAL), Indonesia (LPHS) and Hawaii (IOLE). X_m is the extractable P corresponding to a maximum application, Y_m. X_m is fixed for a given crop but Y_m may vary with the soil location. Sites with native extractable P (no P-added) near or higher than X_m do not respond to P application. The values given for X_m are for maize.

Mineral Nutrition of Maize in Three Benchmark Soils

The Diagnostic and Recommendation Integrated System (DRIS) developed by E. R. Beaufils is a way of assessing the state of mineral nutrition in plants. Unlike most conventional methods that look at critical concentrations of nutrient elements in plant tissue, DRIS examines each element in relation to all other nutrient elements. Instead of critical concentrations, DRIS establishes optimum ratios (norms) of elements. The norms are obtained from a high-yielding population of the crop in question; the assumption being that healthy, high-yielding plants have the proper amount and balance of essential elements.

Results of the Benchmark Soils Project can be used to illustrate how DRIS operates. If one examines the scatter diagrams of yield vs. tissue nitrogen, phosphorus, or potassium (Fig. 11, 12, and 13), one would find it difficult to select a critical concentration associated with maximum yield. This is particularly true for P and K where there appears to be two maxima—one for the Hydric Dystrandept and another for the Tropeptic Eutrustox.

Unlike most conventional methods that look at critical concentrations of nutrient elements in plant tissue, DRIS examines each element in relation to all other nutrient elements . . . norms are obtained from . . . healthy, high yielding plants . . .

If, on the other hand, the scatter diagram for the yield vs. P/K (Fig. 14) is examined, an optimum ratio of about 0.17 can be found. This optimum value is necessary but not sufficient to guarantee high yields. This is to say that the average ratio for the high- and low-yielding population may not differ significantly. What is different is the variances around the mean—they are larger for the low- than the high-yielding population. The mean ratios (norms) and their respective standard deviations have been reported for maize by a number of workers. Since the norms are obtained from a high-yielding population, the

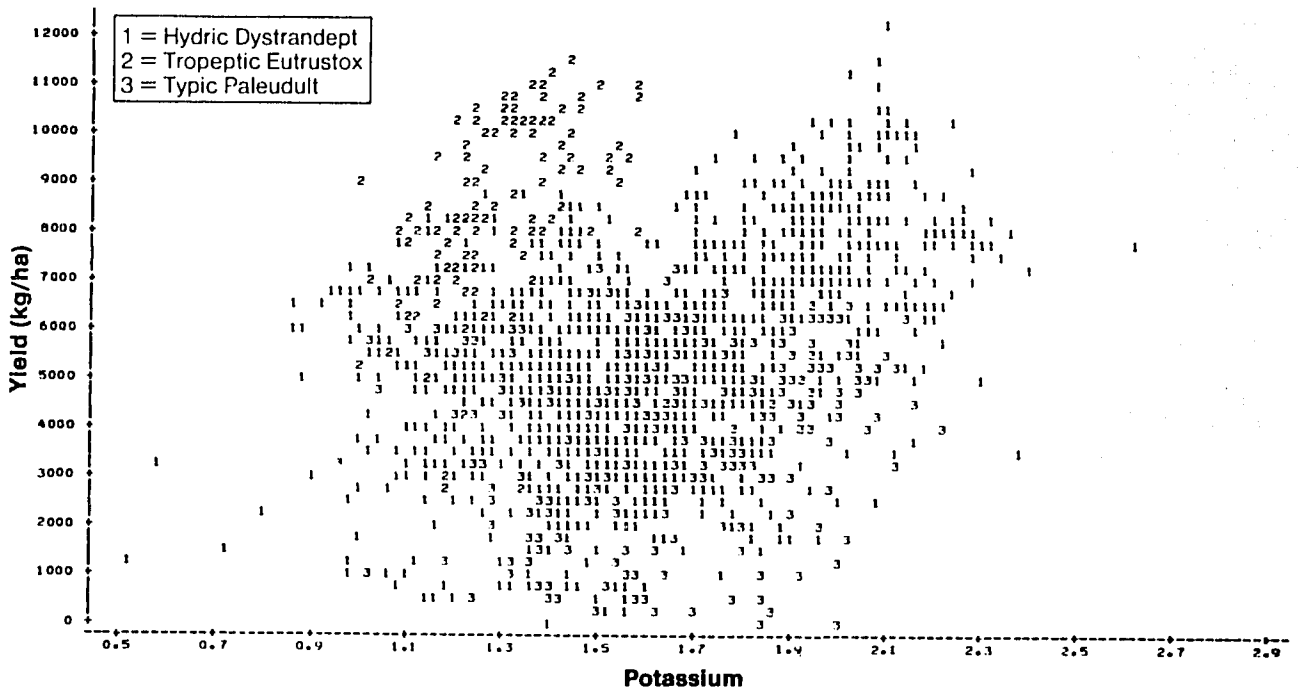


Fig. 11. Relationship between grain yield (kg/ha) and potassium concentration (%) in maize earleaves (50% tasselling) in the Benchmark Soils Project network.

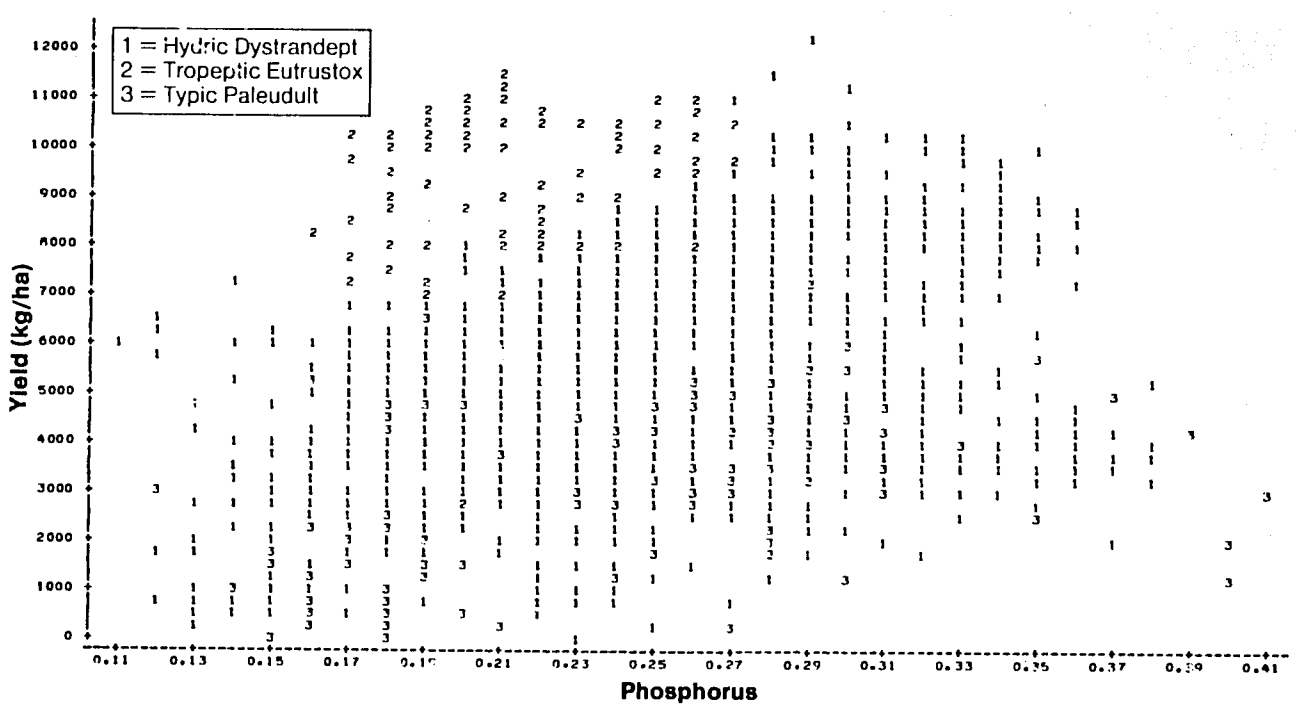


Fig. 12. Relationship between grain yield (kg/ha) and phosphorus concentration (%) in maize earleaves (50% tasselling) in the Benchmark Soils Project network.

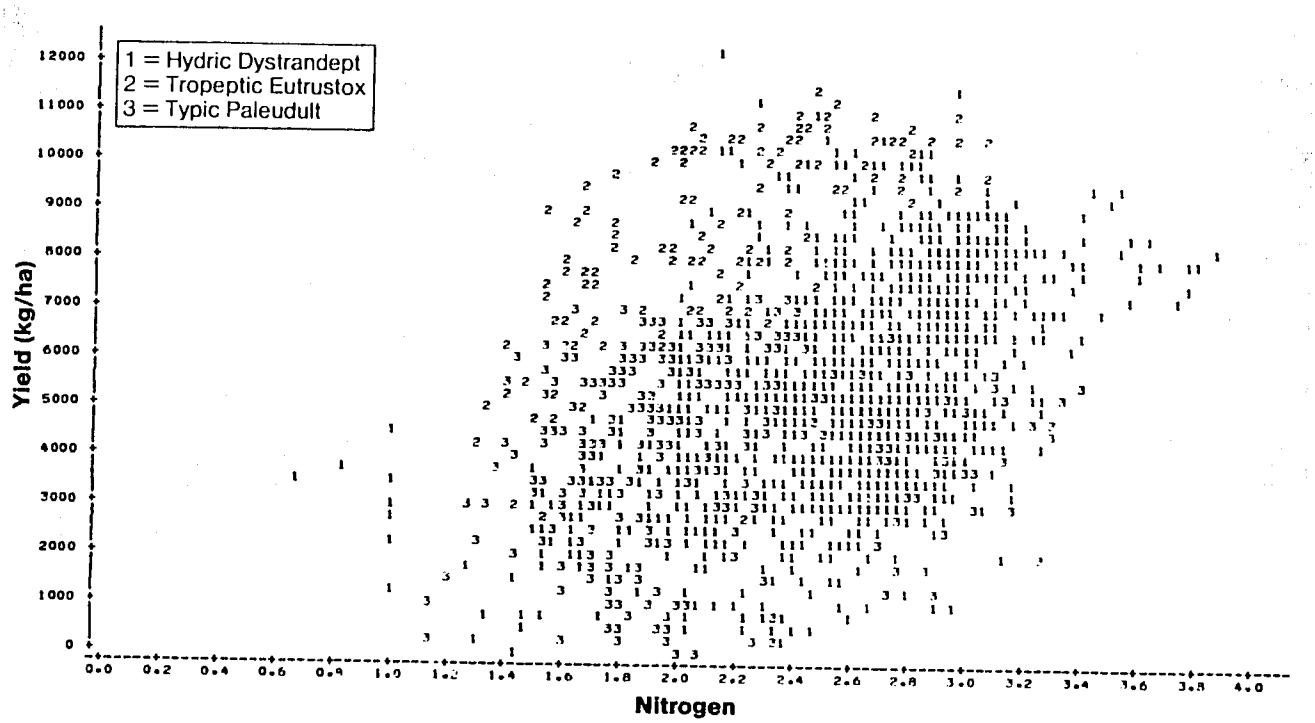


Fig. 13. Relationship between grain yield (kg/ha) and nitrogen concentration (%) in maize earleaves (50% tasselling) in the Benchmark Soils Project network.

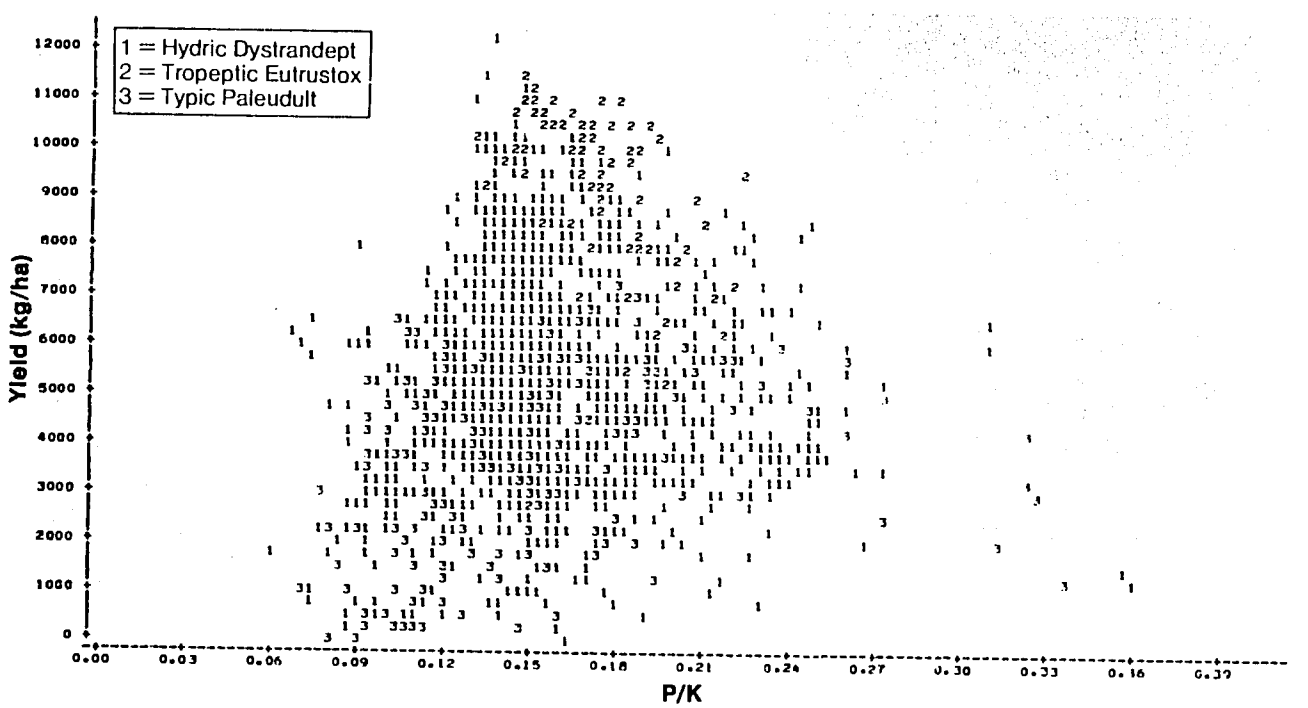


Fig. 14. Relationship between grain yield (kg/ha) and concentration ratio of P/K in maize earleaves (50% tasselling) in the Benchmark Soils Project network.

Table 14. Comparison of optimum values for nutrient ratios in the high-yielding population using two methods of selection: soil family: thixotropic, isothermic Hydric Dystrandepts.

Nutrient ratio	Top 2/rep (n=174)		Top 15% (n=196)		t-value
	Mean	SD	Mean	SD	
N/P	10.46	2.05	10.36	2.12	0.46[a]
N/K	1.88	0.75	1.73	0.49	2.27[b]
P/K	0.19	0.12	0.17	0.06	2.35[c]

[a] Not significant
[b] Significant at 5%
[c] Significant at 1%

Benchmark Soils Project staff was faced with the problem of defining the set of samples that would constitute the high-yielding population.

In the Benchmark Soils Project, the highest maize yields are consistently obtained from the summer harvests on Tropeptic Eutrustox. However, the summer yields on the Hydric Dystrandepts are generally higher than the winter yields of Tropeptic Eutrustox. The high-yielding population from the Project would largely come from the Tropeptic Eutrustox and Hydric Dystrandept and virtually exclude samples from the Typic Paleudults. This situation raised the question of whether the norms derived from a high-yielding maize population from one soil family would in fact be similar to those derived from another soil family.

To resolve this issue the high-yielding population was selected in two ways. In the first case the yields from the top 15 percent of all experiments were selected. In the second case the two highest yields from each replicate in each experiment were selected. The first case excludes yields from wet season experiments and from all yields on Typic Paleudults. The second case allows each experiment to contribute equally to the norms. The norms derived from the two populations are shown in Table 14. Earlier work by Escaño et al. (1981a, 1981b) of BSP indicates that nutrient diagnosis based on norms derived by the second method is better.

An attempt was also made to find the main sources of the variance for each norm. It turned out that most of the variance (>50 percent) could be attributed not to differences among families as we had hoped but to differences among replicates for a given treatment within experiments. The Project staff would have been hard-pressed to explain this finding, except that about the same time research on spatial variability was being conducted on a Benchmark site. The relationship between variance in the norms and soil spatial variability within experimental plots is discussed in the next section.

Spatial Variability of Soil and Leaf P in a Tropeptic Eutrustox

Spatial variation in concentration of essential plant nutrients in soils within land management units can cause significant variation in crop yield and element concentration in leaf tissue. In the Benchmark Soils Project, DRIS (Diagnostic and Recommendation Integrated System) ratios of nutrient concentration in leaf tissue are calculated from the highest yielding populations of a crop grown under optimal conditions of soil fertility in each site. Use of high-yielding populations effectively eliminates variation in DRIS ratios caused by inherent differences in soil fertility between soil families. As a result, variation in Benchmark DRIS ratios is essentially due to within-site and within-experiment variability of soil and environmental properties that affect nutrient uptake and accumulation.

A study of spatial variability of soil P and leaf P was made under two levels (0 and 45 kg P/ha) of P fertilization on a Molokai (Hawaii) BSP Tropeptic Eutrustox site. The objective of this study was to determine if microvariation of soil P was reflected in spatial variation of leaf P in a sorghum cover crop, and as such could be considered as a contributing source to within-experiment variation of DRIS ratios.

The unfertilized and 45 kg P/ha treatments were sampled in two replicates of a residual P experiment. Topsoil samples were collected in a 1.5-m square grid across each of the 15-m × 8-m plots, resulting in 50 samples per plot (Fig. 15). Soil samples were collected 35 days

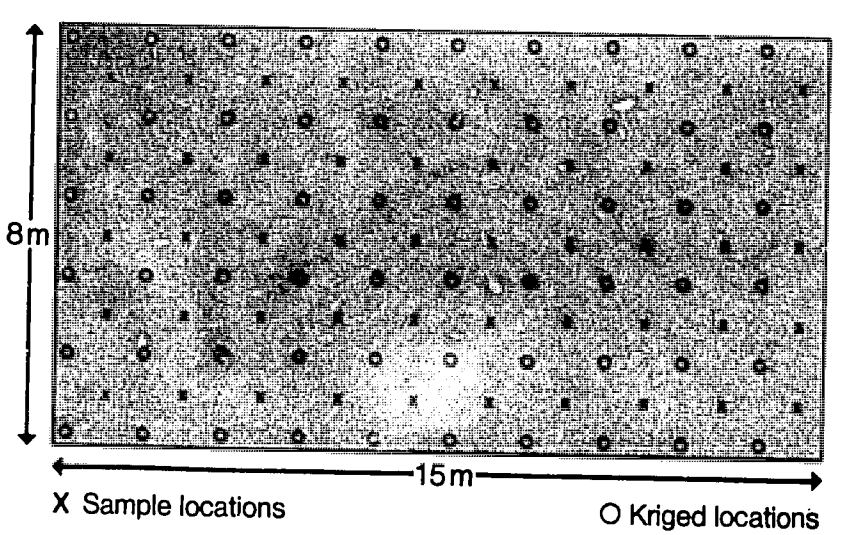


Fig. 15. Location of sample sites and kriged values for soil P and leaf P, rep 2, block K, Molokai, BSP site. Sample spacing is 1.5 m. The same design for sampling and kriging was used for 0 and 45 kg P/ha plots.

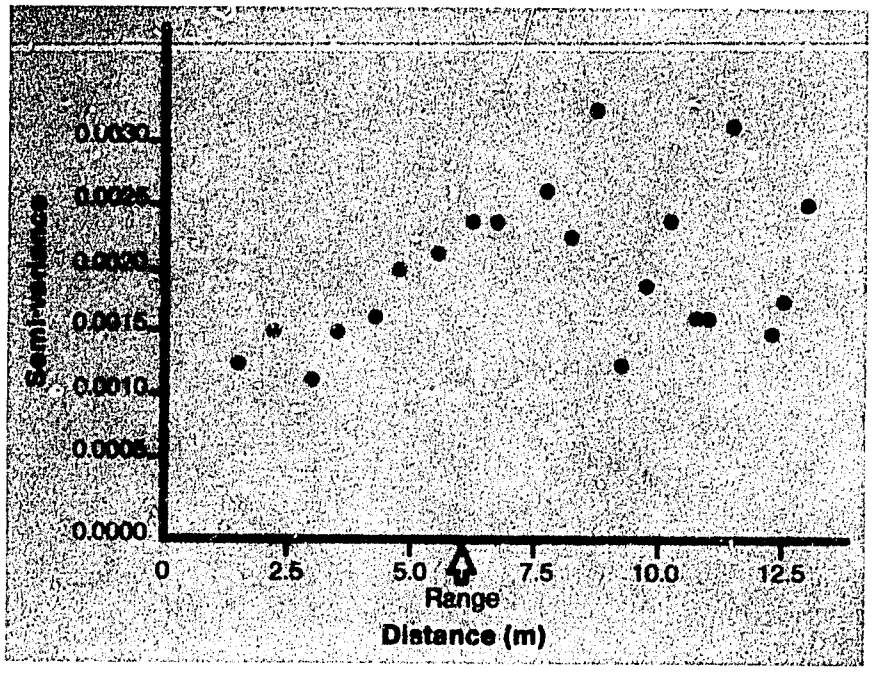


Fig. 16. Semi-variogram for leaf P of sorghum, unfertilized plot, rep 2, block K, Molokai, Hawaii.

after broadcast application of triple superphosphate to the fertilized plots, and P was determined by modified Truog extraction. Following soil sampling, sorghum was planted and flag leaf tissue sampled at 50 percent tasseling. Leaf element concentrations were determined with the X-ray quantometer using bulked samples of flag leaf tissue collected from a maximum of 6 plants located within a 50-cm radius of each original soil sample location.

Semi-variograms and kriging were used to analyze the spatial variability of soil and leaf P for each plot. Semi-variograms and kriging are based on regionalized variable theory, a geostatistical method for analysis of spatial variation of geographic variables which appear to be distributed at random within the environment (Journel and Huijbregts, 1978).[2] A semi-variogram (Fig. 16) is a plot of the average rate of change in semi-variance[3] of a particular variable with distance between sample locations. The semi-variance among samples will increase with distance up to a certain critical distance of separation (range), beyond which the semi-variance remains relatively constant and samples of the variable are no longer considered spatially related. Kriging is an exact interpolation method of estimating values at unsampled locations by using the relationship of semi-variance with distance described by the semi-variogram equation and by inverse distance weighting of experimental values. Sixty values of soil P and leaf P were kriged for each plot at locations shown in Fig. 15.

. . . variation in DRIS ratios involving P is related to random spatial variability of soil P . . .

In the unfertilized plots, sample values for soil P were spatially related over distances up to 5.6 m, but where 45 kg P/ha had been

[2] Journel, A. G., and Huijbregts, Ch. J. 1978. Mining geostatistics. Academic Press, London. 600 pp.

[3] The semi-variance, $\gamma(h)$, is $\gamma(h) = \frac{1}{2}E[z(x)-z(x+h)]^2$, where E is the expected value, z is the sample value, and x and h refer to sample locations.

Table 15. Summary statistics of modified Truog P and sorghum leaf P analyses, Block K, Molokai.

	P applied (kg P/ha)					
	0			45		
P Analysis	$\bar{x}$	CV	Mean range of semi-variograms (m)	$\bar{x}$	CV	Mean range of semi-variograms (m)
Modified Truog P (μg/g)	12.9	13.3	5.6	17.7	21.1	5.0
Leaf P (%)	0.31	17.0	6.1	0.39	11.5	Undetermined due to trends

applied the range of spatial dependence decreased to about 5.0 m (Table 15). This indicates that variation of soil P increased with fertilizer application and is confirmed by an increase in coefficients of variation (Table 15).

Leaf P was significantly correlated with soil P in each plot. In the unfertilized plots, the mean range of spatial dependence of leaf P was similar to that of soil P (Table 15). In the fertilized plots, the presence of distinct southeast by northwest trends in leaf P values across the plots prevented determination of the distance over which leaf P samples were spatially related. Leaf P was significantly correlated with leaf N, Ca, Mg, Si, S, and Zn in both treatments. As with soil and leaf P, the range of spatial dependence of these elements is consistently less than the dimensions of the plots, implying marked heterogeneity of nutrient concentration within individual plots.

The spatial distribution of kriged values for leaf P closely follows that of soil P in both replicates of each treatment. This is illustrated in Fig. 17 and 18 for the unfertilized plot of replicate 2. The similarities in spatial distribution within plots and significant correlation between soil P and leaf P for all plots suggest that variation in DRIS ratios involving P is related to random spatial variability of soil P within plots.

These results suggest that variation of leaf P in response to spatial variability of soil P may be a contributing source of the significant variation of DRIS ratios involving P that have been found within sites and within experiments of the Benchmark Soils Project.

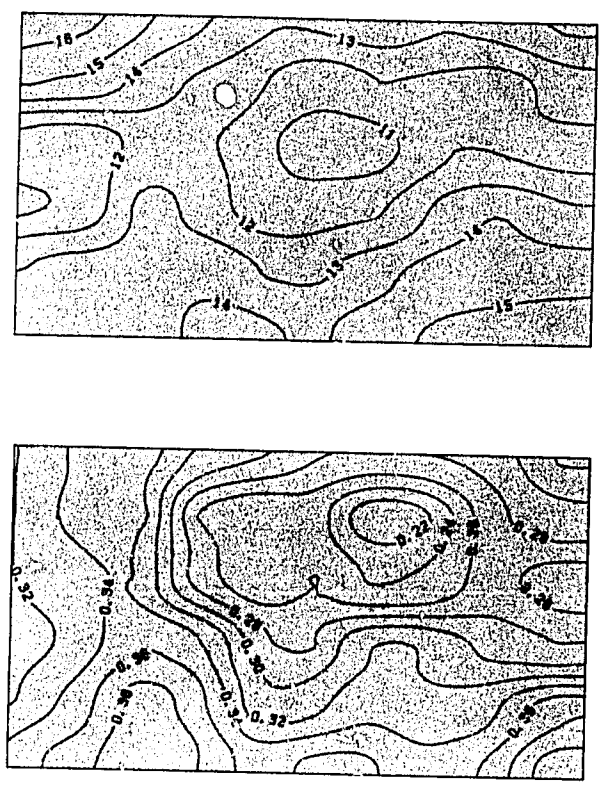


Fig. 17-18 Kriged soil P (μg/g Modified Truog) **(top)** and Kriged leaf P (%) in sorghum **(bottom)**, for a Tropeptic Eutrustox, unfertilized plot, rep 2, block K, Molokai, Hawaii.

Within-site and within-experiment variations of other DRIS ratios using elements besides P may be caused by small-scale spatial variation of related soil nutrients affecting uptake of each particular element. Temporal variation in soil and environmental properties affecting nutrient uptake during the course of an experiment may also contribute to within-site and within-experiment variations in DRIS ratios.

Soil Erosivity of Two Soil Families

On January 14, 1981, a collaborative study was initiated between the Hawaii Institute of Tropical Agriculture and Human Resources' Erosion Project (S. A. El-Swaify, Principal Investigator) and the Benchmark Soils Project. The objectives of this study were to demonstrate the utility of the BSP network of experimental sites and accompanying data sets for assessment of potential rainfall erosion and to provide a body of additional transferable information through soil classification. Intended activities included quantifying erosion-causing parameters at the BSP sites and evaluating the soil conservation effectiveness of alternative cropping systems formulated for the sites. Analysis of the rainfall data collected by BSP from the erosivity standpoint was started during the year.

. . . differences in soil family characteristics (mineralogical composition and moisture regimes) can be used to transfer experience and knowledge of the potential hazards to erosion of each family.

The EI_{30} index, a storm-based index in which E refers to the kinetic energy of rainfall (metric tons/ha) and I_{30} the maximum 30-minute intensity (cm/hr), was used as a basis for this analysis. EI_{30} has been successful in quantifying rainfall erosivity in many agroclimatic zones, including the tropics. Thus far, continuous rainfall records collected at 10 sites in Hawaii, Indonesia, and the Philippines have been analyzed for monitoring periods ranging from 33 to 49 months, all ending December 31, 1980. Of these, eight sites (IOLE, KUK, HAL, PUC, PAL, BUR, ITKA, and LPH) belong to the Hydric Dystrandepts and two (MOL and WAI) belong to the Tropeptic Eutrustox.

Table 16 summarizes the station information, average annual rainfall, and erosion index values for each of the sites. Among the Hydric Dystrandepts, the three Philippine sites yielded higher mean annual erosivity values than either the Indonesia or Hawaii sites. For the Tropeptic Eutrustox, both in

Table 16. Annual rainfall and erosivity values of the various sites.

Site	Monitoring periods: Dates	Monitoring periods: Duration (months)	Average annual rainfall (mm)	Annual rainfall erosion index: Mean	Annual rainfall erosion index: Range
Soil Family A: thixotropic, isothermic Hydric Dystrandepts					
Hawaii					
IOLE	12/76-12/80	49	2035	672	239-1017
KUK	7/77-12/80	42	2908	1478	618-2478
HAL	12/77-12/80	37	2420	680	479-1025
Philippines					
PAL	3/78-12/80	34	2720	1609	765-2268
BUR	6/77-12/80	43	3622	2355	1492-3074
PUC	12/76-12/80	49	2503	1277	932-1548
Indonesia					
LPH	6/77-12/80	43	2739	1670	1360-1971
ITKA	8/77-12/80	41	2011	902	637-1079
Soil Family B: clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox					
Hawaii					
WAI	4/78-12/80	33	942	411	160-671
MOL	12/77-12/80	37	902	355	186-621

*EI_{30} values in hundreds of metric units (ton-meters/ha). Each metric unit = 0.567 English unit (ft-ton/acre)

Table 17. Monthly distributions of the EI_{30} index.

Site	Average annual EI_{30} (metric unit)	Average percentage of annual EI_{30} occuring from 1/1 to: 2/1	3/1	4/1	5/1	6/1	7/1	8/1	9/1	10/1	11/1	12/1	12/31
Soil Family A: thixotropic, isothermic Hydric Dystrandepts													
Hawaii													
IOLE	671.5	25	28	58	64	65	66	67	74	74	76	96	100
KUK	1478.1	34	38	56	67	68	70	72	75	75	76	95	100
HAL	679.5	18	23	54	60	62	62	64	72	72	80	94	100
Philippines													
PAL	1609.5	4	4	9	16	27	29	36	47	71	75	95	100
BUR	2354.7	4	4	10	22	31	37	46	52	69	78	95	100
PUC	1277.0	3	5	9	14	26	33	49	56	80	87	95	100
Indonesia													
LPH	1670.3	12	20	31	41	48	53	59	60	69	75	88	100
ITKA	901.9	5	11	29	43	51	55	57	59	64	73	86	100
Soil Family B: clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox													
Hawaii													
WAI	411.4	21	27	34	39	54	58	58	58	61	91	93	100
MOL	354.7	48	63	64	66	82	83	83	83	86	92	93	100

Hawaii, a slightly higher mean annual erosivity value was obtained for WAI than for MOL. Since these trends are based on a limited number and variety of storms, significant changes are expected as additional rainfall data are acquired.

The monthly distributions of the EI_{30} values within the year is shown in Table 17. For Family A, the Indonesia and Hawaii sites display similar erosivity distributions; low values were recorded from May to October and high values from November to April. In contrast, the high erosivity values for the Philippine sites were observed during the period from May to October, which corresponds to the typhoon season. Typhoons are rare in Hawaii and Indonesia. For Family B, the excessively high EI_{30} percentages received

by the MOL site in January and by the WAI site in October are not consistent with earlier observations of Hawaii's rainfall. These were caused by major storm occurrences, two of which are discussed in the section below. Clearly, the short monitoring period was insufficient to smooth out irregular trends in monitored rainfall patterns. However, the results in both Tables 16 and 17 do reflect the differences of the udic moisture regimes of the Hydric Dystrandepts and the ustic moisture regimes of the Tropeptic Eutrustox of both soil families. Clearly, even with the limited time over which these weather data were collected, differences in soil family characteristics (mineralogical composition and moisture regimes) can be used to transfer experience and knowledge of the potential hazards to erosion of each family.

It is instructive to examine the characteristics of the most erosive storms (storms with the highest EI_{30} value) at the various sites. A summary of these characteristics is presented in Table 18. Within the Hydric Dystrandepts, the KUK site (Hawaii) received the largest storm amount but the LPH site (Indonesia) and the PAL site (Philippines) were characterized by the highest short-duration intensities. Total storm erosivity was highest for KUK (Hawaii), but that reflected more the high rainfall quantity than it did intensity. For comparable rainfall amounts, the Hawaii sites displayed least-erosive storms. For Family B, the largest storm at the WAI site was nearly twice as erosive as that on the MOL site. These two storms were responsible for the irregular monthly EI_{30} distribution patterns discussed above.

To overcome the limitations of short-term observations, it would be desirable to extend the data base for rainfall erosivity estimation. To determine which readily available data would be most desirable, a linear regression analysis was conducted between the EI_{30} index and corresponding total rainfall amount on a storm, daily, monthly, seasonal, and annual basis. The results are shown in Tables 19 and 20. It is noted that various indicators of total rainfall amount vary considerably in their success of predicting rainfall erosivity at the various locations. With the inclusion of EI_{30} data subsequent to 1980 and the use of additional erosivity indices, it is anticipated that the most reliable predictive parameters will be identified. These, together with other long-term rainfall data from the various locations, will be used to achieve a reliable rainfall erosivity and potential soil loss analysis for the BSP network.

Table 18. Characteristics of the most erosive storms recorded during the monitoring period.

Site	Date	Duration (hr)	Total rain (cm)	Maximum rain intensity 30-min. (cm/hr)	Erosion Index EI_{30} (metric unit)
Soil Family A: thixotropic, isothermic Hydric Dystrandepts					
Hawaii					
IOLE	1/11/79	107.5	60.9	3.00	383.0
KUK	1/11/79	134.0	107.6	5.00	1202.5
HAL	3/22/80	52.5	28.8	5.41	339.0
Philippines					
PAL	9/17/79	43.5	43.7	7.10	755.3
BUR	4/15/79	69.5	50.3	5.99	696.1
PUC	9/17/79	39.0	36.7	5.59	500.0
Indonesia					
LPH	1/09/79	13.5	14.2	8.41	314.9
ITKA	10/31/79	2.5	7.6	6.60	130.6
Soil Family B: clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox					
Hawaii					
WAI	10/30/78	9.5	19.1	7.01	343.3
MOL	1/08/80	12.0	13.6	5.21	167.3

Table 19. Coefficients of linear correlation between storm, daily, monthly and annual rainfall erosivity index and the corresponding rainfall amount (number in parenthesis is the sample size).

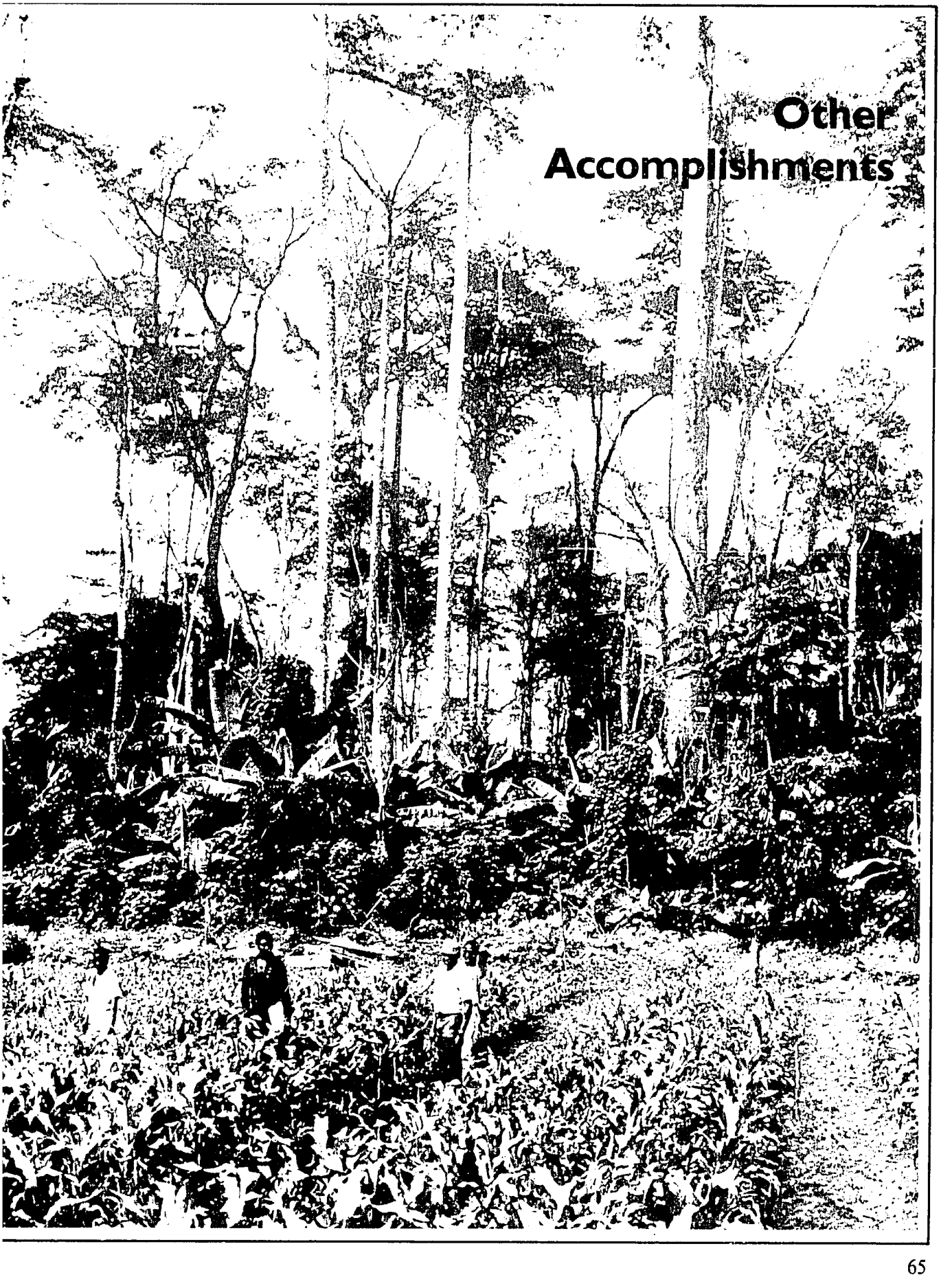
Site	Storm	Daily	Monthly	Annual
Soil Family A: thixotropic, isothermic Hydric Dystrandepts				
Hawaii				
IOLE	0.952(121)	0.924(86)	0.917(45)	0.970(5)
KUK	0.965(127)	0.937(92)	0.941(40)	0.960(4)
HAL	0.825(152)	0.831(128)	0.857(37)	0.872(4)
Philippines				
PAL	0.878(142)	0.860(126)	0.853(34)	0.953(3)
BUR	0.930(238)	0.893(211)	0.876(43)	0.908(4)
PUC	0.885(198)	0.864(180)	0.825(49)	0.851(5)
Indonesia				
LPH	0.899(247)	0.903(238)	0.937(41)	0.989(4)
ITKA	0.845(202)	0.841(189)	0.813(43)	0.803(4)
Soil Family B: clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox				
Hawaii				
WAI	0.899(42)	0.782(35)	0.751(33)	0.599(3)
MOL	0.891(58)	0.909(54)	0.917(37)	0.973(4)

Table 20. Correlation coefficients between EI_{30} values for seasonal rainfall and corresponding rainfall amount (number in parenthesis is the sample size).

Site	Season Type[a]			
	IA	IB	IIA	IIB
Soil Family A: thixotropic, isothermic Hydric Dystrandepts				
Hawaii				
IOLE	0.945(16)	0.907(29)	0.869(16)	0.939(29)
KUK	0.987(12)	0.976(28)	0.913(15)	0.949(25)
HAL	0.672(13)	0.905(24)	0.944(12)	0.879(25)
Philippines				
PAL	0.766(10)	0.924(24)	0.936(12)	0.794(22)
BUR	0.872(14)	0.900(29)	0.940(16)	0.844(27)
PUC	0.833(17)	0.893(32)	0.930(16)	0.704(33)
Indonesia				
LPH	0.924(14)	0.960(27)	0.968(14)	0.923(27)
ITKA	0.824(16)	0.827(27)	0.204(14)	0.785(29)
Soil Family B: clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox				
Hawaii				
WAI	0.944(10)	0.740(23)	0.605(12)	0.728(21)
MOL	0.936(13)	0.924(24)	0.641(12)	0.924(25)

[a]Season type IA includes months from November to February,
type IB includes months from March to October,
type IIA includes months from June to September,
type IIB includes months from October to May.

This is a contribution of S. A. El-Swaify, Professor of Soil Science, College of Tropical Agriculture and Human Resources, University of Hawaii, and Andrew Lo, Assistant Soil Scientist in the Department of Agronomy and Soil Science, University of Hawaii.



Other Accomplishments

Training

BSP's training in Soil Taxonomy consists of lectures and field work, conducted over a 3-4 week period. These workshop participants from the Philippines were given a special assignment to classify the soils of experiment stations in their respective regions. They then convened a year later to report their findings, which also provided an opportunity to evaluate the effectiveness of the training.

Recommendations for a strengthening of the training component of the Benchmark Soils Project were made in 1976 and reinforced in 1979 by the AID (U.S. Agency for International Development) review teams. Workshops and training programs were conducted in soil classification and identification, soil survey interpretation, and soil-based agrotechnology transfer.

The major programs or activities are training workshops in Soil Taxonomy and Agrotechnology Transfer and graduate training for selected individuals recommended by the host-country cooperating agency in Cameroon, Indonesia, and the Philippines.

Workshops on Soil Taxonomy and Agrotechnology Transfer

The main thrust of the training package is to promote and encourage adoption of Soil Taxonomy as the soil classification system essential for understanding the concept of agrotechnology transfer. It is expected that the workshops will promote a closer working relationship between agricultural scientists and planning agencies at both the national and international levels to facilitate the transfer of agrotechnology for agricultural development.

PHILIPPINES – 1979

In cooperation with PCARRD (Philippine Council for Agriculture and Resources Research and Development), Los Baños, the Benchmark Soils Project conducted its first training workshop in Soil Taxonomy from June 4-29, 1979, in Los Baños. H. Ikawa of the University of Hawaii and Wayne H. Hudnall of West Texas State University were the instructors, assisted by Arturo Dayot and Alfonso Crucena of the Bureau of Soils, the Philippines. Guest lecturers also assisted.

Participants were enthusiastic about conducting their own workshops in the future and about training co-workers in soil classification according to Soil Taxonomy. The 13 participants were technical staff from the Bureau of Soils, the Philippine Coconut Authority, Central Luzon State University, the National Irrigation Authority, and the

Dr Muljadi, Director, Center for Soil Research, presented a commemorative banner to one of the trainees who completed the Soil Taxonomy Training Workshop conducted in Bogor, Indonesia in June, 1980

Philippine Ministry of Agrarian Reform. Sessions included classroom and field activities and a final seminar presentation by the participants.

As a direct result of the workshop, a project entitled "Soil Classification of Selected Research Centers/Stations in the Philippines Using Soil Taxonomy Framework" has been initiated by five national agricultural agencies in the Philippines. The five funding agencies include the Philippine Council for Agriculture and Resources Research and Development, the National Irrigation Administration, the Philippine Ministry of Agrarian Reform, the Philippine Coconut Authority, and the Benchmark Soils Project.

In order to catalyze in-country user-oriented programs, workshops on soil classification and agrotechnology transfer were conducted in Indonesia in June and July 1980, followed by an agrotechnology workshop in the Philippines in July 1980. This latter workshop was a follow-up of one held in 1979. These workshops were conducted in consultation with the local AID missions and the host countries. The Soil Research Institute (SRI) of Indonesia and the Philippine Council for Agriculture and Resources Research and Development (PCARRD) and the Bureau of Soils selected the participants and assisted in the arrangement and conduct of the workshop.

INDONESIA – 1980

Twenty-five participants from the Soil Research Institute, Agricultural Extension Service, Directorate of Planning, Pajajaran University, Andalas University, and Central Research Institute of Agriculture (CRIA) attended the workshops on Soil Taxonomy and Agrotechnology Transfer. The first two weeks were devoted to Soil Taxonomy. H. Ikawa, Wayne Hudnall, and Martin Raymundo, BSP/Philippines, taught the course. Additional lectures were given by Darryl Gallup, FAO (Food and Agriculture Organization) scientist at SRI, and Roel Oldeman, Agricultural Climatologist from CRIA.

At the conclusion of the workshop, the participants were able to use soil descriptions and laboratory data to identify the different diagnostic soil horizons and to classify soils according to criteria set forth in Soil Taxonomy. The purpose of this exercise was to enable the participants to use Soil Taxonomy as a universal language to communicate soil information for technology transfer.

The participants made a field trip to Lam-

pung, Sumatra, at the end of the second week to visit field experiments for agrotechnology transfer—these included the BSP sites in Nakau, SRI's own Benchmark experiments on corn and legumes, and the newly established cropping systems experiments of IRRI/CRIA for the transmigration communities.

The third week was devoted to the Agrotechnology Transfer workshop, which was held at SRI's conference hall. Papers were presented in the morning and the afternoons were devoted to workshop exercises. As originally planned, 13 papers were presented during the workshop. Four case studies were prepared for the workshop in consultation with local experts. The case studies were local examples and were selected: (1) to give the participants some perspectives on the important issues in agricultural development through the transfer of agrotechnology and (2) to guide the participants in relating the principles and concepts learned about agrotechnology transfer based on agroenvironmental factors. The participants were divided into small discussion groups, and later presented their assessment of the case studies.

The discussion during the workshop sessions were conducted both in English and Indonesian.

PHILIPPINES – 1980

Twenty-four participants attended the Agrotechnology Transfer workshop. Ten of the participants had completed the training workshop on Soil Taxonomy conducted by BSP in June-July of 1979. The other participants consisted of regional agricultural planners of the National Economic Development Authority (NEDA); a program specialist of PCARRD; agriculture planners of the National Irrigation Administration, Bureau of Plant Industry, and Bureau of Lands; and senior soil technologists from the Bureau of Soils.

The workshop began on July 14. Aida Librero, PCARRD Director, Socio-Economics Division, gave the welcome address in the absence of J. D. Drilon, PCARRD Director-General. James A. Silva, BSP Principal Investigator, gave the keynote address.

Paper presentations were divided into three sessions:

Session I	– Establishment of the Foundation of Agrotechnology Transfer. Moderator: A. A. Briones
Session II	– Analysis of Experiences on Agrotechnology Transfer in the Philippines. Moderator: B. G. Cagauan, Jr.
Session III	– Rationalization of Land Use and Policy Direction for Agrotechnology Transfer. Moderator: Amado Maglinao

After each session the participants reviewed principles and concepts and were given the opportunity to orally present their impression before the group.

The workshop sessions started on July 16. Participants were divided into three commodity groups: rice, plantation crops, and upland diversified crops. Soils specialists and agricultural planners were uniformly divided among each group for maximum interdisciplinary interaction.

The first phase of the workshop activity was to identify experiment stations in relation to the above commodities. Participants in the 1979 Soil Classification workshop gave a 15-minute presentation of their work on the soil survey and classification of various experiment stations in the Philippines. With this background, the participants proceeded to identify the *objectives* of an experiment for a given commodity in relation to the area surveyed; made recommendations on the *locations* in relation to *soil* and *agroenvironment;* identified *socioeconomic considerations* in relation to the experiment station for the given commodity; outlined critical *government support* and *institutional involvement;* defined *success indicators* of the experiment stations; and identified *potential problems* in relation to the recommendations made.

The second phase of the workshop dwelled on the development of soil-based research project proposals for the various commodities. These proposals summarized the aims of the workshop, which were to:

1. Develop a framework for soil-based agrotechnology transfer.
2. Organize and integrate existing soil-

One of the key objectives of BSP's training program is to assist in-country cooperators acquire experience in the use of Soil Taxonomy to classify soils (Indonesia)

based information for agrotechnology transfer.

3. Implement soil-based agrotechnology transfer for agricultural development programs.
4. Identify research needs to accelerate soil-based agrotechnology transfer and development planning.

These research proposals were consistent with PCARRD's priorities and the participants were encouraged to write them in PCARRD's format.

CAMEROON – 1983

A seminar/workshop on Soil Classification and Agrotechnology Transfer for Agricultural Development is planned for the United Republic of Cameroon on January 6–15, 1983. This conference will be the first joint effort between BSP and the Soil Management Support Service (SMSS) Project (PASA No. AG/DSB-1129-5-79) of the Soil Conservation Service of the U.S. Department of Agriculture (AID) and will be the third international forum on Soil Taxonomy and Technology Transfer. The seminar and workshop are being planned in collaboration with the Institut de la Recherche Agronomique (IRA) of the General Delegation for Scientific and Technical Research (DGRST), the FAO Soil Resources Project in Ekona, and the local USAID mission in Yaounde.

Graduate Training

Three students under full sponsorship of the Benchmark Soils Project received their graduate degrees during this reporting period. Crisanto R. Escaño received a Ph.D. degree in Soil Science in December 1980 with a dissertation entitled "Comparative Evaluation of Some Diagnostic Techniques for Determining the Nutrient Requirement of Maize Grown on Hydric Dystrandept." He is now Assistant Director, Crops Research Division, Philippine Council for Agriculture and Resources Research and Development (PCARRD).

Modesto Recel received his M.S. degree in December 1980 and is now continuing in a Ph.D. program under BSP sponsorship. His thesis is entitled "Reclassification of Andepts

in the State of Hawaii in the Proposed Order of Andisols." Recel is employed by the Philippine Bureau of Soils and received the concurrence of his director, G. N. Alcasid, to pursue a Ph.D. in Soil Science at the University of Hawaii.

Djoko Santoso received a M.S. degree in Agronomy in May 1981. His thesis was entitled "Performance of Maize Varieties in Three Tropical Soil Families and the Response to N and P Fertilization." He returned to Indonesia and is on the staff of the Center for Soil Research in Bogor.

A fourth student with partial stipend support from the Project also completed his degree requirements. Luis A. Manrique did part of his Ph.D. dissertation research entitled "Development of Land Suitability Classification for Potatoes *(Solanum tuberosum)*" at two of the BSP sites in Hawaii. Manrique is currently employed as a postgraduate scholar on the BSP.

Six other graduate students supported by the Project are nearing completion of their studies. They are listed below with their target date of completion, thesis or dissertation topic, and country.

	Program	Thesis topic
Cameroon		
John N. Awemo	M.S. 1983	Effect of Mychorrhiza on Maize Growth
Indonesia		
I P. Widjaja-Adhi	Ph.D. 1982	Predicting Maize Response to Phosphorus Application in Relation to Residual P on Typic Paleudults and Tropeptic Eutrustox
M. Soekardi	Ph.D. 1983	Soil Interpretation of Agricultural and Non-Agricultural Uses Within Benchmark Soil Families
Philippines		
Modesto R. Recel	Ph.D. 1983	Revision of Classification of Soils Low Activity Clays in Soil Taxonomy
Beatriz P. del Rosario	Ph.D. 1982	Nutritional Diagnosis in Maize Grown in Three Tropical Soil Families
U.S.A.		
David J. Harris	Ph.D. 1982	Phosphorus Placement and Sources for Maize on Three Soil Families

Several other graduate students who are funded from other sources have developed interest in the Project and are now conducting their thesis research on some aspects of the Project. They are also listed below with degree objective, thesis topic, sources of support, and country of origin. The research programs of graduate students listed contribute heavily to the attainment of Project objectives and adds to their academic goals.

	Support	Program	Thesis topic
Fiji			
Upendra Singh	East West Center	Ph.D.	Crop Modelling in Benchmark Locations of the Tropics
India			
Naraina P. S. Varde	East West Center	Ph.D.	Cropping Systems Research on Benchmark Soils
New Zealand			
Bruce B. Trangmar	National Research Academy of New Zealand	Ph.D.	Assessing Spatial Variability of Soil Properties
Senegal			
Jean-Pierre N'diaye	African American Institute	Ph.D.	Effect of Long-Term Phosphate Fertilization on Cation Exchange Capacity and Cation Movement in Variable Charge Soils
U.S.A.			
Joel Fithian	self	M.S.	Response of Maize to Climate and Sulfur
Ken McDicken	Grad. Res. Asst. in Horticulture	Ph.D.	Performance of Nitrogen-Fixing Fuelwood Trees on Three Benchmark Soils
Zambia			
Vernon Chinene	African American Institute	Ph.D.	Water Uptake by Maize as Affected by N and P Fertilization on a Tropeptic Eutrustox

Communication and Dissemination

Publications

Dissemination of information on Project progress, concepts, and achievements has continued through printed and visual mediums and participation of personnel in national and international meetings. Communication with national and international agricultural research centers and individuals continues to be maintained through regular mailing of various publications including the *Benchmark Soils News*. In association with the Soil Management Support Service (SMSS) project of SCS, the mailing list now totals 1959 recipients.

Since Progress Report 2 was distributed in 1979, the following publications were printed and made available for distribution.

	Title
Tech. Rep. 2	Laboratory Data and Description of Soils of the Benchmark Soils Project: Vol. 2—Puerto Rico Project (F. H. Beinroth)
Tech. Rep. 3	Procedures and Guidelines for Agrotechnology Transfer Experiments with Maize in a Network of Benchmark Soils (BSP Staff)
Tech. Rep. 5	Classification of the Soil Series of Hawaii in Four Systems: A Guide to Correlating Tropical Soils (F. H. Beinroth, H. Ikawa, and G. Uehara)
Tech. Rep. 6	Quantitative Evaluation of Agrotechnology Transfer: A Methodology Using Maize Response to Phosphorus on Hydric Dystrandepts in the Benchmark Soils Project (F. B. Cady, C. P. Y. Chan, C. L. Garver, J. A. Silva, and C. L. Wood)
Dept. Paper 49	Experimental Designs for Predicting Crop Productivity with Environmental and Economic Inputs for Agrotechnology Transfer (J. A. Silva, ed.)
Reprint	Reprints from Advances in Agronomy, Vol. 33: Beinroth et al., Agrotechnology Transfer in the Tropics Based on Soil Taxonomy; and Cline, Experience with Soil Taxonomy of the United States

In addition, a leaflet was printed after the BSP/FAO panel consultation in Rome:

Leaflet 3	Strategy for Land Evaluation and Agrotechnology Transfer in the Tropics and Subtropics

The article by Beinroth et al. was invited for publication in Advances in Agronomy in FY 1979–80 by Nyle Brady, editor of the monograph series and then director of IRRI, the Philippines. The companion article by Cline, which was prepared without consulta-

tion with BSP personnel, cites Benchmark scientists in the sections "Use of Soil Taxonomy Internationally" and "Impact of Soil Taxonomy Internationally." Through a cooperative arrangement between BSP and SMSS, these two articles were prepared in booklet form in FY 1980-81 for distribution by AID to scientists in developing countries who may not have access to the monograph series from Academic Press.

Publications currently in press include:

Dept. Paper 61	Planning Agroforestry and Fuelwood Production on the Basis of Soil Taxonomy
Tech. Rep. 4	Soils of the Hawaii Agricultural Experiment Station, University of Hawaii: Soil Survey, Laboratory Data, and Soil Descriptions
Tech. Rep. 7	A Multidisciplinary Approach to Agrotechnology Transfer: Proceedings of a Benchmark Soils Project/Hawaii Institute of Tropical Agriculture and Human Resources Workshop
Tech. Rep. 8	Proceedings of the Benchmark Soils Project Symposium at the International Conference of Soils with Variable Charge
Tech. Rep. 9	Agrotechnology Transfer in Indonesia and the Philippines. Proceedings of workshops held in Bogor, Indonesia, and in Los Baños, Philippines.

Several technical papers by Project scientists about the Project concept were published in various magazines and scientific journals.

1. Upon invitation from the editor after initial contact by the BSP, an article by Goro Uehara entitled "Tropical Soils Management and Its Transfer" was published in the Aspen Institute for Humanistic Studies' current Food and Climate Review 1980-81.
2. An article by Goro Uehara on vertical and horizontal agrotechnology transfer appears in the 1981 McGraw-Hill Yearbook of Science & Technology under the heading "Agricultural Engineering." Other concepts included analog transfer, matching transfer, and gap analysis.
3. An article entitled "Intersite Transfer of Estimated Response Surfaces" by Constance L. Wood and Foster B. Cady appeared in Biometrics 37 (March 1981). Wood and Cady describe the methodology and apply the transfer residuals using Benchmark Soils Project data.
4. A paper entitled "The Benchmark Soils Project of Hawaii in Puerto Rico: Researching a Method for Agrotechnology Transfer in the Tropics," prepared by H. Ikawa when he was on a 1979 sabbatical leave in the Netherlands, has been published in FAO's Land Evaluation Guidelines for Rainfed Agriculture, World Soil Resources Report No. 52.
5. M. Sudjadi of the Center for Soil Research, Bogor, presented a paper entitled "Influence of P Application on Maize Yields in the Typic Paleudults in South Sumatra," which was written by R. G. Manuelpillai, M. Sudjadi, M. Supartini, and J. A. Silva, in the Symposium on the Management of Clay Soils in the Tropics Trinidad. The paper later was published in Tropical Agriculture (Trinidad) Vol. 59.
6. C. A. Jones, formerly of the Hawaii Sugar Planters Association and currently with ARS/USDA, Temple, Texas, presented a paper entitled "Nutrient Diagnosis on Corn Growth in Hydric Dystrandepts," written in collaboration with C. A. Escaño and G. Uehara, at the 1980 Annual American Society of Agronomy meetings in Detroit, Michigan. Two papers were subsequently published in 1981 in the Soil Science Society of America Journal, Vol. 45.

The *Benchmark Soils News* continues to be published and is approximately 8 pages each issue. Highlights of research results are featured.

An irregularly printed newsletter, the *BSP Communiqué,* was continued as a means of internal employee communication, since the network of Project personnel encompasses widely-separated geographic locations. Feedback from field and laboratory employees indicates this medium continues to enhance feelings of unity within the Project.

A bibliography of papers presented at various meetings and published materials are listed in Appendix 3.

Slides/Visuals

An overview of the BSP concept was made into a slide/tape presentation and a 3/4-inch videocassette which are now available to interested parties from the Hawaii office on a two-week loan basis. The 80-slide, 15-minute show, entitled "Promising Opportunities for Agrotechnology Transfer: The Benchmark Soils Project Concept," is synch-pulsed, and has both audible tones for manual slide advancement and inaudible tones for automatic projecting systems. The show was originally prepared for presentation at the International Conference on Soils with Variable Charge at Palmerston North, Massey University, New Zealand, but has proved popular at various Benchmark locations to provide visitors with a quick introduction to Project objectives and activities. A tapescript is included. The slide/tape show was duplicated (15 sets) and packaged for distribution to BSP sites, cooperating agencies, and AID officials.

Approximately 300 original slides of titles, graphs, and tables were produced for various paper presentations by BSP scientists. Several of these slides in sets (about 375 slides total) were duplicated and sent to BSP sites and researchers outside Hawaii. Some transparencies were also produced for BSP graduate students and researchers for use in seminar presentations.

Mailing List

The BSP mailing list is an international list of individuals, institutions, and agencies that have expressed interest in BSP. In the last year, the mailing list for the *Benchmark Soils News* has increased from just over 900 to 1360 individuals and organizations in a total of 89 countries.

The mailing list program was designed and developed to allow sorting and retrieval by clientele base, clientele interest, year originally put on list, organization, individual, country, and zip code. The master data base was expanded to include the SMSS list and then they cooperatively maintained and shared this master list.

Symposiums and Conferences

Presentation of papers on Project accomplishments and concepts was made at a number of conferences and symposiums. Since 1979, several papers have been presented at each of the annual American Society of Agronomy meetings. Titles of these papers are listed in Appendix 3. In addition, reports presented at the 4th International Soil Classification meetings held in Kigali, Rwanda, also are listed in the Appendix.

The accomplishments and impact of the Benchmark Soils Project can best be illustrated by its participation in two meetings that are described below.

The first was an international conference on Soils with Variable Charge held under the auspices of the New Zealand Society of Soil Science and the Royal Society of New Zealand from February 11-18, 1981, at Massey University in Palmerston North, New Zealand. This was a meeting of Commissions IV, V, VI, and VII of the International Society of Soil Science.

The Benchmark Soils Project was invited to present a symposium on February 16, at which the Project background, activities, and progress to date were discussed. Special presentations were made by BSP in-country Project leaders and heads of the cooperating host-country agencies detailing the needs and strategies for transfer of agrotechnology in the developing countries. The proceedings for the one-day symposium is being prepared for publication.

Displays of Benchmark findings were installed in a room adjacent to the conference room, and a continuous slide/tape presentation provided background of the Project. The Project appreciated this opportunity to present its findings to an international body so that many people would become aware of the potential for agrotechnology transfer in the tropics. Two poster presentations were prepared by Benchmark personnel, one on the behavior, classification, and management of the Andepts of Hawaii, and one on the quantitative evaluation of agrotechnology transfer.

The second meeting was the South Pacific Regional Forum on Soil Taxonomy. An example of the effectiveness of the BSP/

SMSS collaboration in providing information on soil classification and agrotechnology was provided by the outcome of the South Pacific Regional forum on Soil Taxonomy, cosponsored by SCS and AID and the Institute of Natural Resources of the University of the South Pacific, held in Suva, Fiji, between November 1-13, 1981. One of the principal recommendations was to develop a Benchmark Soils Project for the South Pacific, and an important aspect of the forum was that so much was achieved with so little U.S. input.

All the major countries of the South Pacific (Fiji, Tonga, Western Samoa, Papua New Guinea, New Caledonia, the Solomons, and French Polynesia) were represented in the forum. Most of the representatives were high-ranking scientists/administrators of the Ministries of Agriculture. The forum consisted of a training session in the use of Soil Taxonomy, discussion sessions among participants and resource staff, field tours to examine soils in the field, and a final day of formulating recommendations for future action.

The purpose of the forum was to promote the use of a common international resource language (embodied in Soil Taxonomy) in the region to enable the small island nations with equally small economies to benefit from agricultural research conducted in the larger nations of the region and the world.

The participants of the forum very quickly recognized the importance of using Soil Taxonomy as a basis for making soil surveys in the region. They realized that a great deal of research was being conducted on the same soil and climate in virtually every island nation in the South Pacific. The participants realized that a great deal of duplication of effort could be avoided and that research stations of the region could work as a network of cooperating stations. This realization was expressed in the form of a major forum recommendation to create a regional network of Benchmark experimental stations to enhance sharing of agrotechnology. The resource people supported this recommendation and suggested that the nations of the South Pacific approach international funding agencies to support such an effort.

Impact

Conclusion

The reader may have wondered about the meager reference to farmers in a report with a theme on technology transfer. It is important, therefore, to distinguish between technology transfer that refers to the taking of a technology from its site of origin to a new location where it is likely to succeed, and innovation diffusion, which is the extension of this technology to the farmer.

Technology transfer is horizontal in that it entails innovation sharing among research centers. Innovation diffusion, on the other hand, is vertical in that it involves the transfer of a technology from the research center to farmer fields.

The Benchmark Soils Project is designed to research the horizontal component—the first step in the two-step process of technology transfer and innovation diffusion. One can say that technology transfer is necessary but not sufficient to ensure adoption of innovations by farmers.

Technology transfer depends on matching the requirements of a technology to the environmental characteristics of the farmers' land. Innovation diffusion, on the other hand, depends on matching the requirements of a technology to the cultural and resource characteristics of the farmer himself.

Technology transfer can be achieved by physical and biological scientists; innovation diffusion requires heavy inputs from social scientists.

Attempts to lessen the technological gap that exists between the industrialized countries of the north and the developing countries of the tropics have taken three forms. They are:

1. Development of agricultural technology for the tropics through a network of research centers located in the tropics as exemplified by the work of the International Agricultural Research Centers.
2. Research to accelerate the flow of technology among national and international research centers (horizontal technology transfer) exemplified by the efforts of the Benchmark Soils Project.

3. Efforts to increase the adoption rate of new technology by resource-poor farmers (vertical technology transfer) now generally referred to as farming systems research and development (FSR&D).

All three are complementary and necessary, but not sufficient to achieve the agricultural development goals of development countries. The role of the Benchmark Soils Project should be viewed in this context.

The BSP's aim is to test the hypothesis that agrotechnology can be transferred among locations that are agroecologically similar. This hypothesis is based on the premise that the soil family as defined in Soil Taxonomy stratifies agroenvironments into narrow agroproduction niches sufficient to enable planners to transfer agroproduction among soils that are members of the same family.

The soil family stratifies such agronomic factors as plant nutrient deficiency, soil acidity, nutrient immobilization, soil climate including soil temperature and soil moisture regimes, soil suitability for various crops, soil suitability for engineering uses, likelihood of the occurrence of specific insects, weeds and plant pathogens, and a host of other variables. Soil Taxonomy is also the common language that enables soil users to communicate and share this knowledge with others on an international scale.

Appendix I.

Crop and Soil Performance Data

Table 1. Experiments completed, July 1979 - June 1982.

Soil/Location	Experiments		
	Transfer	Variety	Management
Hydric Dystrandepts			
Hawaii	14	1	3
Indonesia	9	1	8
Philippines	34	1	11
Subtotal	57	3	22
Tropeptic Eutrustox			
Brazil	20	2	2
Hawaii	12	2	7
Puerto Rico	19	0	4
Subtotal	51	4	13
Typic Paleudults			
Cameroon	8	0	3
Indonesia	29	3	7
Philippines	12	2	6
Subtotal	49	5	13
TOTAL	157	12	48 = 217

TABLE 2. HYDRIC DYSTRANDEPTS TRANSFER EXPERIMENTS ON MAIZE, YIELD DATA (KG/HA), JULY 1979-JUNE 1982

TREATMENT		HAWAII LOCATION/SITE:						
P	N	ICLEE11 D 79	ICLEI10 D 79	IOLEK10 D 81	HALB22 D 79	HALD12 W 79	KUKA22 W 79	KUKA23 W 81
+.85	+.85	7176	6600	8777	8629	5857	4909	6965
+.85	0	7439	5580	7527	6863	5666	4796	6354
+.85	-.85	5079	3268	6389	2992	3550	3264	4544
+.40	+.40	6957	6409	7419	7815	5873	4642	6995
+.40	-.40	6638	4076	7285	5339	4332	4319	6055
0	+.85	7209	7640	7768	8298	6459	4511	6872
0	0	6875	6497	6559	7027	5225	4393	6074
0	-.85	4389	3686	6740	3172	2915	3298	4385
-.40	+.40	7081	6944	6902	7455	5639	4704	7284
-.40	-.40	7157	4221	5690	5766	4735	4061	5383
-.85	+.85	7956	6973	6927	8373	5323	4228	6679
-.85	0	7828	6448	6883	7099	4755	4183	5759
-.85	-.85	4794	2946	5722	2401	3163	3508	5035
COMPLETE CONTROL		2909	****	4465	****	1161	1597	2059
PARTIAL CONTROL		3494	3723	4118	1004	1020	1870	2210
0	NO N	****	2291	****	****	****	****	****
NO P	0	****	6135	6124	****	****	****	****
0	0 NO MICRO	****	****	****	****	****	****	****
MEAN/P TREATMENT		6660	5484	6968	6248	4884	4217	6030
MEAN/ CONTROL		3202	3723	4292	1004	1091	1734	2135
P TREATMENT OVER PARTIAL CONTROL (%)		91	47	69	522	379	126	173

TREATMENT		HAWAII LOCATION/SITE:						
P	N	KUKA24 D 81	KUKC12 D 79	KUKC13 D 80	KUKC14 D 81	KUKD20 D 79	KUKD21 D 80	KUKD22 W 81
+.85	+.85	10119	9262	9338	9118	8828	9265	7856
+.85	0	8865	8984	7329	8127	7766	7958	7003
+.85	-.85	4956	7249	4363	6864	5546	3853	3145
+.40	+.40	8691	9213	8482	8684	7892	8776	7527
+.40	-.40	6457	8221	5761	7539	6889	5901	5898
0	+.85	9801	9230	9011	8152	8212	9255	7839
0	0	8781	9448	7354	8212	6723	7552	6772
0	-.85	5490	8411	3783	6663	5039	2890	3079
-.40	+.40	9525	8824	7723	7599	6543	7881	6297
-.40	-.40	6917	8137	5874	7490	6121	6020	5312
-.85	+.85	9203	8462	7631	7257	6751	7626	6155
-.85	0	8323	8419	7610	7115	6892	7479	6320
-.85	-.85	4881	7170	4387	6755	4481	2968	2805
COMPLETE CONTROL		2742	3245	541	3699	2885	7169	****
PARTIAL CONTROL		3334	4404	329	3529	2849	1274	1472
0	NO N	****	****	****	****	****	****	****
NO P	0	****	****	****	****	****	****	****
0	0 NO MICRO	****	****	****	****	****	****	****
MEAN/P TREATMENT		7847	8541	6819	7660	6745	6725	5847
MEAN/ CONTROL		3038	3825	435	3614	2867	4222	1472
P TREATMENT OVER PARTIAL CONTROL (%)		135	94	1973	117	137	428	297

TABLE 2. CONTINUED

TREATMENT		PHILIPPINES LOCATION/SITE:											
P	N	PUCA15 D 80	PUCK20 W 81	PUCQ20 D 80	PUCQ30 D 81	PUCQ40 D 82	PUCR11 W 79	PUCR20 W 80	PUCR30 W 81	PUCS10 W 79	PUCS11 D 80	PUCS20 D 81	PUCS30 D 82
+.85	+.85	3841	6289	6159	7720	7517	865	4943	4830	5047	6103	8601	7973
+.85	0	3113	6322	3994	6702	6767	1456	4974	4587	4941	6530	7991	7238
+.85	-.85	3237	5233	3990	5679	5325	487	4464	4179	4209	4466	3660	4545
+.40	+.40	2268	6327	5460	6959	7544	892	4832	4424	3916	5378	7273	7064
+.40	-.40	2088	5698	3515	6312	6147	752	4792	4491	4322	4855	6677	6510
0	+.85	2117	6271	5087	6524	6082	1036	4802	3969	4266	4234	8422	5815
0	0	3042	6210	3707	6575	5757	1196	4818	4169	3640	4123	7864	5759
0	-.85	2611	5460	2821	4634	4120	648	4536	4043	3842	3555	4930	4324
-.40	+.40	1780	5051	3739	7427	5305	488	4313	2554	2823	2451	6902	5170
-.40	-.40	1020	4513	3764	5497	4771	778	4443	3172	2949	2632	6175	4902
-.85	+.85	170	3224	3711	2622	571	0	2584	104	933	583	6551	301
-.85	0	225	4080	3127	2864	688	207	2767	619	574	442	5800	181
-.85	-.85	430	3357	2779	2377	648	135	2126	388	810	539	4837	484
COMPLETE CONTROL		0	2948	****	****	****	0	****	****	0	41	****	****
PARTIAL CONTROL		0	2879	0	234	73	****	0	205	****	****	456	100
0	NO N	****	****	3134	4411	3206	506	3411	3845	2510	2819	3798	2994
NO P	0	****	****	293	1415	624	0	0	57	77	437	495	313
0	0 NO MICRO	****	****	****	****	****	****	****	****	****	****	****	****
MEAN/P TREATMENT		1996	5233	3989	5530	4711	688	4184	3195	3252	3530	6591	4636
MEAN/ CONTROL		0	2914	0	234	73	0	0	205	0	41	456	100
P TREATMENT OVER PARTIAL CONTROL (%)		****	82	****	2263	6353	****	****	1459	****	****	1345	4536

TREATMENT		PHILIPPINES LOCATION/SITE:											
P	N	PALC14 W 79	PALC15 D 80	PALD20 W 80	PALD30 W 81	PALE11 D 80	PALE20 W 80	PALE30 W 81	PALF10 W 79	PALF11 D 80	PALF20 D 81	PALF30 D 82	PALG10 D 80
+.85	+.85	1771	4537	4912	4605	3116	3877	3986	3714	3934	7549	6902	6878
+.85	0	1936	4150	5736	4663	2851	4100	4661	3562	4195	7426	6745	7036
+.85	-.85	973	3307	4691	4040	2628	3006	4639	4164	3610	6708	6009	5664
+.40	+.40	1077	3671	5050	4531	2402	3660	5816	3494	3497	7205	6025	6429
+.40	-.40	1073	3677	4801	4277	2277	3542	4038	3379	3314	6409	5763	6196
0	+.85	844	3757	3442	3525	1542	3266	3328	3222	2543	7147	5164	6798
0	0	1184	2714	4573	3396	1454	3023	3115	3703	2481	6885	4873	6125
0	-.85	576	3359	4177	3804	1992	3022	3319	2857	2946	6059	4107	5837
-.40	+.40	995	3577	3580	3343	774	2890	2010	3024	1184	6160	4015	5825
-.40	-.40	707	2723	4124	3116	1224	2882	2682	2487	1514	6088	4163	5628
-.85	+.85	692	2981	2784	1121	424	1858	854	795	647	3335	85	3377
-.85	0	728	2631	2476	694	529	1658	906	902	696	3437	225	2794
-.85	-.85	349	2265	3006	2231	570	1591	1005	745	606	3488	609	3102
COMPLETE CONTROL		0	1566	81	****	261	****	****	163	294	****	****	890
PARTIAL CONTROL		323	1700	3966	631	****	0	573	****	****	1262	353	1151
0	NO N	****	****	175	3641	2241	2633	2368	2864	2676	6002	4071	4279
NO P	0	****	****	****	566	50	****	50	108	266	1419	191	****
0	0 NO MICRO	****	****	****	****	****	****	****	****	****	****	****	****
MEAN/P TREATMENT		993	3335	4104	3334	1676	2952	3105	2773	2397	5992	4207	5515
MEAN/ CONTROL		162	1633	2024	631	261	0	573	163	294	1262	353	1021
P TREATMENT OVER PARTIAL CONTROL (%)		207	96	3	428	****	****	442	****	****	375	1092	379

TABLE 2. CONTINUED

PHILIPPINES

TREATMENT P	TREATMENT N	PALG2C D 81	PALG3C D 82	BURA14 D 80	BURC20 D 80	BURC30 D 81	BURD11 W 79	BURD20 W 80	BURE10 W 79	BURE11 D 80	BURE20 D 81
+.85	+.85	7884	6941	1168	5087	5399	392	2756	1317	3384	7950
+.85	0	7079	6652	485	4615	4707	382	2760	2357	3783	8205
+.85	-.85	6050	5801	1359	2892	3473	649	2307	1765	3907	6739
+.40	+.40	7270	7129	605	4680	4591	329	2336	1678	2506	7594
+.40	-.40	6754	6088	1030	4304	3831	559	2425	1899	3661	7312
0	+.85	7172	5066	234	4747	3756	400	2408	1752	2307	8152
0	0	6625	4392	510	4513	4405	657	2317	1861	2008	7382
0	-.85	6043	5110	106	2871	2973	646	2574	1560	2667	5991
-.40	+.40	6462	3584	173	4544	1677	324	2264	1653	1562	6600
-.40	-.40	6182	3715	318	3661	2451	276	2093	1459	1721	6917
-.85	+.85	5850	319	70	4287	1046	48	1116	525	620	4783
-.85	0	5168	52	0	3820	1486	60	821	446	347	5216
-.85	-.85	5239	441	117	3559	1572	62	808	555	601	5751
COMPLETE CONTROL		****	****	0	****	****	0	****	166	358	****
PARTIAL CONTROL		1212	403	237	0	0	****	254	****	****	472
0	NO N	4932	4114	****	1187	1550	620	1520	1672	2556	5409
NO P	0	1089	138	****	0	0	0	68	247	447	577
0	0 NO MICRO	****	****	****	****	****	****	****	****	****	****
MEAN/P TREATMENT		6444	4253	475	4122	3182	368	2076	1448	2236	6815
MEAN/ CONTROL		1212	403	119	0	0	0	254	166	358	472
P TREATMENT OVER PARTIAL CONTROL (%)		432	955	100	****	****	****	717	****	****	1344

INDONESIA

TREATMENT P	TREATMENT N	ITKAC12 D 79	ITKAE11 D 79	ITKAK13 D 79	LPHA16 D 79	LPHD21 W 79	LPHD22 W 81	LPHE13 W 81	LPHG11 D 79	LPHG13 W 81
+.85	+.85	6734	7266	8427	7782	5091	4164	2338	8281	3463
+.85	0	6459	6564	8721	6565	5268	3069	1955	7387	3858
+.85	-.85	5135	6191	7723	5909	5110	2695	1644	5254	3158
+.40	+.40	6325	6772	8185	7978	5438	3593	2640	7637	3475
+.40	-.40	5810	6233	7981	6894	5216	2496	1898	6328	3706
0	+.85	6335	7201	8476	7113	5412	3640	1433	7359	3382
0	0	6163	6706	8305	7109	5359	4008	2469	7298	3775
0	-.85	4700	5481	7734	6260	4608	1707	2401	5286	4131
-.40	+.40	6276	6730	8450	7767	5549	3360	2499	7399	3501
-.40	-.40	6015	6557	7922	6263	5028	2944	1886	7006	4380
-.85	+.85	6712	6979	8236	7821	5024	3071	2188	7227	3663
-.85	0	6043	6797	8817	6710	4585	3152	1297	6620	3628
-.85	-.85	4759	6115	7482	5694	4661	1793	2050	6184	3865
COMPLETE CONTROL		3454	3961	****	****	4864	1118	****	4475	2047
PARTIAL CONTROL		4340	4544	6015	4841	4176	2129	1678	4591	3232
0	NO N	4425	4621	4571	3896	****	****	1550	3477	3543
NO P	0	6057	7071	****	****	****	****	****	6459	2667
0	0 NO MICRO	5397	4759	****	****	****	****	****	6008	2723
MEAN/P TREATMENT		5959	6584	8189	6913	5104	3053	2054	6867	3691
MEAN/ CONTROL		3897	4253	6015	4841	4520	1624	1678	4533	2640
P TREATMENT OVER PARTIAL CONTROL (%)		37	45	36	43	22	43	22	50	14

TABLE 3. TROPEPTIC EUTRUSTOX TRANSFER EXPERIMENTS ON MAIZE, YIELD DATA (KG/HA), JULY 1979-JUNE 1982

HAWAII

TREATMENT P	TREATMENT N	MOLA11 W 79	MOLB10 W 79	MOLB11 D 80	MOLJ10 W 81	MOLM10 W 80	MOLM11 W 81	MOLN10 D 81	WAIA11 W 79	WAIA12 D 80	WAIA13 D 81	WAID10 D 79	WAID11 W 80
+.85	+.85	5714	8773	7455	9319	10606	8474	9468	8494	10653	9354	9992	6094
+.85	0	5625	6985	5355	9143	10487	8092	8460	8254	9436	7376	8149	5358
+.85	-.85	3535	4983	2679	8446	9350	5625	6857	5973	6095	4116	6661	4879
+.40	+.40	5313	8546	6502	8875	9911	7478	8038	8446	10178	8147	8750	5609
+.40	-.40	5130	6087	4031	8732	9796	6811	7521	7058	7792	4926	7982	4633
0	+.85	5835	8185	7478	9169	9715	6689	8355	8641	10194	8849	9236	6482
0	0	5445	6973	5290	8393	9684	6895	7850	7589	9194	7627	8412	5089
0	-.85	3580	4677	2322	8356	9291	6306	6300	5932	6432	3967	5848	4339
-.40	+.40	5564	6940	5650	9457	9506	7013	6989	8252	9773	8065	7869	6265
-.40	-.40	4811	5969	4772	8586	9156	5964	7092	6830	7582	5589	7344	4949
-.85	+.85	5095	7592	6591	8673	9285	7310	6533	8702	10196	8803	8535	5896
-.85	0	4959	6977	4684	9004	8924	6758	5347	6984	8762	7144	7957	5215
-.85	-.85	3783	4106	2520	8004	8462	5374	5017	5647	6230	4047	6569	5419
COMPLETE CONTROL		1917	2551	****	7465	6118	3841	****	****	****	****	5797	4885
PARTIAL CONTROL		2741	2528	1580	7279	7769	3945	3945	3690	3598	2181	5694	4356
0	NO N	****	****	****	****	9868	****	6551	4020	4490	2069	5701	4007
NO P	0	****	****	****	8645	****	****	5469	7283	8489	6597	****	****
0	0 NO MICRO	****	****	****	****	****	****	****	****	****	****	****	****
MEAN/P TREATMENT		4953	6676	5025	8781	9552	6830	7217	7446	8655	6770	7946	5402
MEAN/ CONTROL		2329	2540	1580	7372	6944	3893	3945	3690	3598	2181	746	4621
P TREATMENT OVER PARTIAL CONTROL (%)		81	164	218	21	23	73	83	102	141	210	40	24

BRAZIL

TREATMENT P	TREATMENT N	B-37 W 79	B-41 W 79	B-43 D 79	B-44 D 80	B-45 D 79	B-46 D 80	B-47 D 79	B-48 D 80	B-52 W 80	B-53 W 80
+.85	+.85	2325	4883	8656	4692	8181	4122	8891	4363	7039	7078
+.85	0	2758	5498	8920	5059	8553	4451	7651	3748	7007	7625
+.85	-.85	2553	5705	8112	5250	8357	4454	8278	3218	7078	6473
+.40	+.40	3161	3426	9187	3906	7583	4456	7794	4203	6942	7701
+.40	-.40	2273	4370	9192	5054	7134	3797	7516	4203	6002	6804
0	+.85	1499	2863	7649	2969	7740	3729	7355	4186	6101	6483
0	0	1126	4418	7503	2963	7106	3775	7358	3142	6361	5618
0	-.85	1705	4157	8227	2895	7663	4141	7749	2493	6702	6757
-.40	+.40	1234	3138	5905	2082	7420	3161	5916	3927	6104	5705
-.40	-.40	1341	2937	5670	2368	7376	3193	5411	3191	5118	4017
-.85	+.85	1071	2511	3578	1663	5207	2299	5533	3659	4525	4807
-.85	0	733	2211	3705	1112	5682	3302	4161	3271	2794	3951
-.85	-.85	595	2847	3819	1107	4492	3039	3357	2148	3188	3839
COMPLETE CONTROL		****	****	****	****	****	****	****	****	****	****
PARTIAL CONTROL		583	1369	2354	949	4243	2670	3899	2235	4094	3604
0	NO N	2148	4856	6233	3393	6446	4273	7172	3641	5327	4148
NO P	0	562	2500	2185	1262	3675	2354	4838	3874	2868	3545
0	0 NO MICRO	****	****	****	****	****	****	****	****	****	****
MEAN/P TREATMENT		1721	3766	6933	3163	7115	3686	6690	3519	5766	5912
MEAN/ CONTROL		583	1369	2354	949	4243	2670	3899	2235	4094	3604
P TREATMENT OVER PARTIAL CONTROL (%)		195	175	195	233	68	38	72	57	41	64

TABLE 3. CONTINUED

BRAZIL

TREATMENT P	TREATMENT N	B-54 W 80	B-55 W 80	B-56 W 80	B-57 W 80	B-64 D 80	B-65 D 80	B-66 D 80	B-67 D 80	B-68 D 80	B-69 D 80
+.85	+.85	7680	5995	7975	7296	6912	3700	7469	4265	7647	5111
+.85	0	7625	5963	7439	7090	6881	2535	7122	4756	7914	5843
+.85	-.85	7197	6921	6884	7568	6590	4209	7837	4883	7367	5831
+.40	+.40	6830	6924	6635	6636	6396	3737	6296	4683	6991	4852
+.40	-.40	7597	6020	6045	7168	6656	2964	7272	4674	6485	4683
0	+.85	8251	6022	6826	6652	5301	3445	6359	4823	6016	4783
0	0	6876	5907	6270	6396	5213	3429	6745	4858	6812	4656
0	-.85	6496	6367	6000	5314	4717	3962	7465	3289	5248	4312
-.40	+.40	5929	6186	6222	5850	4216	3342	6065	3792	5200	3844
-.40	-.40	5753	6269	5644	4809	3909	2670	4836	3141	5949	3150
-.85	+.85	6018	5475	4203	6211	2792	3120	3856	3661	4485	3975
-.85	0	6286	5568	3966	4560	2329	2130	4784	4295	5588	3006
-.85	-.85	5814	3997	4534	3268	1719	2254	4937	3398	4120	3214
COMPLETE CONTROL		****	****	****	****	****	****	****	****	****	****
PARTIAL CONTROL		4372	3811	3418	5023	1606	3075	5994	2525	3897	2775
0	NO N	6175	5388	5504	5650	5205	2841	5915	3745	6135	3899
NO P	0	6578	5324	4515	5152	1446	2173	4136	4396	4391	3935
0	0 NO MICRO	****	****	****	****	****	****	****	****	****	****
MEAN/P TREATMENT		6796	6047	6049	6069	4895	3192	6234	4194	6140	4405
MEAN/ CONTROL		4372	3811	3418	5023	1606	3075	5994	2525	3897	2775
P TREATMENT OVER PARTIAL CONTROL (%)		55	59	77	21	205	4	4	66	58	59

PUERTO RICO

TREATMENT P	TREATMENT N	PR-53 D 80	PR-54 D 80	PR-55 D 80	PR-58 W 80	PR-59 W 80	PR-60 W 80	PR-61 W 80	PR-62 W 80	PR-63 W 80
+.85	+.85	7378	7891	6942	7132	9020	6219	7745	6652	7304
+.85	0	6489	7375	6416	5684	7315	5677	6938	6860	6783
+.85	-.85	5081	6249	5238	2433	3451	3157	5853	6900	5475
+.40	+.40	6953	8127	6938	6796	8008	6400	6416	7039	7011
+.40	-.40	5921	7235	5708	3906	5763	5272	5819	7877	6924
0	+.85	7280	8237	6878	6876	9054	5061	5160	7482	6333
0	0	6268	7165	6311	5737	6754	5517	6867	7083	6905
0	-.85	4414	6248	4582	2268	4372	3013	5187	6599	6464
-.40	+.40	7007	7873	6917	6211	8004	5670	6033	7832	6870
-.40	-.40	5758	7278	6745	4488	6228	4949	6614	7884	6151
-.85	+.85	7561	8513	6932	7577	8285	6985	5882	6990	6258
-.85	0	6915	7163	6763	5373	6618	5927	5238	6882	7055
-.85	-.85	5396	6489	5032	2765	4974	3174	4706	7461	6638
COMPLETE CONTROL		****	****	****	****	****	****	****	****	****
PARTIAL CONTROL		4136	6338	5195	1649	2582	2705	4477	6164	4903
0	NO N	3329	6346	4553	1108	2879	2272	3494	6264	6284
NO P	0	6386	7616	5843	5761	7021	4807	5989	7473	6865
0	0 NO MICRO	****	****	****	****	****	****	****	****	****
MEAN/P TREATMENT		6340	7373	6262	5173	6758	5155	6112	7195	6629
MEAN/ CONTROL		4136	6338	5195	1649	2582	2705	4477	6164	4903
P TREATMENT OVER PARTIAL CONTROL (%)		53	16	21	214	162	91	37	17	35

TABLE 3. CONTINUED

TREATMENT P	TREATMENT N	PUERTO RICO LOCATION/SITE: PR-34 D 79	PR-41 W 79	PR-42 W 79	PR-43 W 79	PR-44 W 79	PR-45 W 79	PR-46 W 79	PR-48 W 79	PR-50 D 80	PR-51 D 80
+.85	+.85	6598	8519	7115	7026	6444	6407	4848	6021	5502	7387
+.85	0	4430	7129	6379	6365	5763	6995	4015	5758	6051	7980
+.85	-.85	2481	5664	2898	2254	6020	6023	3872	4852	4038	6175
+.40	+.40	5439	6892	7718	6733	7878	6454	4955	4428	6402	7299
+.40	-.40	3933	4434	4036	4540	7233	7032	4372	5088	5032	7160
0	+.85	6408	8426	9321	7626	6552	6637	4524	4972	5692	8229
0	0	4919	7498	4479	6218	5974	6384	3703	4981	5835	7603
0	-.85	1133	3849	1823	1894	5551	5719	3952	5028	4686	5073
-.40	+.40	6717	7763	7233	7486	6948	7123	4360	4942	6394	7652
-.40	-.40	4288	6598	5086	5057	6601	6121	4674	4390	5222	7142
-.85	+.85	6045	7671	8232	7683	6634	7101	4657	5243	6744	7969
-.85	0	4790	6662	6160	6838	6190	6633	4824	4310	5019	7372
-.85	-.85	972	4660	3173	2011	6124	5252	3302	3620	4091	6644
COMPLETE CONTROL		****	****	****	****	****	****	****	****	****	****
PARTIAL CONTROL		813	2805	1678	2099	4218	5549	3469	4252	3769	4699
0	NO N	1401	2602	902	2289	5290	6143	2708	4906	3182	4477
NO P	0	5152	6958	6123	6376	6683	6292	5038	4995	6164	6964
0	0 NO MICRO	****	****	****	****	****	****	****	****	****	****
MEAN/P TREATMENT		4473	6597	5666	5518	6455	6452	4312	4895	5439	7207
MEAN/ CONTROL		813	2805	1678	2099	4218	5549	3469	4252	3769	4699
P TREATMENT OVER PARTIAL CONTROL (%)		450	135	238	163	53	16	24	15	44	53

TABLE 4. TYPIC PALEUDULTS TRANSFER EXPERIMENTS ON MAIZE, YIELD DATA (KG/HA), JULY 1979-JUNE 1982

PHILIPPINES

TREATMENT P	TREATMENT N	DAVA12 W 79	DAVH10 W 79	DAVI10 D 80	DAVK10 D 81	DAVL10 D 81	SORA10 W 81	SORA20 D 81	SORA30 D 82	SORB10 D 81	SORB20 D 82	SORD10 W 81	SORE10 W 81
+.85	+.85	4837	5261	4704	6848	8454	6233	7798	6715	7724	7661	5411	5806
+.85	0	4375	5092	4684	7257	8226	5458	6764	6146	6532	7101	5706	4719
+.85	-.85	4382	4340	4788	6505	6055	3067	5144	4522	3946	4949	3552	3112
+.40	+.40	4863	5474	4373	6588	8235	5504	6609	6763	6479	6697	5676	5422
+.40	-.40	4310	4625	4226	6547	7555	4867	6116	5400	5254	5738	4086	4121
0	+.85	4040	4935	4028	6397	7863	5516	7434	5885	7426	7222	4249	4728
0	0	4718	4901	4665	6702	7739	5038	6973	4777	6392	6559	3798	4590
0	-.85	3534	3622	4096	6294	6996	3819	5128	4261	3710	4630	3345	2784
-.40	+.40	3367	4980	4089	5582	6690	4357	6099	5224	6396	5124	2969	4368
-.40	-.40	3875	4576	4636	6565	7682	4001	5749	4819	5124	5250	3271	2962
-.85	+.85	3838	4760	4743	3391	5949	1346	952	1096	2425	523	0	85
-.85	0	4248	4955	4929	3465	5921	1518	2245	2557	2902	1523	37	272
-.85	-.85	3692	3339	4694	4747	5657	1623	3201	2512	2620	2162	143	290
COMPLETE CONTROL		2954	3107	4395	3279	4414	286	****	****	0	****	0	0
PARTIAL CONTROL		3060	3122	4000	2264	5098	121	281	1045	0	869	0	0
0	NO N	****	****	4191	****	****	1320	3693	2475	3297	3900	2938	2145
NO P	0	3557	4934	****	1997	4997	****	23	78	****	244	****	****
0	0 NO MICRO	****	****	****	****	****	****	****	****	****	****	****	****
MEAN/P TREATMENT		4160	4685	4512	5914	7232	4027	5401	4667	5148	5011	3249	3328
MEAN/ CONTROL		3007	3115	4200	2772	4756	204	281	1045	0	869	0	0
P TREATMENT OVER PARTIAL CONTROL (%)		36	50	13	161	42	3228	1822	347	****	477	****	****

INDONESIA

TREATMENT P	TREATMENT N	NAKA20 D 80	NAKA30 D 81	NAKA31 W 82	NAKD11 W 79	NAKD20 W 81	NAKD30 D 81	NAKJ10 W 79	NAKJ11 D 80	NAKL10 W 81	NAKL20 W 82
+.85	+.85	4765	6223	6078	5820	6405	6346	7002	4387	10061	8338
+.85	0	4999	5009	6025	5719	6013	6169	6362	4530	9524	7880
+.85	-.85	3944	4620	4931	4261	4406	4322	5837	4144	6686	6343
+.40	+.40	5003	5191	5661	5617	6070	5958	6720	3849	9610	8228
+.40	-.40	4696	4977	5311	5279	5285	5926	6425	4141	9436	7341
0	+.85	4964	5148	5451	5780	6394	6212	6553	3273	10433	8646
0	0	4921	4933	5154	5448	6092	5908	6519	3812	8188	7671
0	-.85	4289	4430	4267	4260	4294	3900	5088	3440	7981	6348
-.40	+.40	4663	5213	4010	3913	5422	5325	5527	2165	9392	7457
-.40	-.40	4621	4371	4178	4187	4682	5222	5116	2606	7772	6453
-.85	+.85	2867	3043	1764	1577	3360	3163	2981	181	5258	3015
-.85	0	2933	2809	1805	671	3282	3734	3594	920	6885	3947
-.85	-.85	2283	2623	2238	1696	2862	2879	2958	1066	6545	3535
COMPLETE CONTROL		334	984	1329	1447	2105	1540	2274	1093	5736	2328
PARTIAL CONTROL		599	1411	1392	1137	2002	1126	1594	572	4327	2002
0	NO N	3455	3705	2716	5270	3360	2473	4868	2595	6898	5710
NO P	0	313	1193	1237	645	1487	807	2203	1957	7487	2922
0	0 NO MICRO	4156	2507	1462	4367	4783	1861	5991	3148	8836	6580
MEAN/P TREATMENT		4227	4507	4375	4171	4967	5005	5437	2963	8290	6554
MEAN/ CONTROL		467	1198	1361	1292	2054	1333	1934	833	5032	2165
P TREATMENT OVER PARTIAL CONTROL (%)		606	219	214	267	148	344	241	418	92	227

TABLE 4. CONTINUED

INDONESIA

TREATMENT P	TREATMENT N	BPMDA20 D 80	BPMDA30 D 81	BPMDA31 W 82	BPMDC11 W 79	BPMDC20 W 81	BPMDC30 W 82	BPMDD10 W 79	BPMDD20 D 80	BPMDD30 D 81
+.85	+.85	6227	4446	7091	6404	8737	7402	6334	5679	3881
+.85	0	6229	3853	7596	6407	8728	6314	5986	6214	3640
+.85	-.85	5250	3732	5882	4936	7058	3830	3668	4022	2598
+.40	+.40	5871	4524	7131	5810	8082	7147	5877	5912	3587
+.40	-.40	6054	3864	6563	5856	7457	5320	4588	5191	3638
0	+.85	6652	4269	7044	4973	6162	6855	5559	5724	3723
0	0	6059	4114	6400	4842	7204	6050	5381	5629	3541
0	-.85	4726	3604	5276	4559	6713	3987	3677	4280	2996
-.40	+.40	5694	3524	4940	2907	5697	5941	3941	5431	2494
-.40	-.40	5269	3585	5837	3425	6072	5291	4159	4057	2932
-.85	+.85	4444	731	3395	1646	3735	3414	1706	3453	121
-.85	0	4453	1310	3128	491	3310	2234	2450	3688	459
-.85	-.85	3553	1164	2264	1041	3339	2611	1566	3396	805
COMPLETE CONTROL		244	0	1075	677	1223	525	450	164	0
PARTIAL CONTROL		474	212	1433	476	826	1073	334	0	61
0	NO N	3626	3427	4672	4518	5671	2181	3099	1929	2100
NO P	0	581	102	1816	112	203	568	594	0	0
0	0 NO MICRO	499	1572	2093	1753	7194	2303	3721	3063	1910
MEAN/P TREATMENT		5422	3286	5581	4100	6330	5107	4222	4821	2647
MEAN/ CONTROL		359	106	1254	577	1025	799	392	82	31
P TREATMENT OVER PARTIAL CONTROL (%)		1044	1450	289	761	666	376	1164	****	4239

INDONESIA

TREATMENT P	TREATMENT N	BUKA11 W 79	BUKA20 D 80	BUKA30 D 81	BUKC10 W 79	BUKC20 W 81	BUKC30 W 82	BUKD10 D 80	BUKD20 D 81	BUKE10 W 81	BUKE20 W 82
+.85	+.85	7500	5897	6114	7210	6310	8519	7339	5938	8566	8089
+.85	0	6849	6406	6730	6690	6051	7523	7632	6067	9263	7953
+.85	-.85	5959	6477	5616	6961	5785	6441	6903	5995	7426	5842
+.40	+.40	7427	6039	6449	6851	6463	8424	6892	6058	9575	7572
+.40	-.40	6568	6397	5913	6969	6058	7230	6355	5709	7661	6763
0	+.85	6404	5202	5977	6917	6927	8062	7156	5391	8775	7706
0	0	6822	5762	6123	6328	5935	7542	7042	5656	8613	7041
0	-.85	6092	5601	5957	6571	4853	5780	6682	5205	8435	5685
-.40	+.40	5078	4718	5492	6424	5514	7044	6726	6061	8495	7448
-.40	-.40	5244	4935	5921	6582	5866	6943	6298	5630	7202	6442
-.85	+.85	3726	3879	4122	4072	3981	5893	3718	3949	5815	5644
-.85	0	3588	3279	3670	5130	4304	6221	4719	4728	6169	5336
-.85	-.85	3820	3345	3896	4693	3702	5141	4233	4502	5333	4930
COMPLETE CONTROL		3056	2444	2298	2613	2786	3023	2411	2282	5801	3624
PARTIAL CONTROL		3368	3238	3259	3100	2720	2995	2857	2628	6211	2841
0	NO N	6612	5515	5574	6137	4367	5147	6289	6552	8320	6117
NO P	0	3277	2884	2340	3179	5613	5344	3548	2940	6108	3980
0	0 NO MICRO	6506	4870	4702	7021	5278	5959	4781	4752	7406	6665
MEAN/P TREATMENT		5775	5226	5537	6261	5519	6982	6284	5453	7794	6650
MEAN/ CONTROL		3212	2841	2779	2857	2753	3009	2634	2455	6006	3233
P TREATMENT OVER PARTIAL CONTROL (%)		71	61	70	102	103	133	120	107	25	134

TABLE 4. CONTINUED

TREATMENT P	TREATMENT N	CAMEROON LOCATION/SITE: CAMA10 D 81	CAMA11 W 81	CAMA12 W 81	CAMA20 D 81	CAMB10 D 81	CAMC10 W 82	BAKA10 D 81	BAKC10 W 82
+.85	+.85	8950	6433	3358	7883	7655	5565	9804	7910
+.85	0	8775	6693	4182	7689	6837	5785	8708	7516
+.85	-.85	8199	4310	2460	8188	7098	6070	9140	7683
+.40	+.40	8536	6632	3688	8671	7455	5570	10749	7516
+.40	-.40	8157	6459	3609	6994	7291	5284	10363	7424
0	+.85	8656	7073	4203	8063	7476	5708	10240	7271
0	0	8203	5695	3294	7186	7533	5397	9233	7486
0	-.85	7762	4989	2737	7643	5806	6118	9667	7797
-.40	+.40	8354	6294	3828	8596	6553	5626	8577	6873
-.40	-.40	7363	6026	3343	7722	7315	5280	9017	6339
-.85	+.85	7588	5963	3773	8048	7374	5321	6671	5506
-.85	0	8985	6521	3407	7864	6659	4817	7931	5565
-.85	-.85	7561	4945	3459	7299	6219	4786	7508	5697
COMPLETE CONTROL		6456	3320	2368	6128	6077	4794	6183	5302
PARTIAL CONTROL		7082	5456	2539	7365	7188	5246	7602	5449
0	NO N	****	****	3936	****	****	****	****	****
NO P	0	8776	6368	3197	7874	5715	4704	7497	6654
0	0 NO MICRO	****	****	****	****	****	****	****	****
MEAN/P TREATMENT		8238	6003	3488	7834	7021	5487	9047	6968
MEAN/ CONTROL		6769	4388	2454	6747	6633	5020	6893	5376
P TREATMENT OVER PARTIAL CONTROL (%)		16	10	37	6	0	5	19	28

TABLE 5. HYDRIC DYSTRANDEPTS VARIETY EXPERIMENTS ON MAIZE, YIELD DATA (KG/HA), MEANS OF 3 OR 4 REPS, JULY 79 - JUNE 82

HAWAII/IOLE-G-12
DRY 1980

CODED TREATMENT P	CODED TREATMENT N	H610	X304C	X4816	H688	X5859	H763	H823	UPCA-2
-0.85	-0.85	7694	7826	6935	7990	9172	7898	6111	6631
-0.85	0	8129	8138	7937	7870	8131	7653	6567	6954
0	-0.85	8768	7857	7821	8891	8811	8498	6433	6987
0	0	8169	8380	8403	8031	9526	9145	8187	8601
		8190	8050	7774	8196	8910	8298	6825	7293

PHILIPPINES/PUC-L-22
DRY 1980

CODED TREATMENT P	CODED TREATMENT N	H610	UPCA-1	X304C	H6	NK-T66
-0.85	-0.85	1679	2780	2513	2460	2526
-0.85	0	2300	2383	2315	2802	2951
0	-0.85	5331	4559	5475	5279	4960
0	0	6816	5750	6782	5871	6133
		4032	3868	4271	4103	4142

INDONESIA/ITKA-F-10
DRY 1979

CODED TREATMENT P	CODED TREATMENT N	H610	UPCA-1	X304C	HARAPAN	H6	WONOSOBO
-0.85	-0.85	5759	5040	6383	5540	6302	5908
-0.85	0.40	5814	5388	7818	6690	6192	7085
0.40	-0.85	4826	4945	7374	5873	5857	5449
0.40	0.40	6920	6560	7165	7132	6813	8681
		5835	5483	7185	6309	6291	6781

TABLE 6. TROPEPTIC EUTRUSTOX VARIETY EXPERIMENT ON MAIZE, YIELD DATA (KG/HA), MEANS OF 3 REPS, JULY 79 - JUNE 82

CODED TREATMENT P	CODED TREATMENT N	VARIETY							
HAWAII/MOL-D-10 WET 1979									
		H610	X304C	X5800	H688	6874	X5859	6277	H763
-0.85	-0.85	3416	4804	4897	3605	4053	4852	4272	3306
-0.85	0	4643	7258	6726	4846	6703	7789	7527	4955
0	-0.85	3923	7024	5795	4989	5774	6872	5628	3790
0	0	6592	7407	7527	6650	7409	7922	7972	6185
		4644	6623	6236	5023	5985	6859	6350	4559
HAWAII/MOL-D-11 DRY 1980									
		H610	X304C	X4816	H688	X5859	H763	H823	H888
-0.85	-0.85	6221	6477	5605	5899	7339	5582	4879	6514
-0.85	0	7793	9020	8017	7622	8297	7925	7631	8482
0	-0.85	5485	8474	7849	6039	8130	5819	5736	5839
0	0	7100	10753	8608	9715	9143	8452	8509	8849
		6650	8681	7520	7319	8227	6945	6689	7421

TABLE 7a. TYPIC PALEUDULTS VARIETY EXPERIMENTS ON MAIZE, YIELD DATA (KG/HA), MEANS OF 3 OR 4 REPS, JULY 79 - JUNE 82

INDONESIA/NAK-B-20
WET 1980

CODED TREATMENT P	CODED TREATMENT N	UPCA-1	TINIGUIB	H6	DMR-5	WONOSOBO	KODOK
-0.85	-0.85	3091	3102	2562	2946	2893	2071
-0.85	0	2923	2526	2584	2818	3015	1359
0	-0.85	3199	4724	4249	5133	4798	3877
0	0	6370	5313	6364	5973	6105	5339
		4074	3916	3940	4217	4203	3161

INDONESIA/NAK-B-30
WET 1981

CODED TREATMENT P	CODED TREATMENT N	UPCA-1	X304C	TINIGUIB	H6	WONOSOBO	ARJUNA
-0.85	-0.85	3195	4856	3186	3579	2763	3021
-0.85	0	2834	5479	3123	2813	2565	3170
0	-0.85	3201	4767	3450	2970	3232	3594
0	0	5676	7685	4780	5881	4023	5978
		3727	5697	3635	3811	3146	3941

INDONESIA/NAK-E-20
DRY 1980

CODED TREATMENT P	CODED TREATMENT N	H610	X304C	TINIGUIB	H6	KODOK	ARJUNA
-0.85	-0.85	3180	3573	2909	3233	2283	3603
-0.85	0	2955	3486	2626	3356	2866	3370
0	-0.85	3629	4400	3218	3265	3014	3589
0	0	3714	4148	2963	2975	2600	2936
		3370	3902	2929	3207	2691	3374

TABLE 7b. TYPIC PALEUDULTS VARIETY EXPERIMENTS ON MAIZE, YIELD DATA (KG/HA), MEANS OF 3 OR 4 REPS, JULY 79 - JUNE 82

CODED TREATMENT P	CODED TREATMENT N	VARIETY				
PHILIPPINES/DAV-B-13 DRY 1980						
		H610	UPCA-1	X304C	TINIGUIB	H6
-0.85	-0.85	2724	2777	3720	3178	2469
-0.85	0	5005	4699	5451	4663	4368
0	-0.85	2645	2372	3234	2603	1963
0	0	4383	4710	5777	4558	4653
		3689	3640	4546	3751	3363
PHILIPPINES/DAV-G-10 WET 1979						
		DMR-1	UPCA-1	X304C	TINIGUIB	NK-T66
-0.85	-0.85	2905	2219	3624	2507	1808
-0.85	0	3921	3927	6686	3817	2259
0	-0.85	3107	2549	4343	3069	1939
0	0	3617	3987	6111	3456	2415
		3388	3170	5191	3212	2105

Appendix 2.

Weather Data

WEATHER DATA GATHERED AT ALL SITES, BENCHMARK SOILS PROJECT/HAWAII
FAMILY A: THIXOTROPIC, ISOTHERMIC HYDRIC DYSTRANDEPTS

SITE/SEASON	VARIETY	PLANT DATE	HARVEST DATE	SOLAR RADIAT. (G CAL/ DAY)	CUMULATIVE RAINFALL (MM)	TEMPERATURE (DEGREE C) MAX.	TEMPERATURE (DEGREE C) MIN.	RELATIVE HUMIDITY (%) MAX.	RELATIVE HUMIDITY (%) MIN.	WIND RUN (KM/HR)	YIELD (KG/HA)* PART. CNTL.	YIELD (KG/HA)* MEAN	YIELD (KG/HA)* HIGH
HAWAII													
IOLE-E-11-DRY	H610	6/ 7/79	11/ 7/79	442.44	652.30	25.72	18.11	94.99	63.64	13.59	2909	6660	7956
IOLE-I-10-WET	H610	2/12/79	7/31/79		453.00	23.70	16.60	97.50	63.10	14.00	3723	5484	7640
IOLE-K-10-DRY	H610	5/ 6/81	10/ 7/81	414.86	442.20	26.14	17.77	95.22	53.22	12.14	4118	6968	8777
HAL-B-22-DRY	H610	7/ 3/79	11/20/79	423.94	673.00	26.01	17.54	94.01	69.27	9.71	1004	6284	8629
HAL-D-12-WET	H610	1/30/79	7/ 5/79	435.47	740.00	23.70	16.00	96.00	69.60	10.57	1020	4884	6459
KUK-A-22-WET	H610	12/13/79	6/ 3/80	340.94	2868.00	25.68	18.32	91.23	63.72	9.53	1870	4217	4909
KUK-A-23-WET	H610	11/ 6/80	4/20/81	374.45	428.80	23.90	15.41	88.07	54.58	10.47	2210	6030	7284
KUK-A-24-DRY	X304C	6/24/81	12/ 1/81	406.97	893.70	25.04	18.01	86.84	62.66	9.21	3334	7848	10119
KUK-C-12-DRY	H610	5/23/79	10/23/79	382.33	581.00	27.83	19.88	93.79	66.04	8.77	4404	8541	9448
KUK-C-13-DRY	H610	6/ 8/80	11/13/80	434.35	569.60	27.32	19.91	92.03	63.46	9.25	330	6819	9338
KUK-C-14-DRY	H610	6/18/81	11/10/81	429.19	628.60	25.25	18.14	86.66	61.78	9.31	3529	7659	9118
KUK-D-20-WET	H610	2/ 2/79	8/ 6/79	374.88	749.00	26.00	18.50	92.30	64.60	9.09	2849	6745	8828
KUK-D-21-DRY	H610	6/ 6/80	10/29/80	416.71	546.70	27.28	19.93	92.03	63.53	9.65	1274	6725	9265
KUK-D-22-WET	H610	1/ 7/81	6/19/81	430.85	445.00	23.92	15.66	87.80	55.17	10.98	1472	5847	7856
PHILLIPPINES													
PUC-A-15-DRY	UPCA-1	11/20/79	4/17/80	346.27	1282.60	29.64	19.53	91.52	57.43	7.33	0	1996	3841
PUC-K-20-WET	X304C	6/23/81	10/26/81	329.52	1611.20	29.37	22.06	91.33	69.66	9.10	2879	5233	6327
PUC-Q-20-DRY	UPCA-1	2/ 7/80	6/11/80	394.61	780.20	31.42	19.51	95.56	53.25	5.97	0	3989	6159
PUC-Q-30-DRY	CARGILL	2/ 5/81	6/17/81	384.70	542.30	31.20	19.80	88.09	49.54	6.96	234	5530	7720
PUC-Q-40-DRY	X304C	1/29/82	6/ 7/82	373.06	908.00	30.59	20.17	93.19	55.07	7.37	73	4711	7544
PUC-R-11-WET	UPCA-1	6/13/79	10/16/79	319.20	1590.20	30.23	21.41	96.05	70.32	6.39		688	1456
PUC-R-20-WET	UPCA-1	6/ 5/80	10/ 8/80	341.09	1187.70	31.02	22.06	92.75	72.62	6.03	0	4184	4974
PUC-R-30-WET	X304C	6/29/81	10/30/81	326.06	1602.90	29.24	22.09	91.47	70.45	9.15	205	3194	4830
PUC-S-10-WET	UPCA-1	5/29/79	10/ 8/79	319.71	1560.20	30.29	21.28	95.69	70.01	6.36	2510	3252	5047
PUC-S-11-DRY	H610	11/16/79	3/19/80	324.38	1013.10	29.28	19.60	90.23	58.51	7.57		3530	6530
PUC-S-20-DRY	X304C	2/ 6/81	6/11/81	388.92	484.30	31.37	19.67	88.02	48.00	6.59	456	6591	8601
PUC-S-30-WET	X304C	2/ 8/82	6/17/82	383.86	971.00	31.07	20.40	93.57	56.32	6.71	100	4636	7973
PAL-C-14-WET	UPCA-1	6/ 9/79	10/17/79	300.45	1486.10	30.80	21.25	96.60	62.98	6.13	323	993	1771
PAL-C-15-DRY	X304C	12/ 8/80	4/22/81	353.90	1155.70	31.05	18.76	90.94	45.99	6.33	1700	3335	4537
PAL-D-20-WET	UPCA-1	5/31/80	10/ 2/80	314.98	1443.70	32.08	22.64	97.98	66.57	4.82	3966	4104	5736
PAL-D-30-WET	X304C	7/ 2/81	11/ 9/81	314.18	1571.30	31.51	22.12	94.10	61.97	5.31	631	3334	4663
PAL-E-11-DRY	UPCA-1	11/27/79	4/10/80	297.62	696.50	28.53	19.81	95.79	61.45	8.19		1676	3116
PAL-E-20-WET	UPCA-1	6/10/80	10/11/80	314.28	1408.30	32.02	22.63	97.60	66.55	4.92	2633	2952	4100
PAL-E-30-WET	X304C	7/ 3/81	11/ 9/81	313.90	1557.00	31.50	22.13	94.12	62.06	5.30	573	3104	5816
PAL-F-10-WET	UPCA-1	5/30/79	10/10/79	333.14	1653.30	31.00	21.17	96.78	62.88	5.96		2773	4146
PAL-F-11-DRY	UPCA-1	11/17/79	3/29/80	244.80	597.60	20.54	12.46	65.48	33.06	3.88		2397	4195
PAL-F-20-DRY	X304C	1/16/81	5/26/81	373.03	689.00	32.88	19.44	91.75	41.23	5.39	1262	5995	7549
PAL-F-30-DRY	X304C	1/30/82	6/ 8/82	361.73	632.10	33.13	20.65	99.73	59.32	5.93	353	4207	6902
PAL-G-10-DRY	UPCA-1	2/ 9/80	6/21/80	357.53	774.00	32.74	20.29	99.23	48.54	5.65	1151	5514	6878
PAL-G-20-DRY	CARGILL	1/23/81	6/ 5/81	373.87	774.00	33.25	19.83	92.12	71.95	5.27	1212	6444	7884
PAL-G-30-DRY	X304C	2/ 6/82	6/14/82	368.81	866.40	33.39	20.89	99.69	59.31	5.67	403	4253	7129
BUR-A-14-DRY	UPCA-1	11/24/79	4/23/80	332.69	1858.70	28.14	20.36	94.51	53.99	11.70	237	475	1359
BUR-C-20-DRY	UPCA-1	2/15/80	6/26/80	369.67	1126.80	31.03	21.51	98.63	51.96	7.97		4122	5087
BUR-C-30-DRY	CARGILL	2/ 4/81	6/26/81	306.18	752.70	30.67	21.22	95.39	58.06	7.88	0	3182	5399
BUR-D-11-WET	UPCA-1	6/ 5/79	10/19/79	259.62	1952.70	29.98	23.01	96.53	72.86	10.53		368	657
BUR-D-20-WET	UPCA-1	5/27/80	9/26/80	250.49	1523.10	29.58	22.28	99.74	70.00	8.96	254	2076	2760
BUR-E-10-WET	UPCA-1	6/ 2/79	10/18/79	260.35	1954.30	30.01	23.01	96.46	72.78	10.47		1448	2357
BUR-E-11-DRY	UPCA-1	11/22/79	4/22/80	329.11	2005.20	28.03	20.35	94.44	54.57	11.80		2236	3907
BUR-E-20-DRY	X304C	2/ 4/81	6/ 8/81	315.00	572.80	31.10	21.03	94.78	54.95	6.94	472	6815	8205
INDONESIA													
ITKA-C-12-WET	H6	2/25/79	7/19/79	322.73	497.50	26.10	16.10	93.90	55.30	5.04	4340	5959	6734
ITKA-E-11-DRY	H6	6/28/79	12/20/79	351.98	822.70	26.06	15.13	97.77	51.03	5.25	4544	6584	7266
ITKA-K-13-DRY	H610	6/12/79	11/14/79	364.01	547.60	26.18	14.98	96.53	47.78	5.37	6015	8189	8817
LPH-A-16-DRY	H6	6/20/79	11/17/79	362.17	929.50	27.67	15.28	87.17	45.37	3.09	4841	6913	7978
LPH-D-21-WET	H6	11/26/79	4/28/80	311.06	2073.90	26.96	16.73	99.35	71.07	3.49	4176	5104	5549
LPH-D-22-WET	H6	11/17/80	4/14/81	301.97	1677.20	28.07	18.25	99.40	78.74	3.86	2129	3053	4164
LPH-E-13-WET	H6	11/25/80	4/28/81	299.04	1931.00	28.02	18.32	99.08	78.98	3.86	1678	2054	2640
LPH-G-11-DRY	H6	6/ 4/79	11/ 7/79	367.20	697.30	27.80	15.17	85.19	43.00	3.09	4591	6866	8281
LPH-G-13-WET	H6	11/20/80	4/21/81	301.22	1829.50	28.06	18.25	99.32	78.44	3.87	3232	3691	4320

* BLANK SPACE INDICATES NO TREATMENT WAS INSTALLED ON THIS PLOT.

WEATHER DATA GATHERED AT ALL SITES, BENCHMARK SOILS PROJECT/HAWAII
FAMILY B: CLAYEY, KAOLINITIC, ISOHYPERTHERMIC TROPEPTIC EUTRUSTOX

SITE/SEASON	VARIETY	PLANT DATE	HARVEST DATE	SOLAR RADIAT. (G CAL/ DAY)	CUMULATIVE RAINFALL (MM)	TEMPERATURE (DEGREE C) MAX.	TEMPERATURE (DEGREE C) MIN.	RELATIVE HUMIDITY (%) MAX.	RELATIVE HUMIDITY (%) MIN.	WIND RUN (KM/HR)	YIELD (KG/HA)* PART. CNTL.	YIELD (KG/HA)* MEAN	YIELD (KG/HA)* HIGH
HAWAII													
MOL-A-11-WET	X304C	12/13/79	5/28/80	457.13	881.80	25.04	17.81	87.96	69.57	20.44	2741	4953	5714
MOL-B-10-WET	X304C	1/ 9/79	7/17/79	508.10	565.20	26.40	18.50	91.10	69.80	19.13	2528	6676	8773
MOL-B-11-DRY	X304C	6/11/80	11/ 6/80	541.68	185.30	28.74	20.30	99.74	65.61	20.60	1579	5025	7478
MOL-J-10-WET	X304C	1/ 9/81	6/ 9/81	504.50	234.90	26.58	17.27	98.33	57.96	17.63	7279	8781	9457
MOL-M-10-DRY	X304C	6/24/80	11/13/80	529.20	186.10	28.83	20.27	99.73	65.32	20.37	7769	9552	10606
MOL-M-11-WET	X304C	1/29/81	7/14/81	550.54	274.70	27.19	17.82	97.75	56.60	19.20	3945	6830	8474
MOL-N-10-DRY	X304C	5/20/81	10/29/81	549.41	159.40	29.03	19.74	94.19	53.43	20.21	3945	7217	9468
WAI-A-11-WET	X304C	12/13/79	5/27/80	382.26	299.00	25.25	19.85	91.35	56.11	9.87	3690	7446	8702
WAI-A-12-DRY	X304C	7/22/80	12/ 2/80	399.74	255.30	28.35	21.01	90.55	52.52	7.24	3598	8655	10654
WAI-A-13-WET	X304C	3/ 6/81	7/30/81	469.49	210.00	29.76	19.46	89.18	48.61	8.30	2181	6770	9354
WAI-D-10-DRY	X304C	6/ 7/79	10/24/79	468.91	123.80	31.13	23.05	92.04	51.04	8.19	5694	7946	9992
WAI-D-11-DRY	X304C	2/13/80	7/10/80	498.34	163.50	26.75	21.51	91.20	58.87	9.42	3842	5402	6482
BRAZIL													
B-37-WET	X304C	1/16/79	7/10/79	436.00	445.00	29.30	15.40	98.00	48.00	1.39	583	1721	5742
B-41-WET	X304C	1/12/79	7/ 6/79	427.00	501.00	31.10	15.70			1.56	1369	3766	6342
B-43-DRY	X304C	6/ 6/79	11/22/79	454.00	458.00	31.00	13.40	99.00	39.00	2.28	2354	6932	10886
B-44-DRY	X304C	6/28/79	1/ 3/80	469.00	704.00	31.40	14.90	98.00	43.00	2.03	949	3163	6104
B-45-DRY	X304C	6/ 9/79	11/21/79	412.00	290.00	31.90	13.60				4243	7115	10780
B-46-DRY	X304C	6/28/79	1/ 3/80	429.00	583.00	32.40	14.90				2670	3686	5059
B-47-DRY	X304C	3/ 8/79	11/20/79	449.00	286.00	32.30	13.50			2.88	3899	6690	9492
B-48-DRY	X304C	7/ 4/79	1/ 3/80	470.00	553.00	32.80	15.10			2.55	2235	3519	5667
B-52-WET	X304C	11/26/79	5/ 8/80	461.00	640.00	30.80	17.70	82.00	70.00	1.10	4094	5766	8616
B-53-WET	X304C	12/19/79	5/30/80	441.00	595.00	30.60	17.30	89.00	63.00	1.14	3604	5912	9379
B-54-WET	X304C	11/28/79	5/ 7/80	412.00	626.00	32.20	17.50				4372	6795	9140
B-55-WET	X304C	12/19/79	5/29/80	386.00	607.00	32.00	17.10				3811	6047	8952
B-56-WET	X304C	11/28/79	5/ 7/80	484.00	611.00	32.30	17.50			1.36	3418	6049	8645
B-57-WET	X304C	12/19/79	5/29/80	462.00	597.00	32.10	17.10			1.35	5023	6069	8440
B-64-DRY	X304C	4/26/80	10/14/80	400.00	39.00	31.20	13.00	93.00	38.00	2.12	1606	4895	7744
B-65-DRY	X304C	5/17/80	11/ 5/80	404.00	40.00	31.40	13.20	99.00	36.00	2.31	3075	3192	5087
B-66-DRY	X304C	4/26/80	10/14/80	363.00	53.00	32.70	13.00				5944	6234	8559
B-67-DRY	X304C	5/17/80	10/27/80	380.00	56.00	33.00	12.90				2525	4194	6938
B-68-DRY	X304C	4/26/80	10/15/80	447.00	71.00	32.90	12.60			2.30	3897	6140	8506
B-69-DRY	X304C	5/17/80	11/ 5/80	465.00	72.00	33.50	12.80			2.46	2775	4405	6199
PUERTO RICO													
PR-34-DRY	X304C	11/17/78	3/21/79	379.00	221.00	28.00	18.50	77.00	56.00	6.08	813	4473	7398
PR-41-WET	X304C	5/ 2/79	8/27/79	443.00	645.00	29.50	21.10	83.00	56.00	4.96	2805	6597	8914
PR-42-WET	X304C	5/ 2/79	8/29/79	444.00	646.00	29.50	21.10	83.00	55.00	4.93	1678	5665	10002
PR-43-WET	X304C	5/ 3/79	8/29/79	444.00	646.00	29.50	21.10	83.00	55.00	4.93	2099	5518	9038
PR-44-WET	X304C	5/17/79	9/ 6/79	431.00	599.00	29.60	21.20	84.00	57.00	5.12	4218	6455	9930
PR-45-WET	X304C	5/18/79	9/ 7/79	426.00	602.00	29.60	21.20	84.00	58.00	5.17	5549	6452	8057
PR-46-WET	X304C	5/25/79	9/11/79	428.00	501.00	29.60	21.30	84.00	57.00	5.28	3469	4312	7035
PR-48-WET	X304C	5/30/79	9/10/79	424.00	498.00	29.60	21.30	84.00	57.00	5.33	4252	4895	8035
PR-50-DRY	X304C	11/14/79	3/19/80	372.00	365.00	27.40	18.30	90.00	56.00	4.91	3769	5439	8441
PR-51-DRY	X304C	11/14/79	3/24/80	380.00	366.00	27.40	18.30	90.00	56.00	4.95	4699	7207	9053
PR-53-DRY	X304C	12/ 1/79	3/ 7/80	371.00	200.00	27.20	18.10	90.00	55.00	4.74	4136	6340	8354
PR-54-DRY	X304C	12/ 1/79	4/ 9/80	405.00	210.00	27.50	18.20	90.00	54.00	5.12	6338	7373	9469
PR-55-DRY	X304C	12/ 5/79	3/31/80	395.00	251.00	27.40	18.10	90.00	55.00	5.11	5195	6262	8018
PR-58-WET	X304C	4/22/80	8/11/80	454.00	663.00	30.30	21.00	86.00	57.00	3.32	1649	5173	8348
PR-59-WET	X304C	4/22/80	8/12/80	454.00	663.00	30.30	20.90	86.00	57.00	3.32	2582	6758	10023
PR-60-WET	X304C	4/24/80	8/15/80	455.00	667.00	30.30	20.90	86.00	57.00	3.36	2705	5155	8106
PR-61-WET	X304C	4/25/80	8/19/80	457.00	711.00	30.30	21.00	86.00	57.00	3.38	4477	6112	10494
PR-62-WET	X304C	4/29/80	8/22/80	462.00	658.00	30.50	21.00	86.00	57.00	3.34	6164	7196	8690
PR-63-WET	X304C	4/30/80	8/25/80	462.00	670.00	30.50	21.00	86.00	56.00	3.33	4903	6629	8354

* BLANK SPACE INDICATES NO TREATMENT WAS INSTALLED ON THIS PLOT.

WEATHER DATA GATHERED AT ALL SITES, BENCHMARK SOILS PROJECT/HAWAII
FAMILY C: CLAYEY, KAOLINITIC, ISOHYPERTHERMIC TYPIC PALEUDULTS

SITE/SEASON	VARIETY	PLANT DATE	HARVEST DATE	SOLAR RADIAT. (G CAL/ DAY)	CUMULATIVE RAINFALL (MM)	TEMPERATURE (DEGREE C) MAX.	TEMPERATURE (DEGREE C) MIN.	RELATIVE HUMIDITY (%) MAX.	RELATIVE HUMIDITY (%) MIN.	WIND RUN (KM/HR)	YIELD (KG/HA)* PART. CNTL.	YIELD (KG/HA)* MEAN	YIELD (KG/HA)* HIGH
PHILLIPPINES													
DAV-A-12-WET	TINIGUIB	5/ 8/79	8/21/79	407.54	388.20	36.07	24.23	99.79	59.77	4.50	2954	4160	4863
DAV-H-10-WET	TINIGUIB	6/ 8/79	9/26/79	416.86	490.30	36.07	24.10	99.79	59.50	4.47	3107	4685	5474
DAV-I-10-DRY	TINIGUIB	2/15/80	6/ 3/80	473.93	402.10	36.05	23.23	94.65	41.08	5.92	4000	4512	4929
DAV-K-10-DRY	X304C	11/24/81	3/18/82	377.02	333.00	31.42	21.54	98.15	57.10	6.28	2264	5914	7257
DAV-L-10-DRY	X304C	8/29/81	12/22/82	409.66	900.30	33.33	21.90	97.89	56.29	4.89	5098	7232	8454
SOR-A-10-WET	UPCA-1	7/10/80	11/ 5/80	350.95	1616.40	32.46	23.11	90.13	58.18	5.63	121	4027	6233
SOR-A-20-DRY	X304C	2/12/81	6/11/81	460.68	257.50	33.71	23.25	83.46	52.65	6.68	281	5401	7798
SOR-A-30-DRY	X304C	2/13/82	6/15/82	402.34	502.90	30.67	20.28	73.72	60.58	7.57	1045	4667	6715
SOR-B-10-DRY	X304C	2/12/81	6/ 4/81	460.49	243.40	33.76	23.24	83.48	52.41	6.69	0	5148	7724
SOR-B-20-DRY	X304C	5/ 9/82	6/ 6/82	394.15	700.50	30.42	20.19	74.02	61.36	7.77	869	5011	7661
SOR-D-10-WET	X304C	6/29/81	10/30/81	370.56	1893.90	31.97	23.23	81.69	65.64	6.92	0	3249	5706
SOR-E-10-WET	X304C	5/ 2/81	10/30/81	371.59	1770.10	31.95	23.23	81.70	65.64	6.94	0	3328	5806
INDONESIA													
NAK-A-20-DRY	H6	5/ 8/80	9/ 9/80	396.38	536.50	34.85	21.30	98.50	30.32	3.44	519	4426	4964
NAK-A-30-DRY	X304C	6/ 1/81	10/ 6/81	384.50	622.50	33.17	23.64	98.51	36.70	3.26	1411	4507	6223
NAK-A-31-WET	X304C	12/ 1/81	4/13/82	415.58	1268.10	33.13	20.39	96.25	39.44	3.53	1392	4375	6078
NAK-D-11-WET	H6	11/13/79	3/11/80	401.35	1549.60	32.46	21.26	92.72	35.86	4.21	1137	4171	5821
NAK-D-20-WET	H6	12/ 1/80	3/31/81	416.78	2167.60	34.58	22.92	99.67	49.41	3.49	2002	4967	6405
NAK-D-30-DRY	X304C	6/12/81	10/16/81	386.90	614.80	33.22	23.75	98.46	35.78	3.34	1126	5005	6346
NAK-J-10-WET	H6	11/ 7/79	3/ 3/80	397.75	1497.60	32.27	21.21	92.62	36.48	4.18	1594	5437	7002
NAK-J-11-DRY	H6	5/12/80	9/10/80	399.77	491.77	34.78	21.28	98.47	30.57	3.43	354	2963	4530
NAK-L-10-WET	X304C	12/11/80	4/ 7/81	414.65	2091.90	34.03	23.16	99.78	50.52	3.53	4327	8290	10433
NAK-L-20-WET	X304C	11/25/81	3/31/82	412.03	1269.40	32.76	20.42	96.63	40.78	3.67	2002	6554	8646
BPMD-A-20-DRY	H6	5/13/80	9/11/80	374.62	619.60	34.79	20.43	99.71	45.81	1.90	474	5422	6652
BPMD-A-30-DRY	X304C	6/11/81	10/14/81	389.62	425.00	34.94	21.49	99.08	54.07	1.53	212	3286	4524
BPMD-A-31-WET	X304C	12/ 3/81	4/15/82	396.74	1677.00	34.59	23.18	99.38	57.71	1.85	1433	5581	7596
BPMD-C-11-WET	H6	11/19/79	3/13/80	408.50	1167.90	35.01	23.34	99.20	48.37	2.16	476	4100	6407
BPMD-C-20-WET	X304C	12/13/80	4/ 9/81	398.98	1572.90	32.42	21.06	95.21	45.97	1.79	826	6330	8737
BPMD-C-30-WET	X304C	11/27/81	4/ 1/82	390.58	1645.40	34.39	23.35	99.31	59.50	1.87	1073	5107	7402
BPMD-D-10-WET	H6	11/ 9/79	3/ 4/80	401.50	1160.80	34.96	23.12	98.89	48.28	2.14	334	4222	6334
BPMD-D-20-DRY	H6	5/26/80	9/17/80	369.60	686.70	34.75	20.53	99.70	46.25	1.92	0	4821	6214
BPMD-D-30-DRY	X304C	6/11/81	10/14/81	389.62	425.00	34.94	21.49	99.08	54.07	1.53	61	2647	3881
BUK-A-11-WET	H6	11/15/79	3/12/80	483.14	1156.40	32.95	22.69	85.48	46.27	4.01	6687	5775	7500
BUK-A-20-DRY	H6	6/ 5/80	10/ 2/80	501.58	827.70	34.64	22.22	88.57	33.30	4.26	3238	5226	6477
BUK-A-30-DRY	X304C	6/ 3/81	10/13/81	581.35	804.80	35.75	22.99	96.27	47.12	4.10	3259	5537	6730
BUK-C-10-WET	H6	11/ 3/79	3/ 5/80	474.31	1203.80	32.91	22.70	85.32	46.42	4.03	3100	6261	7210
BUK-C-20-WET	H6	12/ 3/80	4/ 1/81	564.22	2315.40	32.84	22.47	92.47	53.61	4.00	2720	5519	6927
BUK-C-30-WET	X304C	11/26/81	3/31/82	371.54	1651.00	30.80	20.89	96.55	56.70	4.21	2995	6982	8519
BUK-D-10-DRY	H6	5/14/80	9/17/80	481.75	786.50	34.79	22.40	88.32	34.07	4.15	2857	6284	7632
BUK-D-20-DRY	X304C	6/ 4/81	10/13/81	585.96	804.80	35.73	22.99	96.29	47.02	4.10	2628	5453	6551
BUK-E-10-WET	X304C	12/12/80	4/ 8/81	556.97	2259.90	32.89	22.45	92.62	53.71	4.03	6211	7795	9575
BUK-E-20-WET	X304C	12/ 2/81	4/14/82	372.53	1704.00	31.10	21.01	96.73	55.49	4.19	2841	6650	8089
CAMEROON													
CAM-A-10-DRY	X304C	11/12/80	3/ 4/81	335.28	173.70	34.75	22.40	99.72	37.90	1.98	7082	8238	8985
CAM-A-11-WET	X304C	3/18/81	6/24/81	343.30	725.00	34.58	22.64	92.79	71.85	1.66	5456	6003	7073
CAM-A-12-WET	X304C	7/ 2/81	10/19/81	271.66	1105.90	31.35	22.02	97.52	86.74	1.58	2539	3488	4203
CAM-A-20-DRY	X304C	12/11/81	3/19/82	366.72	108.00	35.18	22.03	99.64	40.50	1.99	7365	7834	8671
CAM-B-10-DRY	X304C	12/ 8/81	3/10/82	373.32	80.00	35.22	21.99	99.71	42.13	1.92	7188	7021	7655
CAM-C-10-WET	X304C	3/15/82	6/28/82	330.74		34.16	21.85	99.37	48.54	1.53	5246	5487	6118
BAK-A-10-DRY	X304C	12/19/81	3/30/82	336.12		36.19	23.14	98.14	38.78	1.50	7602	9047	10749
BAK-C-10-WET	X304C	3/ 5/82	6/11/82	319.56		35.10	22.12	98.14	50.55	1.38	5449	6968	7910

* BLANK SPACE INDICATES NO TREATMENT WAS INSTALLED ON THIS PLOT.

Appendix 3.

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BSP Project Personnel

1979–1982

BRAZIL

EPAMIG Liaison:	Derli Prudente Santana[a]
	Fernando Zinho Antunes[a]
Project Leaders:	Cristopher C. Seubert (resigned)
	Donald C. L. Kass (resigned)
	Mervyn L. Olson
Agronomists:	Narbal de Sá
	Umbemar Silveira Dias[b]
	Marcos A. C. Torres
EPAMIG Counterpart:	Antonio M. Coelho[a]
Secretary:	Carole Seubert (resigned)
Typist:	Ademar Fernandes dos Anjos
Field Foreman:	Delcino C. Jorge
Driver/Mechanic:	Ivandir Pereira Miranda

CAMEROON

Project Specialist:	Donald A. Berger
Project Manager/FAO:	G. W. van Barneveld[c] (1980-81)
	J. C. Greisbach[c] (1981-82)
Project Counterpart:	John N. Awemo (on leave)
FAO Associate Expert:	Bruno Delvaux[c]
	Jan Hof (1981)
Agricultural Assistants:	Paul Mbonde[d]
	Kinge David[d]
Driver/Assistant:	Mwanga Ndumbe
Secretary:	Rose Mahop

HAWAII

Principal Investigator:	James A. Silva[e]
Soil Scientist:	Goro Uehara[e]
Associate Soil Scientist:	Haruyoshi "Ike" Ikawa[e]
Project Manager:	Gordon Y. Tsuji
Hawaii Agronomist:	Alan R. Hurdus (resigned)
	Patrick C. Ching
Training Coordinator:	Bernardino G. Cagauan, Jr.
Editor/Communication Coordinator:	Cynthia L. Garver (resigned)
Graphic Artist/ Publications Specialist:	Victoria L. Pecsok
Data Analyst/ Computer Specialist:	Clement P. Y. Chan
Administrative Aide:	Jill D. Kosaki (resigned)
Account Clerk:	Suemi Sakumoto
Administrative Assistant:	Annette E. Chang
Soil Chemist:	Ada E. Chu
Laboratory Technician Assistants:	Dwight T Tanoue (resigned)
	Keane Suzuki
Research Associate:	Luis A. Manrique
Agricultural Research Technicians:	
Hawaii	William K. Y. Wong
	James Couttie
	Lawrence Pasco
	Richard M. Uehara[e]
Molokai	Thomas R. Hill
	Rudy Dela Cruz (resigned)
Oahu	Marc T. Meisner (resigned)
	Benito Ordillo (resigned)
	Aaron Imamura (resigned)
	Lori Murai
	Valentine Ah Loy
Graduate Assistants:	John N. Awemo
	Crisanto R. Escaño (graduated)
	David J. Harris
	Alan R. Hurdus (on leave)
	I Putu Gedjer Widjaja-Adhi
	Beatriz P. del Rosario
	Modesto R. Recel
	Djoko Santoso (graduated)
	M. Soekardi
Student Assistants:	
Editorial Services:	Karin Wong
Graphic Services:	Jeffrey Uehara
Computer Services:	Alvin Nekoba
	Darcy Kouchi
	Andy Chan
	Maggie Ho (graduated)
	Desmond Pang (graduated)
	Phyllis Matsuura (graduated)
Clerical Services:	Marie Nikaido (resigned)
	Monica Pelletier (graduated)
	Susan Tamura
	Cary Okimoto
Laboratory Services:	Jason You
	Richard Ogoshi
	Janelle Lee
	Lester Parilla
	Raye Koyanagi
	Bryan Sakka
	Lisa Schattenburg
	Jo Ann Goya (resigned)
	Carl Yamaoka (graduated)
Agricultural Services:	Richard Horiuchi
Temporary Employees:	Debra Nanod
	Robert Traxler
	Bradley Kneece
Consultants:	Foster B. Cady
	G. W. van Barneveld

INDONESIA

Project Leader:	R. George Manuelpillai
Project Coordinators, CSR:	M. Sudjadi[f]
	Ir. Supartini[f]
Agricultural Assistants/Farm Managers:	
Java	Krisnadi
	Endang Hidayat
Sumatra	Ir. Soleh (transferred)
	Achmad Hasanuddin
Secretary/Typist:	Julia Ishaq (resigned)
	Hesti Wachyuni

Administrative Assistant:	Henny Djuhaeni (resigned)
	Nursuwahyanti Soleh (resigned)
	Rusmiati
	Tatang Djuanda[f]
Research Aides:	
Java	Lulus Sunaryo[f]
	Arman A. R.[f]
Sumatra	Agus Tarman[f]
	Tri Haryanto
	Supendi Sanfi
	Burlian
Drivers, Benchmark Vehicles:	
Java	Sulaiman
Sumatra	Windu

PHILIPPINES

Project Leader:	Martin E. Raymundo
Co-Project Leader:	Crisotomo B. Alcalde[g]
Director, Farm Resources and System Research Division, PCARRD:	Amado R. Maglinao[h]
Field Operations Coordinator:	Perfecto [illegible] R. Vicente
Administrative/Fiscal Assistant:	Penafrancia "Anchie" P. Pago
Secretarial Staff:	
Naga	Josefa "Josie" Bautista[h]
Davao	Lolita "Lita" A. de Juan (resigned)
	E. R. Fernandez[h]
Research Assistants:	
Naga	Maria Dolores Ativo Gibe[h]
	Edgardo de la Torre (resigned)
	Joseph Ragay
Davao	Clara A. Jacob[h]
Research Aides:	
Naga	Jaime "Jim" N. Gibe[h]
	Rogelio "Roy" C. Arco[h]
Davao	Rosendo "Sendong" T. Edquila[h]
Sorsogon	Nelson J. Arimado

PUERTO RICO

Principal Investigator:	Friedrich H. Beinroth
Senior Agronomist:	Gene L. Spain
Agronomists:	José Badillo Feliciano[b]
	Luis Calduch (resigned)
	Stevan P. Nightengale
Soil Chemists:	Lillian Costa Mayoral
	Milagros Miró[b]
	Carlos Sarmiento
Soil Scientist:	Juan A. Vega López (resigned)
Administrative Aide:	Elsie G. Sánchez
Secretaries:	Lucy Vélez
	Ingrid A. Vélez Ramos
Research Aides:	Rubén García[b]
	José A. Robles
Consultants:	Jack Keller
	Larry A. Nelson

[a] Supported by Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG), Brazil
[b] Part-time employment with University of Puerto Rico/Benchmark Soils Project
[c] Supported by Food and Agriculture Organization (FAO), Ekona, Cameroon
[d] Supported by Institut de la Recherche Agronomique (IRA), General Delegation for Scientific and Technical Research, Cameroon
[e] Supported by the Hawaii Institute of Tropical Agriculture and Human Resources, University of Hawaii
[f] Supported by Center for Soils Research (CSR), Bogor, Indonesia
[g] Supported by the Bureau of Soils, Manila, Philippines
[h] Supported by the Philippine Council for Agriculture and Resources Research and Development (PCARRD), Philippines