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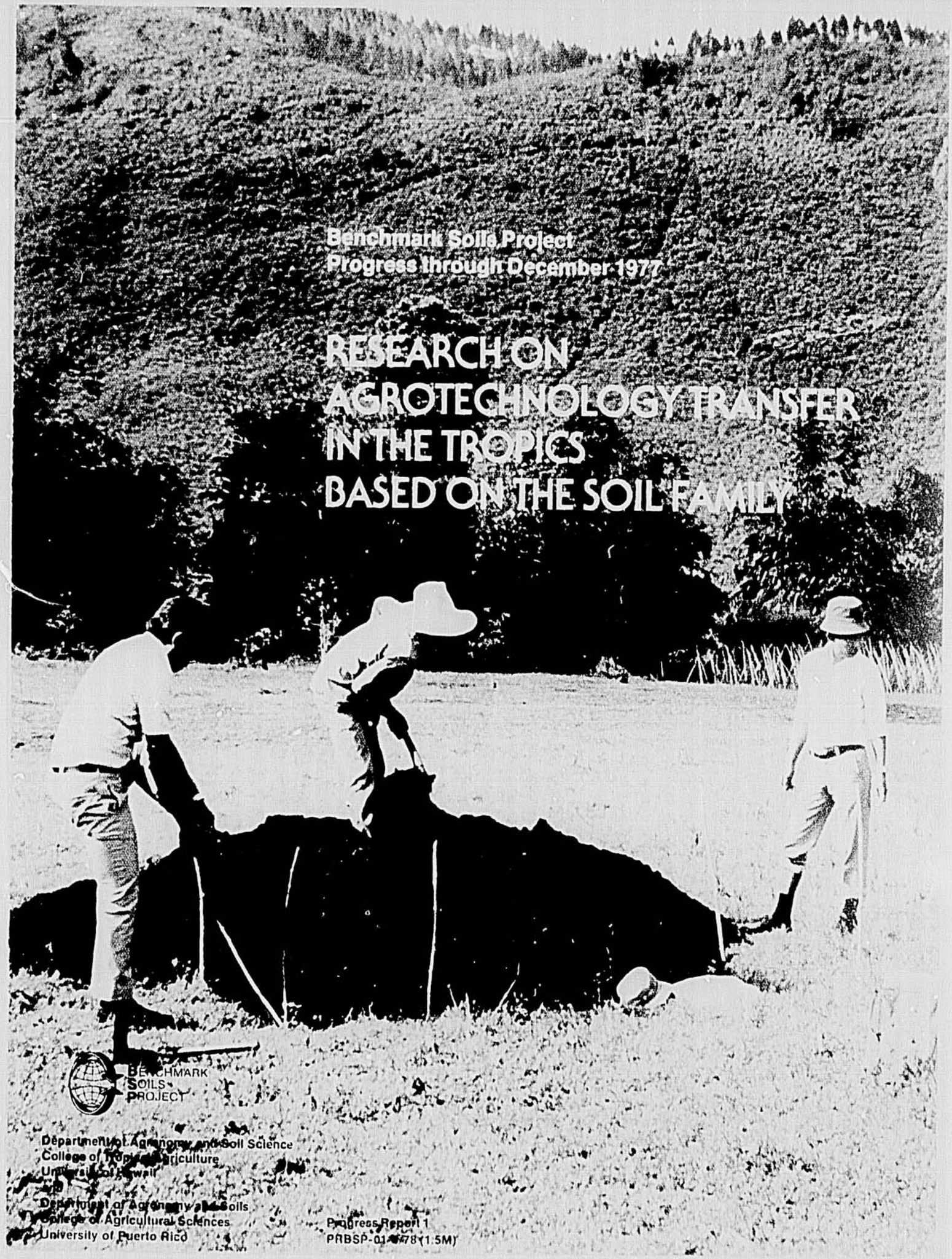
Benchmark Soils Project
Progress through December 1977

RESEARCH ON AGROTECHNOLOGY TRANSFER IN THE TROPICS BASED ON THE SOIL FAMILY



BENCHMARK SOILS PROJECT

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University of Puerto Rico

Progress Report 1
PRBSP-01-1978 (1.5M)

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Benchmark Soils Project
Progress Report 1

ERRATA

p. 3. Photo caption: At Lembang, Indonesia.....

p. 7. Hydric Dystrandepts, column 1.
Delete exchangeable calcium.

p. 28. Photo caption: below photo is incorrect: downy mildew is more prevalent in the warm humid climate of the tropical lowlands of the Typic Paleudults.

p. 51. Figure caption: second to last column should be 50 kg K/ha.

p. 55. The last paragraph before the title "Disseminating Project information for Utilization" is misplaced; it should appear before the head "Soil Data Bank."

highlights

GOAL

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.

AID/ta-C-1108
AID/ta-C-1158

At Lampung, Indonesia, I.P. Gedjer Wijaja Adhi, Project Coordinator, instructed local women in the art of planting a soybean transfer experiment.

OBJECTIVES

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 selective areas.

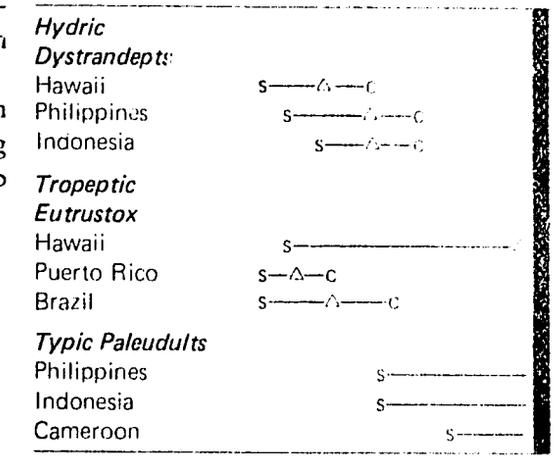
ACTIVITIES

1. Establish and complete the network of soils

Three major soil families of importance in the tropics have been identified. Detailed soil surveys have been conducted in 15 countries, and a network of 3 soil families located in 5 countries and on 17 experimental sites has been established (see pages 14–21).

Potential The focus of the Project can shift toward gathering and disseminating soil and crop data through the Soil and Crop Data Bank.

Activity 1. Soils Network



s Survey potential experimental sites.
△ Negotiate and sign long-term agreements.
c Staff, equip, and prepare sites for experiments.
■ Where we are now.

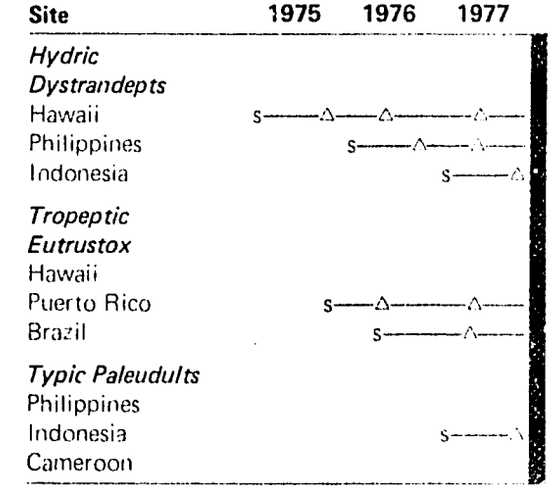
See pages 14–21 for complete story.

2. Establish, install, complete, and analyze transfer experiments

A total of 47 transfer (soil fertility) experiments on 2 soil families has been conducted to generate data. First approximation results of a statistical test on the Hydric Dystrandepts have been released (see pages 40–43), which suggest that the hypothesis of agrotechnology transfer from one location to another on the basis of the soil family is very likely to be accepted and that crop response can be predicted.

Potential First approximations will be completed on the Tropeptic Eutrustox and Typic Paleudults; second and third approximations on each family will also be completed. The hypothesis is expected to be confirmed.

Activity 2. Transfer Experiments



s Set up sites.
△ Conduct experiments and collect data (wet and dry season, each year).
① Test hypothesis across the network, 1st approximation.
② Test hypothesis across the network, 2nd approximation.
③ Test hypothesis across the network, 3rd approximation.
■ Where we are now.

See pages 30–39 for complete story.

3. Establish, install, complete, and analyze crop (variety) and soil management experiments

Crop variety trials (a total of 15 experiments) to identify the maize and soybean varieties that are best adapted to a locality have been installed and are underway on all sites of the Hydric Dystrandepts and on several sites of the Tropeptic Eutrustox (see pages 43–46). Management trials (a total of 18 experiments) at economic levels for farmer inputs have been installed and are underway (see pages 47–52).

Potential Variables of the transfer experiments will be evaluated at levels useful to the small farmers. Levels of in-country management practices will be surveyed and identified on soils similar to those of the soil family network. Overall coordination of soil survey, soil interpretation, and land classification will assist planners in less developed countries by providing alternatives of land use for country development. After first approximation recommendations are formulated, transference levels of agrotechnology can be identified for use by national planning agencies for in-country agricultural development programs.

Activity 3. Crop Variety and Soil Management Experiments

Site	Initial phase 1975	1976	1977
Hydric Dystrandepts		s——	——^—s—
Hawaii		s——	——^—s—
Philippines		s——	——^—s—
Indonesia			
Tropeptic Eutrustox			
Hawaii			
Puerto Rico			s—^—s—
Brazil			s—
Typic Paleudults			
Philippines			
Indonesia			
Cameroon			

s Design experiments.
^ Conduct experiments and collect data (wet and dry season, each year).
① Formulate recommendations, 1st approximation.
② Formulate recommendations, 2nd approximation.
③ Formulate recommendations, 3rd approximation.
■ Where we are now.

See pages 43–52 for complete story.

4. Analyze information for soil interpretation and land classification

As a result of the Project, the value of *Soil Taxonomy* is becoming increasingly evident to host countries (see pages 53–55). The Soil Research Institute of Indonesia has ordered 50 additional copies of the book for distribution to scientists and planners and has conducted a workshop to promote the system's use. The soils of 9 proposed and existing experimental sites on key soils of Sumatra are being classified according to the Soil Taxonomy system.

Potential There are strong indications that the pattern of host-country initiative will continue with the expansion of the soils network and the Soil and Crop Data Bank. The adoption of Soil Taxonomy as the basis for soil interpretation and land classification by tropical countries is potentially the most significant consequence of the Benchmark Soils Project because an international classification system will enable agricultural information exchange within and among tropical countries.

Activity 4. Soil Interpretation and Land Classification

Site	Initial phase 1975	1976	1977
Hawaii			s——
Philippines			s——
Indonesia			
Cameroon			
Puerto Rico			s——
Brazil			

^ Analyze and interpret transfer and management experiments.
s Start survey of farmer management practices.
① Complete survey of farmer management practices.
■ Where we are now.

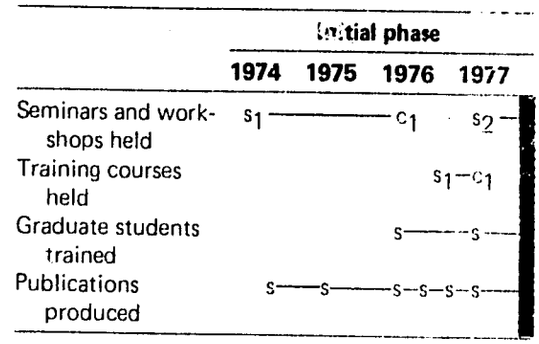
See pages 53–55 for complete story.

5. Disseminate principles, concepts, and results

The Project has entered into cooperative agreements with 8 agencies or institutions and established linkages with 3 international agricultural research centers. Awareness of Project goals has been disseminated through training programs, meetings, workshops, and conferences and via publications (see pages 54–60).

Potential The concept of agrotechnology transfer based on the soil family will be useful for the outreach and farming systems programs of the international centers and for the planning and development of research stations on key soils of the LDCs. The Project will also assist in the training of LDC scientists to carry on additional activities to increase food production.

Activity 5. Dissemination



s Started (planned workshops and training courses; began selecting students; began publication of workshops and training courses).

c Completed (held workshops and training courses; student selection completed; publications produced).

■ Where we are now.

See pages 54–60 for complete story.

FINDINGS

Benchmark Soils Project personnel classified soils according to *Soil Taxonomy* in areas where this classification was unknown or unused before the Project's inception. This means that a unified system of soil classification is slowly becoming a reality and that worldwide acceptance of one international soil classification system is expanding.

In every soil family, there are certain limiting factors affecting good crop yields. These factors were confirmed to be the same within the same family and different between soil families. Management practices depend on the limiting factors and can therefore be predicted for specific soils. The following recommended management interpretations are results of Benchmark Soils Project field experimentations to date on the two soil families studied. Detailed information on these findings is provided in the Results section, pages 29–39.

Within a Soil Family

Although soils of the same family occur in geographically separated areas in the tropics, they require the same agrotechnology (Fig. 1).

Hydric Dystrandepts

Unique soil property	[illegible]	[illegible]
Contain high amounts of amorphous materials that fix high amounts of phosphorus. Frequently deficient in phosphorus.	Yield responses to maize observed at the sites in Hawaii, the Philippines, and Indonesia showed a similar pattern: all responded to application of fertilizer phosphorus in varying degrees.	Much larger applications of phosphorus are necessary than on the Tropeptic Eutrustox.
Have relatively low percentage of aluminum saturation between pH 5.0 and 5.5. exchangeable calcium.	Lime treatments generally had no effect on yield; even though the soil pH was lower than 5.5. In fact, some experiments even showed a decrease in yield with highest rates of lime application.	The existing expensive practice of liming acid tropical soils to obtain good crop response does not necessarily apply to Hydric Dystrandepts.
Have wet climate and low temperatures (uniformly cool and moist).	Only minor incidence of downy mildew (which requires warm, moist conditions) occurred in Indonesia and none occurred in the Philippines, even though downy mildew is a serious disease in these countries.	Downy-mildew-resistant varieties may not need to be used because the isothermic temperature regime may retard the development of this disease.

Tropeptic Eutrustox

Unique soil property	[illegible]	[illegible]
Contain iron and aluminum oxides, which fix phosphorus.	Maize and soybean responded to phosphorus application in Puerto Rico and Brazil.	Phosphorus must be added, but in lower amounts than for the Hydric Dystrandepts.
Are enriched with bases.	Maize and soybeans did not respond to potassium application.	Adding potassium to these soils is not necessary for initial cropping seasons. However, continuous cropping without supplementary addition of potassium will eventually deplete the potassium reserves in these soils.
Have dry, warm climate with high solar radiation.	Registered the highest maize yield in the Benchmark network.	Irrigation is required for optimum yields.

Between Soil Families

Weather as a Limiting Factor

Yields on soils are affected by weather, which differs among soil families and even between sites within a soil family. Quantifying the weather variables will assist in determining the crop response.

- Maize yields were higher overall in the Tropeptic Eutrustox network than in the Hydric Dystrandept network. Tropeptic Eutrustox receive higher solar radiation and thus have higher potential for grain yields of maize than do the Hydric Dystrandepts, which have more cloud cover and therefore less incoming solar radiation.

- There is higher rainfall in the Hydric Dystrandepts than in the Tropeptic Eutrustox; therefore, irrigation is supple-

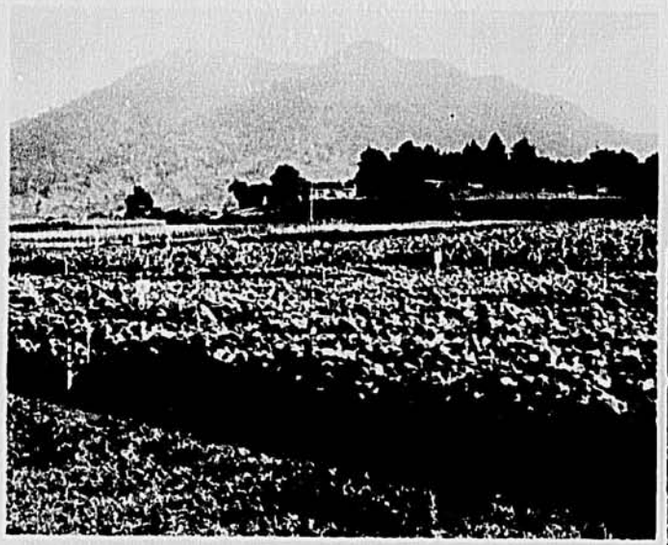
mentary for the Dystrandepts but necessary for the Eutrustox.

- Higher yields were obtained within the warmer isohyperthermic Tropeptic Eutrustox family than in the cooler isothermic Hydric Dystrandept family.

Variety and Disease Incidence

The variety of maize used for the best yields differs among families; disease incidence may be predicted by the soil family.

- 'Pioneer X304' hybrids do best in the Tropeptic Eutrustox network; no single best-adapted variety for the Hydric Dystrandepts has been identified to date.
- Soybeans were affected by anthracnose in the Tropeptic Eutrustox but not in the Hydric Dystrandepts; they were severely affected by rust, leaf spot, and powdery mildew in the Hydric Dystrandepts but not in the Tropeptic Eutrustox.
- Maize was severely affected by rust but generally escaped downy mildew attack in the Hydric Dystrandepts. No particular disease trend was identified in the Tropeptic Eutrustox.



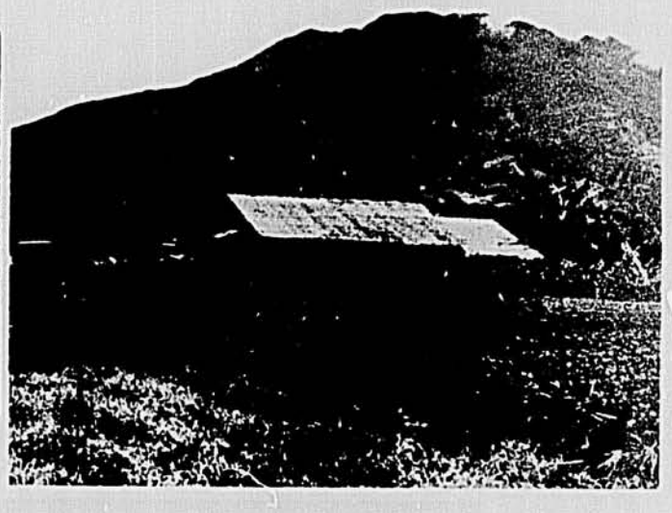


Fig. 1. The transfer hypothesis of the Benchmark Soils Project is that agrotechnology can be transferred between similar soils even though they are widely separated. The volcanic ash soils of the Hydric Dystrandepts soil family occur near Mt. Gede in Cipanas, Indonesia (*upper left*), Mt. Isarog in Naga City, the Philippines(*upper right*), and Mauna Kea, Honokaa, Island of Hawaii, U.S.A. (*bottom*).

THE GOAL: AGROTECHNOLOGY TRANSFER AMONG TROPICAL COUNTRIES

At the World Food Conference (Rome, October 1974), attention was focused on the worldwide, steadily worsening agricultural situation, and it was determined that a concerted international effort is needed to alleviate the present food crisis and to prevent future famines.

Agricultural experimentation is both expensive and time-consuming; thus, it appears expedient to capitalize on agricultural experience gained elsewhere. Time has shown, however, that the extrapolation of agricultural experience from developed countries in the temperate zone to less-developed tropical countries has met with little success. One reason for the failure is that many soils of the tropics have properties that require management practices unique to these soils, which do not necessarily conform to the known practices for soils of the temperate regions. This implies that the process of transfer of agrotechnology to less-developed tropical countries must take place predominantly within the tropics.

To assist in the transfer of agrotechnology, the Benchmark Soils Project was established by U.S. Agency for International Development contracts ta-C-1108 with the University of Hawaii in 1974 and ta-C-1158 with the University of Puerto Rico in 1975. Both projects have been extended to 1980. Sites were established in 1975 in Hawaii and Puerto Rico; in 1976 in the Philippines and Brazil; and in 1977 in Indonesia. In 1978, negotiations began to set up sites in Cameroon.

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, lack of time 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 (Fig. 2).

It is the underlying rationale of the Benchmark Soils Project that soil management knowledge is directly transferable in the tropics on the basis of the soil family in *Soil Taxonomy* (Soil Survey Staff, 1975). If this hypothesis is substantiated, a strategy for mobilizing and utilizing existing soil management information can be conceived and incorporated in the general model of agrotechnology transfer. The action program will conform to the World Food Conference goals of involving innovative approaches in the development of (1) appropriate agricultural technologies, (2) procedures to guide the selection of land re-

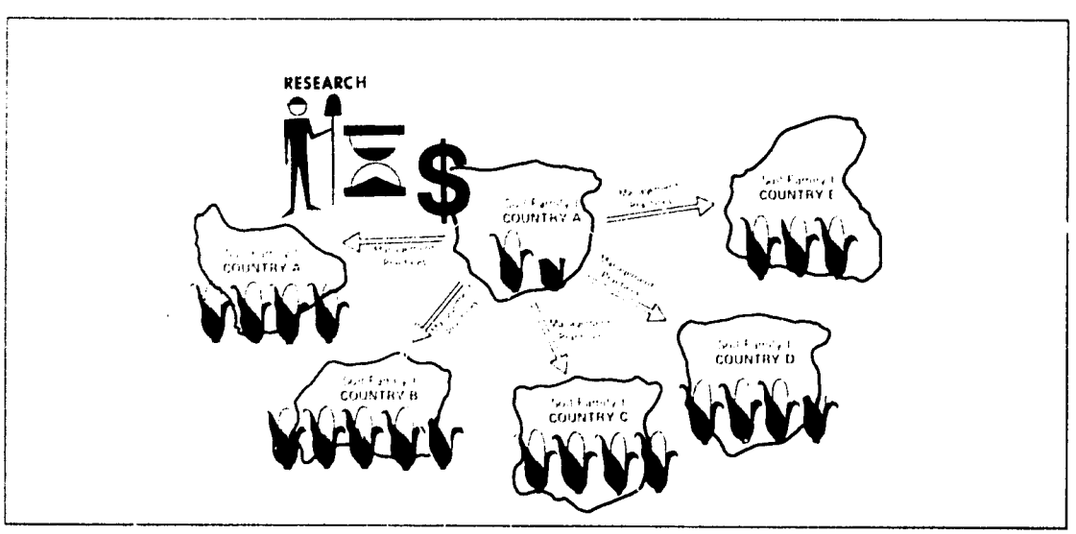


Fig. 2. The transfer hypothesis of the Benchmark Soils Project is that experimental results obtained from one country can be applied to sites on the same soil family in other countries, thus saving time, money, and labor.

Agrotechnology transfer will not be confined to soil management; it will be shown to encompass all associated experience and knowledge.

sources to be developed, and (3) a methodology for the transfer of appropriate agroproduction technology of these areas.

If proven correct, the transfer hypothesis may well have a profound impact on agricultural development and increased food production:

1. Millions of dollars worth of research information produced by thousands of man-years of effort will become available for immediate tapping.
2. Millions of dollars will be saved by avoiding the duplication of agronomic experiments throughout the tropics—a waste of time, money, and effort LDCs can ill afford.
3. A worldwide network of expertise will be formed, and a Crop Production Reference Center by taxonomic soil units will be established.
4. The concept of agrotechnology transfer will not be confined to soil management practices but will be shown to encompass all associated experience and knowledge—for example, information on crops and farming systems, water management, erosion control measures, economics of crop production, and so on.

THE MODEL: FRAMEWORK FOR AGROTECHNOLOGY TRANSFER

The farmer receives technology tailored to his needs.

There are two essential components to the agrotechnology transfer process. A horizontal component delivers information and technology, which meet the physical requirement of a site. Once this is achieved, a technology can be devised using this physical information plus the applicable socioeconomic conditions to fit local customs and conditions. The farmer receives technology tailored to his needs through the vertical component (Fig. 3).

In the Benchmark Soils Project, two types of experiments, one for horizontal and the other for vertical technology transfer, are being conducted. The experiments related to the horizontal component are called "transfer" experiments and are designed to test the suitability of the soil family as an instrument to transfer physically appropriate information and technology. The "management" experiments are conducted to render physically appropriate information and technology socially and economically appropriate to local situations. The management (or vertical transfer) experiments are designed to intercept and digest horizontally transferred information for local assimilation.

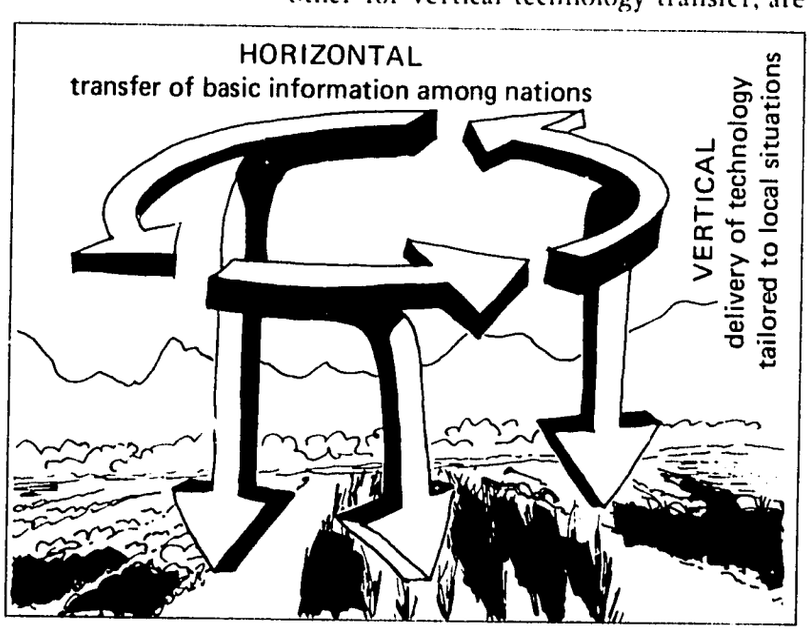


Fig. 3. In the Benchmark Soils Project, two types of experiments, transfer and management experiments, have been designed to study the horizontal and vertical components of agrotechnology transfer.

For example, the physical requirement for phosphorus or lime in the thixotropic, isothermic family of Hydric Dystrandepts is transferable information. It is not necessary to rediscover this knowledge at each site in every country. How this information is used depends, however, on the local situation. Phosphorus, for example, is found in manure or bones, and it can be applied as raw or partially acidulated rock phosphate. It can be purchased as superphosphate, treblesuperphosphate, or mixed fertilizer, in both liquid and solid forms. In addition, the farmer may choose not to apply phosphorus, but to grow crops with low phosphorus requirements.

Effective technology transfer hinges on horizontal information exchange among nations and vertical delivery of appropriate technology to the farmer. Each component is necessary but not sufficient in itself to transfer technology.

BASIS FOR THE HYPOTHESIS: THE SOIL FAMILY CONCEPT

The basis for the Benchmark Soils Project is the soil family, as defined in *Soil Taxonomy* (Soil Survey Staff, 1975), which describes the procedures for identifying similar soils in similar environments on a global scale. The contents are based on more than 50 years of soil research.

The system consists of six categories, from the highest to lowest levels of generalization: order, suborder, great group,subgroup, family, and series (Fig. 4). Each of these is defined by the presence or absence of specific diagnostic horizons, both at and below the surface of soils, which show the accumulation of materials and other properties and features that can be used for soil differentiation. These may include such features as depth, color, texture, and structure and the chemical and physical characteristics, including cation-exchange capacity, extractable bases and hydrogen, total available phosphorus, acidity level, percentage of organic matter, and particle-size distribution of the pedons.

The soil family was selected as the basis for the transference of agrotechnology because it stratifies the soils of the world into relatively narrow groups, integrating the environmental (climatic) information that is important to plant growth with the physical and chemical characteristics that affect soil response to management. Thus, the soil family name constitutes a condensed scientific statement that integrates the knowledge about a soil with its environment.

There are, for example, obvious reasons why bananas grow well in Honduras but not in Canada, and these facts are illustrated by the temperature regimes that are contained in the soil family names of both regions. For practical reasons, the soils of the temperate region are separated from the soils of the tropics through soil temperature at the family level of classification. This leads to the logical conclusion that members of the banana-growing family of Honduran soils cannot occur in Canada. Then, within the tropics, the soil family name further stratifies soils into 16 environmental niches on the basis of soil temperature and moisture. For example, soils of the Amazon jungle are different from soils on the slopes of Mt. Kilimanjaro, and both groups are different from the soils of Sahel. Other differentiae in the classification system separate soils within each of these regions into different families.

A great deal of information is stored in the soil family name (see pages 17–21). Take, for example, the thixotropic, isothermic family of Hydric Dystrandepts used as one of the Benchmark Soils. The name implies that this soil is associated with volcanoes that erupt ash and cinder. Soils developed from volcanic ash or cinder are so distinctly different that they are separated from all other soils at a high taxonomic level. They are called Andepts. But Andepts can occur in Alaska, California, Central and South America, New Zealand, Indonesia, the Philippines, Africa, and Japan. The name Andept does not permit one to make specific management recommendation about this group of soils. If we narrow the Andepts to Dystrandepts we can make more specific statements about Andepts, but it is not until

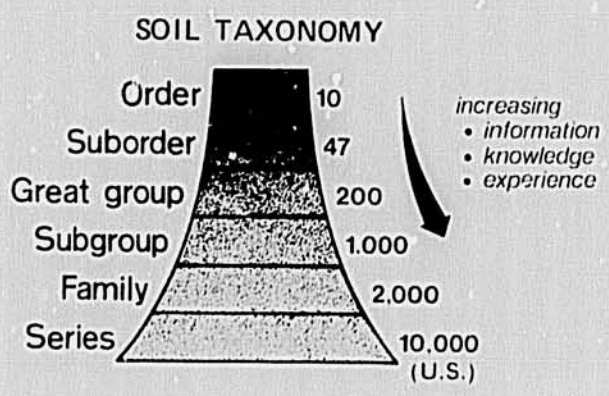


Fig. 4. The number of statements that can be made about a soil increases as one moves down the taxonomic ladder.

Specific soil family constraints determine the suitability of a parcel of land for specific crops.

The theory is that the response of maize obtained in one country can be applied to sites on the same soil family in another country.

we classify soils down to the family level that specific statements about management and crop production potential can be made. The thixotropic, isothermic family of Hydric Dystrandepts occupy distinct ecological niches in the tropics. They cannot occur in Alaska, Japan, or New Zealand. The family name implies that two or even three crops of maize can be grown on this soil each year. The family name also implies that certain plant nutrients will be deficient, that certain plant diseases will be excluded from this niche, and that only minimum supplementary irrigation will be required throughout the year.

Specific constraints associated with a particular soil family determine the suitability of a parcel of land for specific crops. The thixotropic, isothermic family of Hydric Dystrandepts occur in uniformly cool (isothermic) and moist (Hydric) niches. The soil is frequently deficient in phosphorus (as deduced from thixotropic). Thus, crops such as millet and sorghum are not especially suited to this soil because the climate is too wet. The root crop cassava is also not suited, not because of wetness, but because of low temperatures. On the other hand, Irish potatoes, vegetables, and other crops that prefer cool and adequately watered conditions can be expected to perform well on this soil.

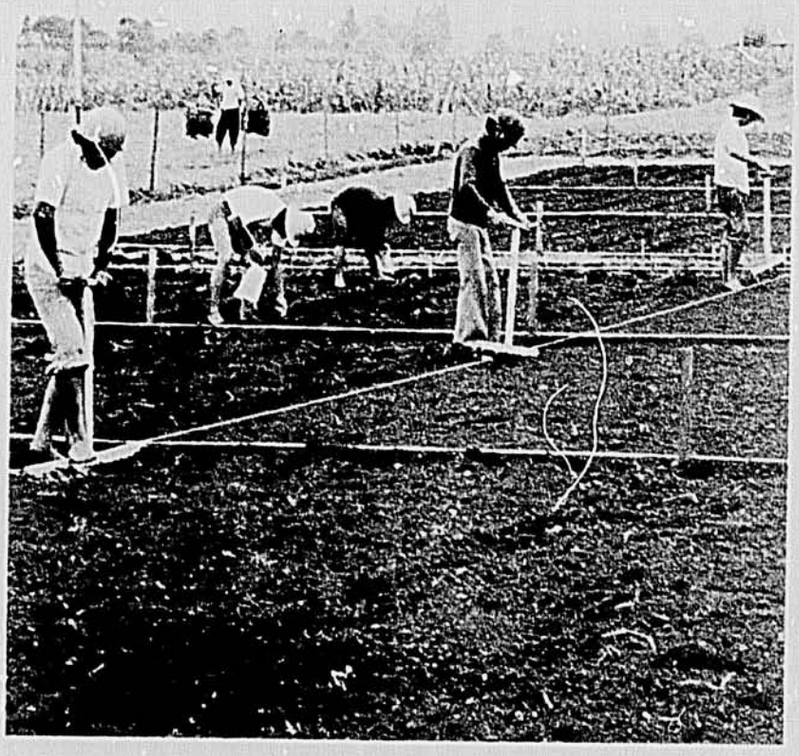
It is possible to extract from the family name not only constraints such as rainfall, temperature, and solar radiation, that are outside the province of human control, but constraints that can be altered or removed by man as well. So that if a crop performs poorly on a soil, the family name should enable one to ascertain whether or not the cause can be corrected.

Thus, the soil family classification provides information related to crop adaptability, the need for irrigation, and appropriate management practices. Direct measurements of soil properties are required to assess the effects of past management or site variations and to determine specific management inputs required for a given crop. Soils belonging to the same family, therefore, should have essentially the same management requirements and responses and should have similar potentials for crop production. Consequently, the inherent qualities of a soil family should make the transfer of agrotechnology possible. In this way, research conducted on a soil in Puerto Rico applies to all members of that family whether they occur in Sumatra, Borneo, Colombia, or Zaire.

RESEARCH DESIGN

The theory is that experimental results (specifically, in this phase of the Project, the response of maize to applications of phosphorus and lime) obtained from one country can be applied to sites on the same soil family in another country.

The research design and methodology to test the hypothesis were developed in concurrence with the recommendations of the Workshop on Experimental Design (Silva and Beinroth, 1975). In the Project design, distinctions are made between two types of experi-



The rigidity of the transfer experimental design requires that standardized procedures and equipment be used in every phase of the field implementation. At ITKA, Indonesia, the first transfer experiment on maize was planted in 1976.

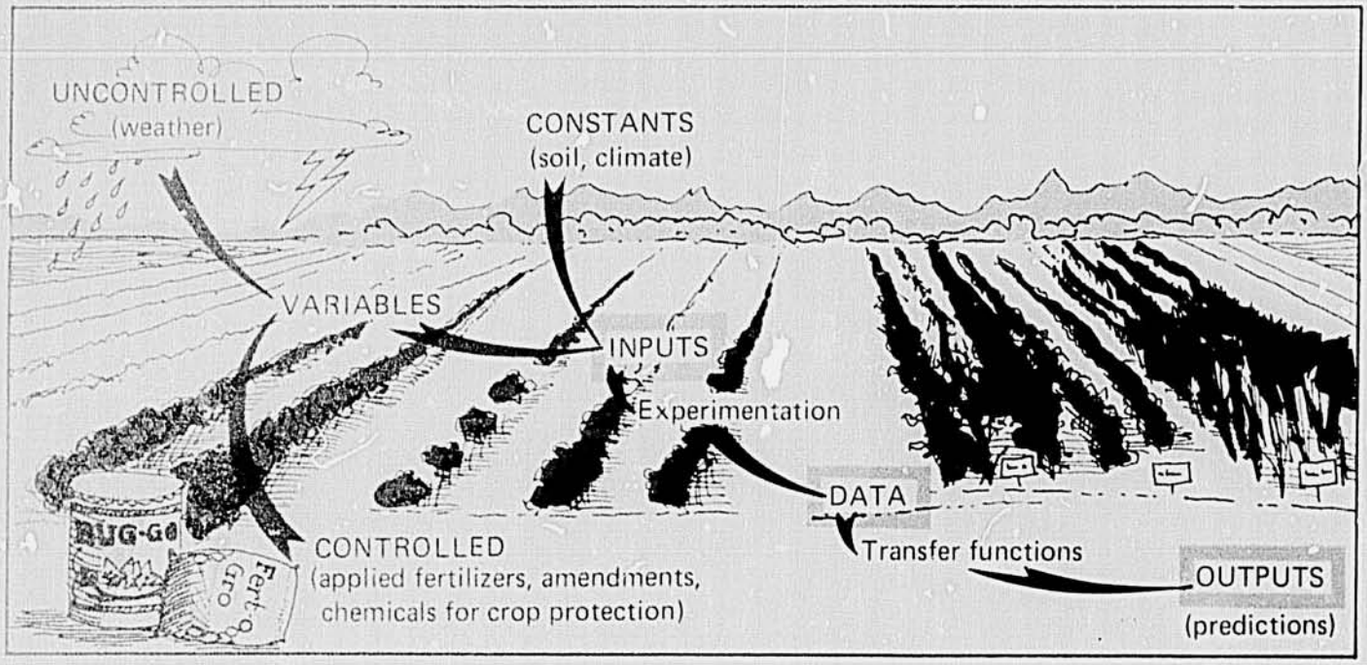


Fig. 5. Sequence of steps required to implement the experimental design of the Benchmark Soils Project. Outputs of the Project are generated from experiments that use two kinds of inputs—controlled and uncontrolled variables.

mental sites, designated primary and secondary sites, and three kinds of experiments, referred to as transfer (soil fertility), variety, and management experiments.

Primary sites are locations where all three kinds of experiments are being conducted and are completely instrumented for collection of pertinent weather data: air temperature, relative humidity, rainfall, solar radiation, wind run, pan evaporation (which is optional), and maximum and minimum soil temperatures at 5-, 15-, 20-, and 50-cm depths. Secondary sites are locations where only transfer experiments are being conducted. They are required to increase the number of experimental sites per soil family in order to have sufficient data for a statistically valid estimate of the effect of uncontrolled variables on crop yields. Secondary sites may differ from primary sites in that they exhibit variations in soil properties important to plant growth, such as pH or base saturation, within the range permitted by the definition of the soil family (see pages 17–20). If located at some distance from the primary site, secondary sites may also have different weather conditions, and the same weather parameters are monitored as at primary sites.

Field operations, data collection, and data processing follow standardized procedures and guidelines to ascertain compatibility of results throughout the network. These guidelines are sufficiently detailed to insure compatability of data obtained at all sites. All field operations—such as land preparation, pest control, irrigation, and harvesting—are considered, as well as field plot designs and data collection at all sites. Experimental yield results, with all related data on controlled and uncontrolled variables (see pages 21–28) are analyzed in conjunction with the Project statistical consultants with the ultimate objective of testing the transfer hypothesis and developing a model of agrotechnology transfer based on soil interpretation and land classification.

Standardized procedures and guidelines are followed to ascertain compatibility of results throughout the network.

The transfer hypothesis of the Benchmark Soils Project is the pivot around which all the activities operate. These fertility experiments are called "transfer" experiments because they provide the data that will be used to show that soils of the same family have similar management needs. This is formally called "the test of the hypothesis of transferability of agrotechnology among soils of the same family."

The ultimate objective is developing a model of agrotechnology transfer based on soil interpretation and land classification.

There are a number of ways to test the transfer hypothesis. The approach taken by the Benchmark Soils Project is schematically shown in Fig. 5. The transfer function generated from experimental data obtained at one site is used to predict outcomes at other sites.

The test of the hypothesis requires careful selection of both sites and experimental variables.

The test requires that a test crop be grown under similar management conditions on the same soil family in a network of sites in the tropics. Because members of a soil family are not identical but similar within a range of characteristics, the outcomes should be expected to vary within a similar narrow range.

The soil constraints place a ceiling on the outcome but, for most soils, this ceiling is attained only under normal weather conditions and proper management. The ceiling is the soil potential. Under normal weather conditions, the input-output relationship should be similar for members of a soil family. But since normal weather cannot be guaranteed, weather parameters must be monitored and included as uncontrolled variables in the transfer function.

The test of the hypothesis requires the selection of sites on which to conduct the experiments and the selection of experimental variables. These are discussed in the following sections, and a summary of results is also included.

Soil samples were collected from various parts of the upland areas surrounding Davao, the Philippines, to locate a suitable site for establishing field plots for the transfer experiments on Typic Paleudults.

ESTABLISHMENT OF THE BENCHMARK SOILS NETWORK

Project personnel had long experience with the Hydric Dystrandepts.

Three soil families from upland areas that have the potential to be productive under necessary management practices were selected to test the hypothesis (Table 1). The locations of the soil network are shown in Table 2 and Fig. 6, and the linkage of the different countries in the network is shown in Fig. 7.

The first family selected was the thixotropic, isothermic Hydric Dystrandepts, because this soil is easy to locate and the Project personnel had long experience with its management. The second family, clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox, occurs in Puerto Rico and Hawaii and was selected to foster closer linkage between the Puerto Rico

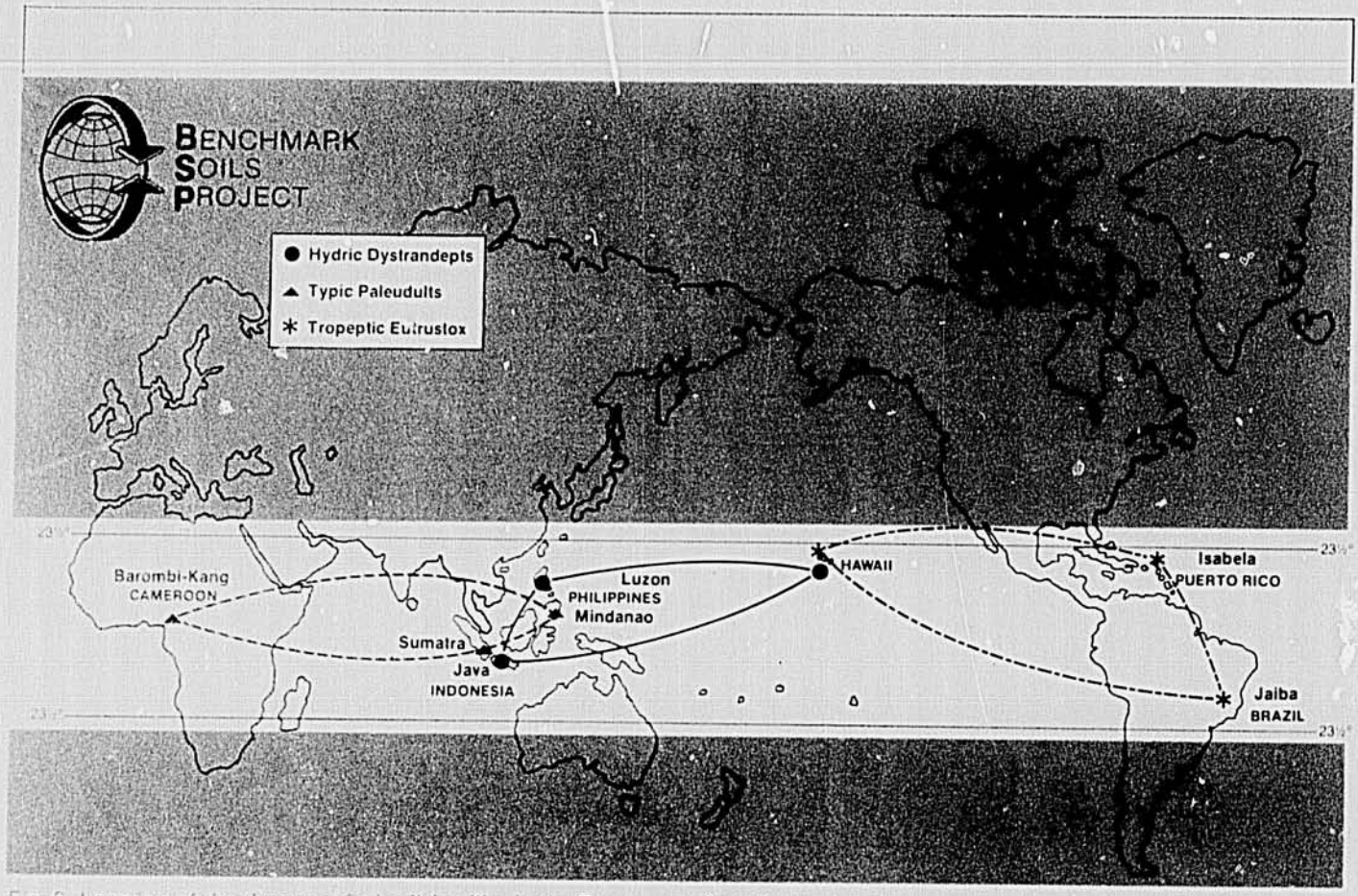


Fig. 6. Location of the three tropical soil families in the Benchmark Soils Project.

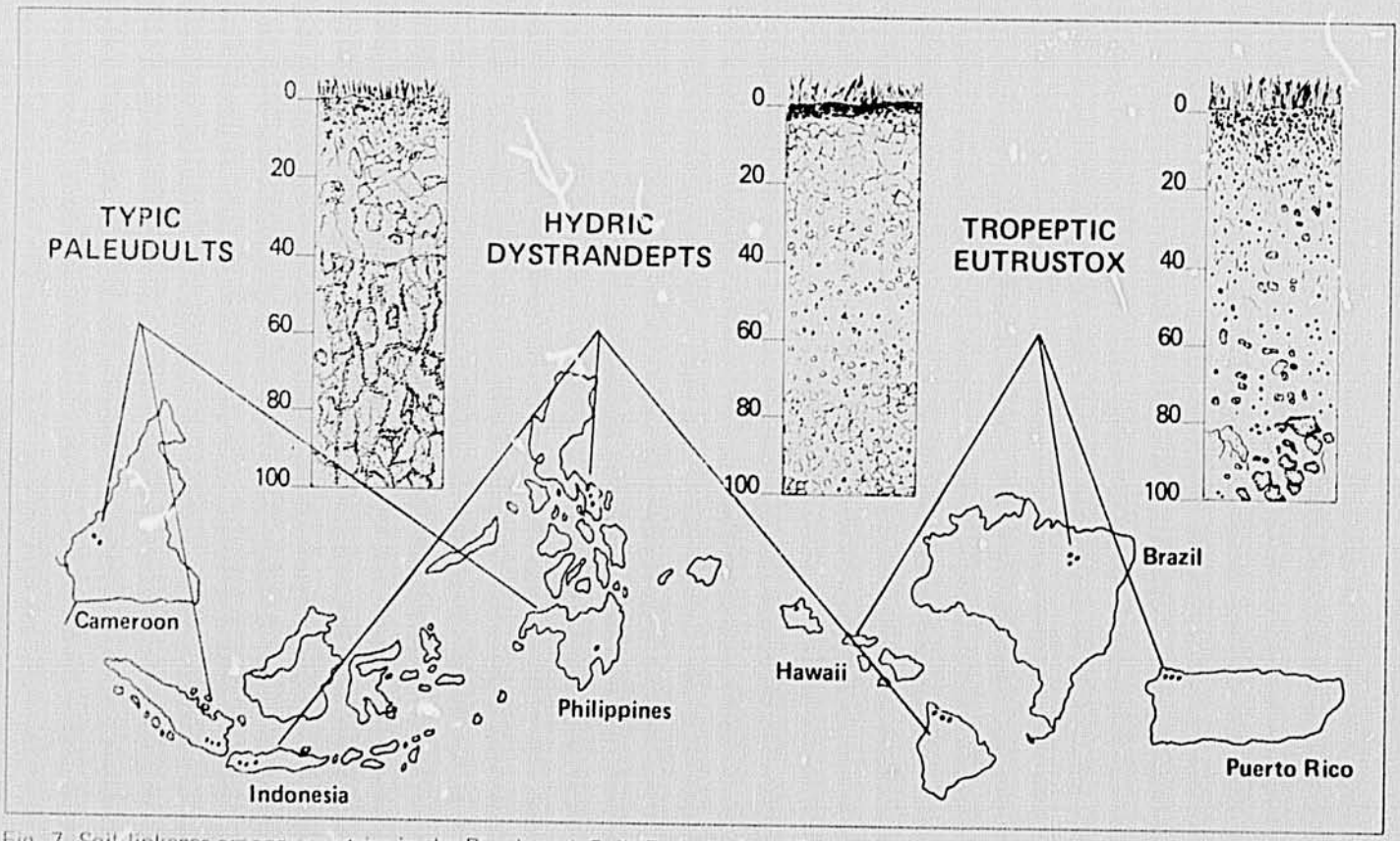


Fig. 7. Soil linkages among countries in the Benchmark Soils Project. As of December 1977, 15 sites are operational. The remaining 9 sites are expected to be operating by the end of 1978.

Hydric Dystrandepts/Iole, Island of Hawaii | Tropeptic Eutrustox/ Isabela, Puerto Rico | Typic Paleudults/Barombi-Kang, Cameroon

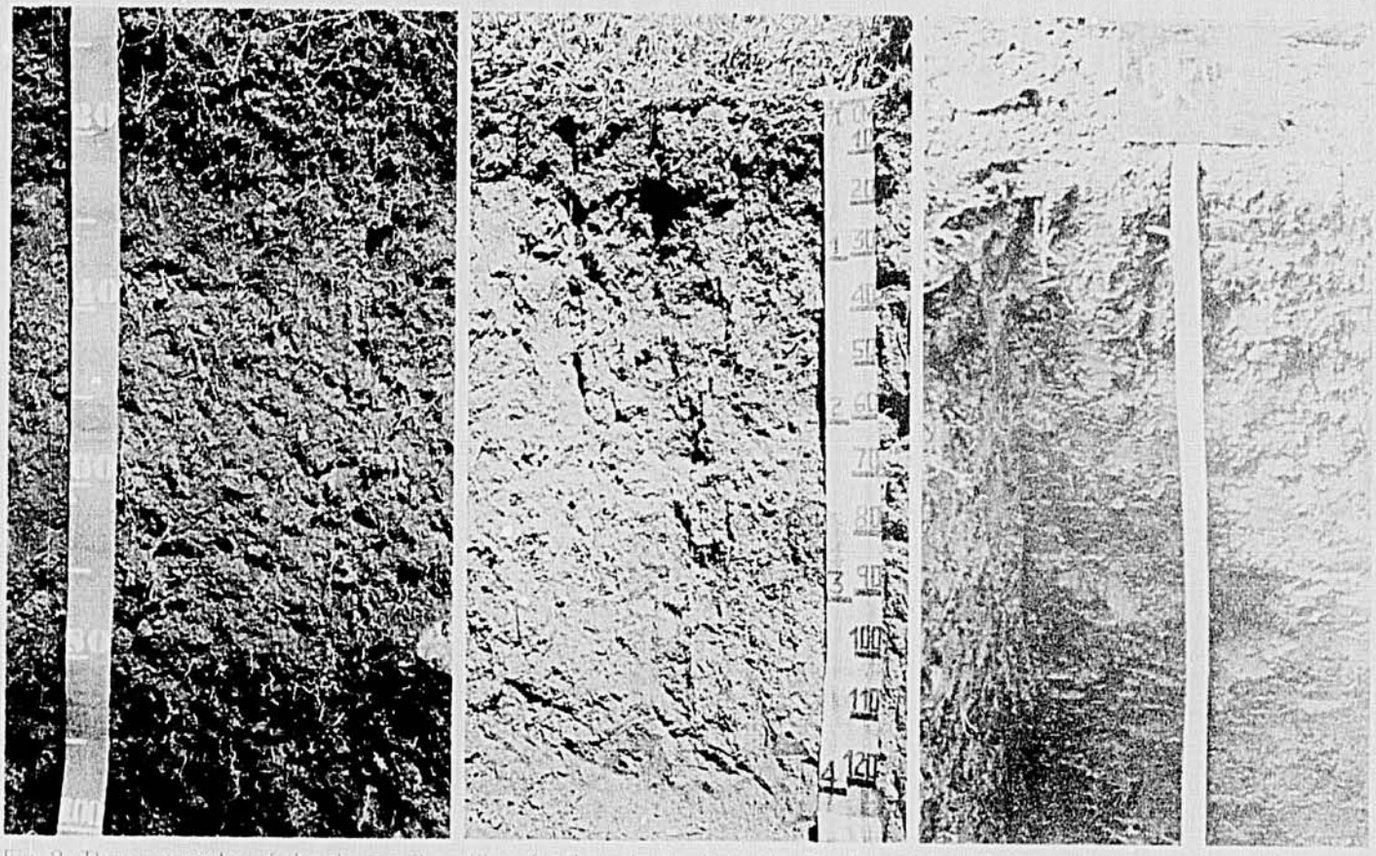


Fig. 8. These examples of the three soil profiles of soils under study by the Benchmark Soils Project are representative of the three soil families, but each soil profile within a family differs in part from the others.

Table 1. Classification of soils in the Benchmark Soils Project[a]

Soil Taxonomy taxa	Soil family A	Soil family B	Soil Family C
Order	Inceptisols	Oxisols	Ultisols
Suborder	Andepts	Ustox	Udults
Great Group	Dystrandepts	Eutrustox	Paleudults
Subgroup	Hydric Dystrandepts	Tropeptic Eutrustox	Typic Paleudults
Family	thixotropic, isothermic	clayey, kaolinitic, isohyperthermic	clayey, kaolinitic, isohyperthermic

[a]Based on *Soil Taxonomy* (Soil Survey Staff, 1975).

Table 2. Location of the network of the three soil families

Soil family	Location
Thixotropic, isothermic Hydric Dystrandepts	1. Island of Hawaii, U.S.A. 2. Luzon, the Philippines 3. Java, Indonesia
Clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox	1. Isabela, Puerto Rico 2. Minas Gerais, Brazil 3. Island of Molokai, Hawaii, U.S.A. 4. Island of Oahu, Hawaii, U.S.A.
Clayey, kaolinitic, isohyperthermic Typic Paleudults	1. Mindanao, the Philippines 2. Sumatra, Indonesia 3. Barombi-Kang, Cameroon

and Hawaii Benchmark projects. The third family, clayey, kaolinitic, isohyperthermic Typic Paleudults, as included at the request of the host countries because it is an important, underutilized soil in the tropics.

Selection of Sites

The selection of the Benchmark Soils Project sites was preceded by a search of existing soil survey data (soil survey reports including laboratory data and maps). Various individuals were also contacted to obtain information before actual field work was implemented. In Hawaii, for example, published soil surveys (Foote et al., 1972; Sato et al., 1973) were used to determine the areas of interest, and an on-site investigation was then made of a particular area. Auger-sampling and laboratory characterization of the soil samples preceded pit-sampling, profile description, and further laboratory characterization. Soil geomorphic relationships were also used to predict the occurrence of a particular soil in a landscape.

The soil-geomorphic relationships were used extensively in locating sites in the Philippines, Indonesia, and Cameroon where soil survey data were unavailable or, if available, of limited nature.

Soil-geomorphic relationships were used to predict the occurrence of a particular soil in a landscape.

For sites outside Hawaii, arrangements were made with appropriate government and research institutions to obtain the help of in-country soil scientists. Working with these soil scientists, the Hawaii personnel or the Hawaii-hired soil consultant evaluated several possible sites for the Project experiments by examining the necessary requisites of a site. Some of these requirements were availability of water, adequate space, nearness to other experimental facilities, and so on. In nearly every situation, soil pits were dug (Fig. 8) and the soils were described and sampled for laboratory characterization and classification according to *Soil Taxonomy* (Soil Survey Staff, 1975).

The sequence of events required to establish a soil family network is shown in Fig. 9.

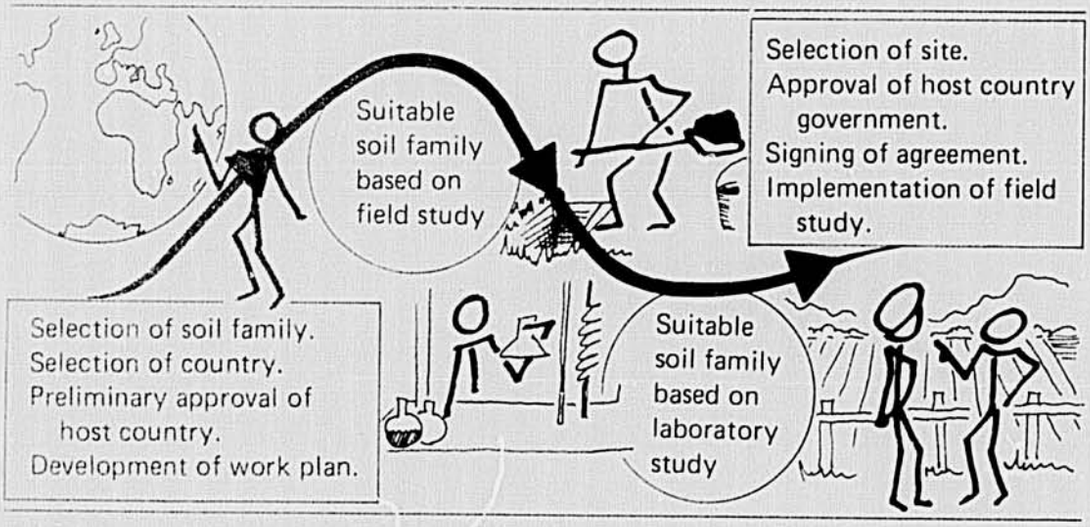


Fig. 9. Sequence of events to establish a soil family network.

Characteristics of the Benchmark Soils

Profile descriptions and laboratory data for the soils at each site (14 soil profiles representing 23 sites) have been collected and compiled by Project personnel and are presented in Tech. Rep. 1 (Ikawa et al., 1978). A summary of the general characteristics of the three soil families under study by the Benchmark Soils Project is found in Tables 3 and 4. Table 3 provides a summary of the inferences from the nomenclature of *Soil Taxonomy* for soil and crop management of the three families in the Benchmark Soils Project. The extent with which these inferences can be made from the taxonomic names is limited, however, by the availability of accessory information associated with each term. In Table

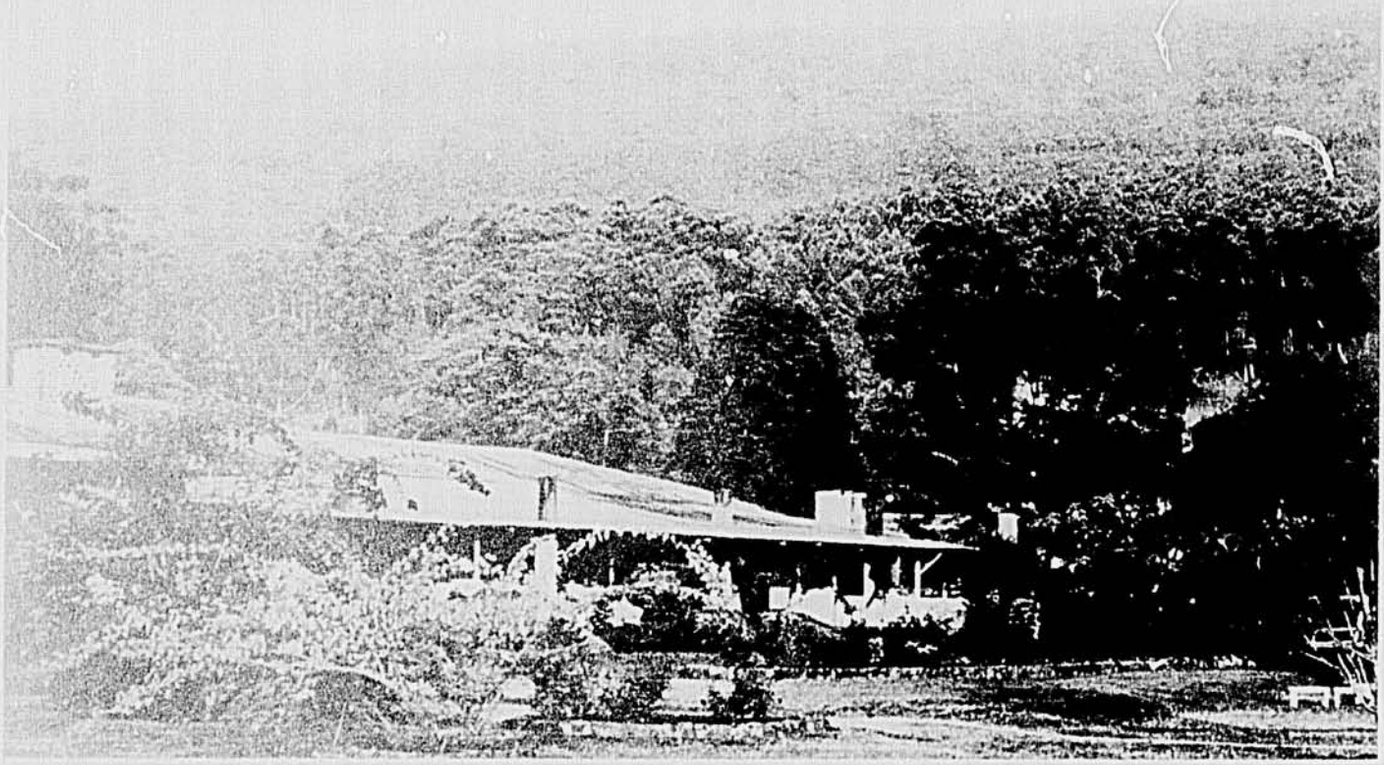
Table 3. Properties of the soil families in the Benchmark Soils Project network, their relationship to the soil family names, and the inferences for management practices

Taxonomic name	Inherent soil family characteristics	Management considerations
Thixotropic, isothermic Hydric Dystrandepts		
thixotropic	High surface activity of colloids.	High amounts of phosphorus must be added.
isothermic	Cool soil temperatures (15–22°C).	Crops must be suited to cool climate.
Hydric	Moist humid soils.	No irrigation or only supplemental irrigation required.
Dystr-	Low base saturation (≤ 35%).	High fertilizer input required; lime application required in some cases.
-andept	Low bulk density (≤ 0.85 g/cm^3).	Low power requirement for tillage; good drainage and infiltration characteristics.
Clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox		
clayey	More than 35% clay.	High power requirement for tillage.
kaolinitic	Inert to low active clay.	Low amounts of physical manipulation required.
isohyperthermic	Warm soil temperatures (> 22°C).	Crops must be suited to warm climate.
Tropeptic	Moderate to strong structure.	Good drainage and infiltration characteristics.
Eutr-	Enriched with nutrients; base saturation ≥ 50%.	Low to moderate amounts of fertilizer required.
-ust-	Pronounced dry season.	Irrigation required for crop growth during the dry season.
-ox	Low nutrient retention; low cation-exchange capacity.	More frequent application of fertilizer required.
Clayey, kaolinitic, isohyperthermic Typic Paleudults		
clayey	Clayey subsoil	Good subsoil water-holding capacity; subsoiling may be required.
kaolinitic	Inert to low active clay.	Less subsoil manipulation required.
isohyperthermic	Warm soil temperatures (> 22°C).	Crops must be suited to warm climate.
Typic	Typical or central concept.	Connotes standard management practices.
Pale-	Deep old soils with low nutrient supply.	Moderate to high fertilizer input generally required.
-ud-	Humid soils.	Only supplemental irrigation required.
-ult	Low base saturation (≤ 35%).	Likelihood of soil acidity; lime probably required.

The transfer of agrotechnology does not always mean using expensive equipment and chemical fertilizers.

item number 5, in particular, illustrates the characteristics that differ from family to family.

Within the same family of a soil, as in any population, there is a range in the general characteristics, but the range that was encountered upon on-site inspection by Project personnel, although acceptable within the family, was wider than expected. A summary of the ranges in characteristics of the three soil families is shown in Tables 5, 6, and 7.



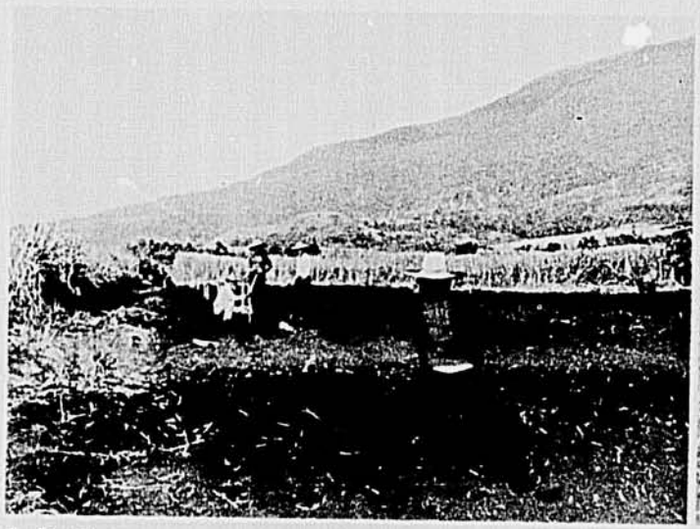
Cameroon, near Buea, Cameroon, one of the highest mountains in West Africa, is a source of the parent material for the Dystrandepts and Hydrandepts, both volcanic ash soils.

Table 4. Summary of the general characteristics of the Benchmark Project soils

Hydric Dystrandepts	Tropeptic Eutrustox	Typic Paleudults
1. Cambic horizon. 2. Udic moisture regime generally.	1. Oxic horizon. 2. Ustic moisture regime.	1. Argillic horizon. 2. Udic moisture regime.
3. Bulk density (at 1/3-bar water retention) of fine-earth fraction of soil is less than 0.85 g/cc and exchange complex is dominated by amorphous material (thixotropic in some horizon) *and/or* vitric volcanic ash, cinders, or other vitric pyroclastic material (by weight) is 60 percent or more of soil.	3. Cation-exchange capacity (by NH_4-OAc) is 16 meq or less/100 g clay. Cation retention from NH_4Cl is 1.5 meq/100 g clay (or over 1.5 meq of extractable bases plus extractable aluminum per 100 g clay) in oxic horizon. Oxic horizon does not extend to a depth of 1.25 m below soil surface and/or structure is at least moderate in grade.	3. Weatherable minerals are less than 10 percent in the 20- to 200-micron fraction of upper 50 cm of argillic horizon. Clay distribution decrease is not more than 20 percent of the maximum within 1.5 m of soil surface.
4. Organic carbon is in large amount.	4. Organic carbon is less than 16 kg/surface cubic meter of soil.	4. Organic carbon is less than 0.9 percent in the upper 15 cm of argillic horizon or less than 12 kg/surface cubic meter of soil.
5. Base saturation is less than 50 percent (by NH_4OAc) in all subhorizons between depths of 25 and 75 cm.	5. Base saturation is 50 percent or more (by NH_4OAc).	5. Base saturation is less than 35 percent at 1.25 m below upper boundary of argillic horizon or 1.8 m below soil surface.

Table 5. Summary of the range in characteristics of the Hydric Dystrandepts

Hawaii	Philippines	Indonesia
1. Surface horizons are dark brown (7.5YR 3/2), B2 horizons range from dark reddish brown (5YR 3/2, 3/3, 3/4) to brown and dark brown (7.5YR 4/4).	1. Surface horizons are black (N 2/ , 10YR 2/1) and very dark grayish brown (10YR 3/2); B2 horizons are very dark grayish brown (10YR 3/2) and dark yellowish brown (10YR 3/3, 3/6, 4/4, 4/6).	1. Surface horizons are dark brown (7.5YR 3/2) and very dark grayish brown (10YR 2/2). B2 horizons range from dark brown to brown (7.5YR 3/2, 4/4, 10YR 3/3) to dark yellowish brown (10YR 3/4) with a horizon that can be black (10YR 2/1) and very dark brown (10YR 2/2).
2. Organic carbon ranges from 3.5 to 7 percent.	2. Organic carbon ranges from 2 to 13 percent decreasing with depth.	2. Organic carbon ranges from 4 to 9 percent in one pedon and from 3 to 10 percent in another.
3. Extractable calcium ranges from less than 0.5 to 1 meq (except for the surface which is 8 meq) for one pedon and from 2 to 6 meq in the other.	3. Extractable calcium is 4 to 8 meq.	3. Extractable calcium is less than 6 meq in the surface but ranges from 6 to 22 meq in the subsoil.
4. Base saturation is less than 2 percent (except for the surface) for one pedon and ranges from 2 to 8 in the other.	4. Base saturation is approximately 10 to 20 percent.	4. Base saturation ranges from 10 to 30 percent with variations in the surface horizon.
5. Depth of surface soil is less than 25 cm.	5. Depth of surface soil is 40 to 60 cm.	5. Depth of surface soil is 15 to 30 cm.
6. Layerings attributed to several ash deposits are apparent.	6. Layerings are not apparent.	6. Layerings are not apparent.



Left: Project personnel at Naga, the Philippines, established the site and began laying out the rigid plot design for the transfer experiments on the Hydric Dystrandepts. **Right:** Six months later, the maize seedlings of the transfer experiments began to emerge, illustrating the treatment differences.

Table 6. Summary of the range in characteristics of the Tropeptic Eutrustox

Hawaii	Puerto Rico
1. Surface horizon is dark reddish brown (2.5YR 2.5/4, 3/4), B2 horizons are either dusky red (10R 3/3) or dark reddish brown (2.5YR 2.5/4, 3/4).	1. Surface horizon is dark brown (7.5YR 4/4). B2 horizons are reddish brown (5YR 4/4) to yellowish red (5YR 4/8) to strong brown (7.5YR 5/8) in the lowest horizons.
2. Soil is derived from basalt.	2. Soil is overlying limestone and quartzitic sands.
3. Cation exchange capacity of oxic horizon is slightly less than 16 meq/100 g clay.	3. Cation exchange capacity of oxic horizon is 5 to 9 meq/100 g clay.
4. Extractable calcium in the oxic horizon is 3 to 6 meq and extractable magnesium is 1 to 4 meq.	4. Extractable calcium in the oxic horizon is 1 to 2 meq and extractable magnesium is less than 1 meq.
5. Base saturation is slightly over 50 percent in the major portion of the oxic horizon; sum of bases is 6 to 9 meq.	5. Base saturation is slightly over 50 percent in the major portion of the oxic horizon; sum of bases is 2 to 3 meq.

Table 7. Summary of the range in characteristics of the Typic Paleudults

Philippines	Cameroon	Indonesia
1. Surface horizon is black (5YR 2.5/1), B2 horizons are dark reddish brown (5YR 3/2, 3/3) and reddish brown (5YR 4/4).	1. Surface horizons are dark brown to brown (10YR 4/3) to dark yellowish brown (10YR 4/4); B2 horizons are yellowish brown (10YR 5/5).	1. Surface horizons of 3 pedons are dark reddish brown (5YR 3/2), dark brown to brown (7.5YR 4/2), and dark grayish brown (10YR 4/2), respectively; B2 horizons with increasing depth are reddish brown (5YR 4/4), yellowish red (5YR 4/6), and dark red (2.5YR 3/6) for one pedon; yellowish red (5YR 4/6), dark yellowish brown (10YR 4/6), and red (2.5YR 4/6) for the second pedon; and strong brown (7.5YR 4/6) and yellowish brown (10YR 5/6) and yellowish red (5YR 4/6) for the third pedon.
2. Cation exchange capacity of the subsoil ranges from 17 to 21 meq/100 g of soil.	2. Cation exchange capacity of the subsoil ranges from 11 to 17 meq/100 g of soil.	2. Cation exchange capacity of the subsoil ranges from 7 to 12 meq/100 g of soil.
3. Sum of bases of the subsoil ranges from 4.5 to 6.5 meq.	3. Sum of bases ranges from 1.7 to 3.7 meq.	3. Sum of bases is less than 2 meq, in most cases being less than 1 meq.
4. Base saturation ranges from 27 to 31 percent.	4. Base saturation ranges from 16 to 24 percent.	4. Base saturation ranges from 4 to 16 percent.
5. Extractable aluminum ranges from 3 to 4 meq.	5. Extractable aluminum is less than 0.2 meq.	5. Extractable aluminum ranges from 1 to 4 meq.

SELECTION OF THE EXPERIMENTAL VARIABLES

The experimental variables were selected by the Benchmark Soils Project to test the transfer hypothesis because they are (1) controllable, (2) important to the test plant—in this case, maize, and (3) key features of the soil families under study. Uncontrolled variables are also being monitored to explain the site-to-site differences that may be encountered and to confirm the climatic regimes of the three soil families. All of these data are essential for describing the potential crop performance at the various sites.

The treatment design is the 5^2 partial factorial modification by Escobar (Fig. 10), as described in a paper by Laird and Turrent (in press) and presented at the Workshop on Experimental Design in Hawaii in 1974.

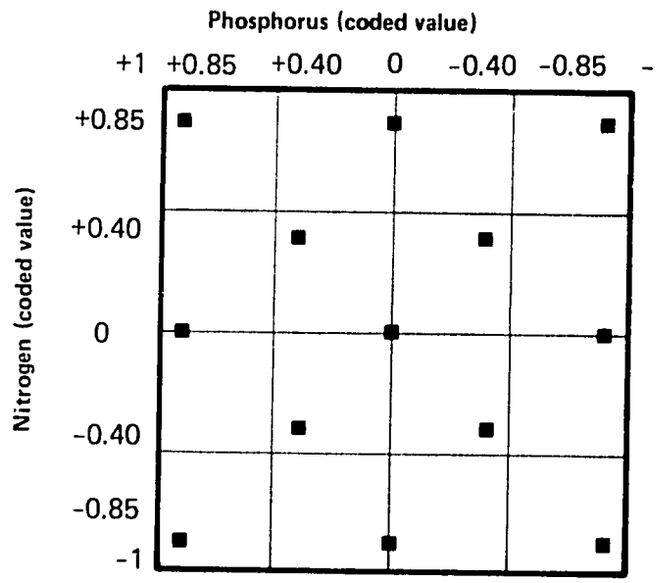


Fig. 10. Treatment design for 5^2 partial factorial modification by Escobar used for the two-factor transfer experiments.

To keep the transfer experiments manageable, and yet obtain sufficient information, 5 levels of each of two variables were combined to give 13 of the 25 possible treatment combinations (Table 8). The same treatment combinations are used for all three families, but the rates used differ among families according to the different levels of these nutrients in the different soils. These treatments are replicated at least 3 times. The experiments have been

designed so that all other controllable factors —such as irrigation, other nutrients, plant protection, and plant density—are maintained near optimum levels so that treatment effects are clear. Both maize and soybeans were used as test crops in the early transfer experiments, but maize is the only crop now being tested since nitrogen, one of the variables used in all transfer experiments, does not constitute a test variable for soybeans. (The legume soybeans fix nitrogen symbiotically.) Varieties initially known to be well adapted are planted in the transfer experiments at each location.

These experiments are called "transfer" experiments because they will provide the data that will be used to show that soils of the same family have similar management needs.

Table 8. Treatments used in transfer experiments (coded values)

Treatment	Phosphorus	Lime or Potassium[a]
A	-0.85	-0.85
B	-0.85	+0.85
C	+0.85	-0.85
D	+0.85	+0.85
E	-0.40	-0.40
F	-0.40	+0.40
G	+0.40	-0.40
H	+0.40	+0.40
J	0[b]	0
K	-0.85	0
L	+0.85	0
M	0	-0.85
N	0	+0.85
O	Complete control[c]	–
P	Partial control[c]	–

[a] Lime was used for the Hydric Dystrandepts, and potassium was used for the Tropeptic Eutrustox.
[b] 0 = optimum treatment.
[c] O = no fertilizer applied; P = no treatment variables applied but given blanket application of macro- and micronutrients.

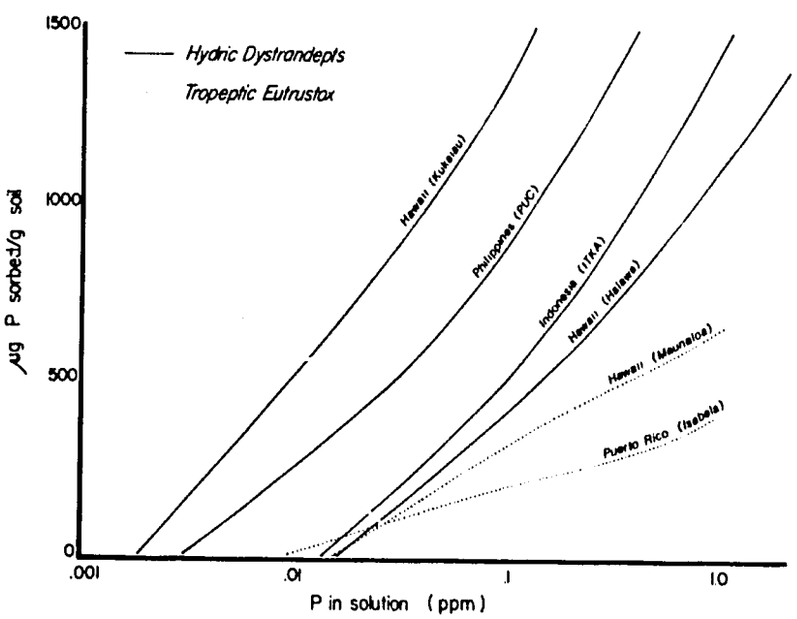


Fig. 11. The steeper slopes of the phosphorus-sorption curves in the Hydric Dystrandepts mean they require more phosphorus fertilizer than the Tropeptic Eutrustox.

Controlled Variables

The variables used in the first set of experiments in 1975–1977 were phosphorus and lime for the Dystrandepts and phosphorus and potassium for the Eutrustox. These variables are associated with the soil family properties of these soils. The controlled variables were recently changed to phosphorus and nitrogen because it was found that the Dystrandepts do not require lime and the Eutrustox contained adequate potassium for several years. Also nitrogen is frequently limiting in tropical soils.

Soil Phosphorus

The nutrient element phosphorus (P) was judged to be an important limiting factor to crop yields from analysis of technical information contained in the soil family name. (The mineral constituents of each soil family determine the ability of the soils to "fix" phosphorus [see pages 18–19].)

In the thixotropic, isothermic family of Hydric Dystrandepts, for example, the word "thixotropic" connotes a high capacity to adsorb and immobilize fertilizer phosphorus. Thixotropic soil materials possess a large surface area per unit of weight, and each unit area of surface has a high affinity for phosphorus. Phosphorus was also selected as an experimental variable in the clayey, kaolinitic, isohyperthermic family of Tropeptic Eutrustox and the clayey, kaolinitic, isohyperthermic family of Typic Paleudults. In both these families, the large mineral surface area for immobilizing phosphorus is indicated by the family designation "clayey." Clayey, or finely divided, particles possess large surface areas, and the affinity of such an extensive surface for phosphorus is implied by the suffixes *ox* in Eutrust*ox* and *ult* in Paleud*ult*. The iron and aluminum oxides in Eutrustox and the high

soil acidity of Paleudults (ultimate soils) contribute to immobilization of fertilizer phosphorus.

Fig. 11 shows the range of phosphorus-sorption capacities found among four experimental sites. Although the general shape (slope) of all four curves is similar, the curve to the left has the highest phosphorus-sorption capacity, while the curves to the right have successively lower phosphorus-sorption capacities. The lower sorption-capacity soils had either high amounts of native phosphorus or the addition of phosphorus fertilizers in the past.

The high capacity of Hydric Dystrandept soils to sorb phosphorus means that much larger applications of phosphorus are required to achieve the particular level of phosphorus in solution required for maximum yield (see pages 31–38).

Soil Acidity and Liming

Lime was selected as the second experimental variable because soil acidity is an important cause of low crop yield throughout the world. The most common way to correct soil acidity is to apply lime.

In soils of the temperate regions, lime is usually applied when a soil pH value of about 5.5 is attained; this is the point below which aluminum (Al), which is toxic to plants, is solubilized in sufficient amounts to seriously affect crop yield. Thus, people trained in the temperate regions normally recommend lime application when the soil pH nears 5.5.

The Project found, however, that in the Hydric Dystrandepts, even though the soil pH is lower than 5.5, because of the low amounts of extractable aluminum and correspondingly higher amounts of calcium (Ca), lime treatments had no effect on yields of maize. In fact, some experiments even showed a decrease in yield with the highest rates of lime application (see pages 34–38 for details). Thus, the Project effectively demonstrated that the existing expensive practice of liming acid tropical soils to obtain good crop response does not necessarily apply to soils of the Hydric Dystrandept network and this information can be transferred to similar soils of the Andept subgroup.

Therefore, the Project has dropped lime as an experimental variable as of December 1977.

Table 9 shows the relatively low amounts of exchangeable aluminum and low aluminum

Table 9. Exchangeable calcium and aluminum of selected surface horizons in the Hydric Dystrandept network

Site	H_2O (pH)	KCl (pH)	Extractable aluminum (meq/100 g)	Exchangeable calcium (meq/100 g)
Hawaii				
Iole	6.91	4.90	0.02	7.93
Kukaiau	6.00	5.45	< 0.01	2.53
Philippines				
PUC	5.40	4.50	1.29	3.84
Palestina	4.60	4.50	1.16	5.25
Burabod	4.80	4.40	2.10	3.54
Indonesia				
ITKA	4.20	3.90	1.53	2.10
PLP	5.00	4.60	0.11	3.80
LPH	5.70	5.10	0.03	6.00

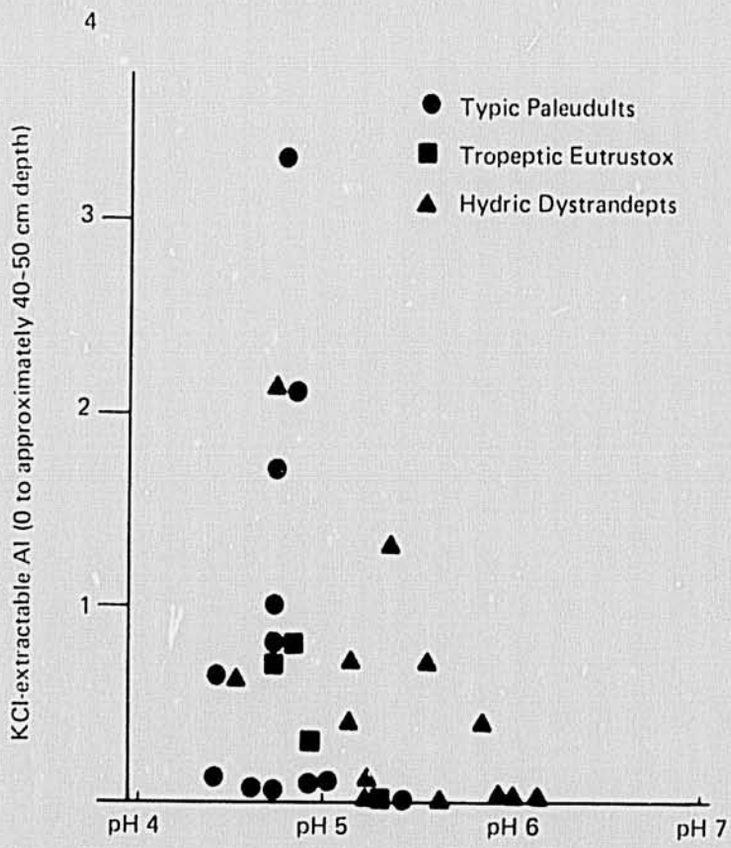


Fig. 12. There is a marked increase in KCl extractable aluminum as the pH falls below 5.5, but low Al values can still occur below pH 5.0. As a general rule, 1000 pounds of lime are needed to neutralize 1 meq of toxic aluminum.

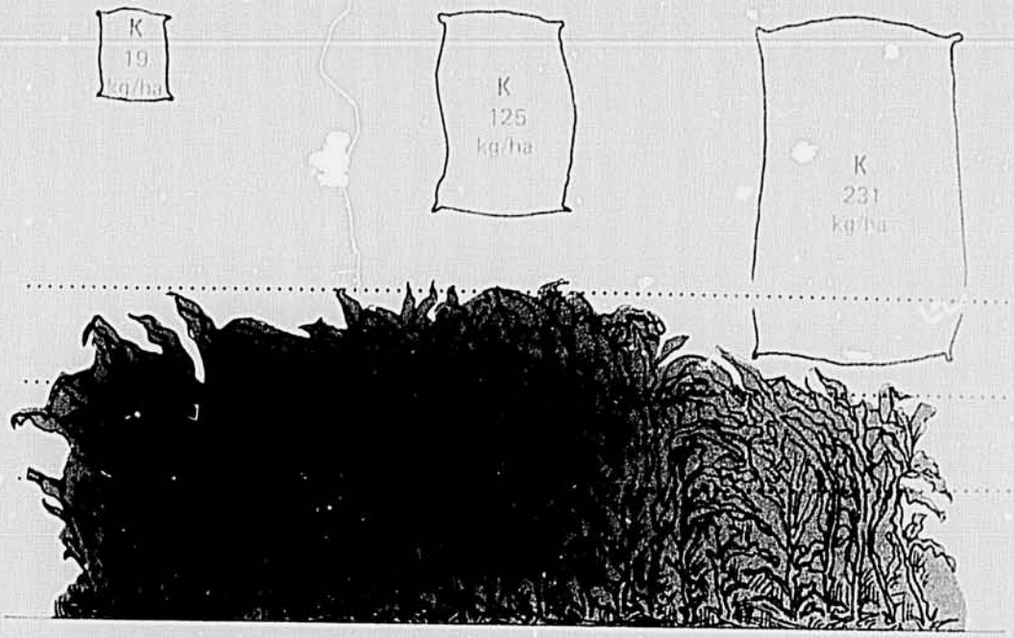
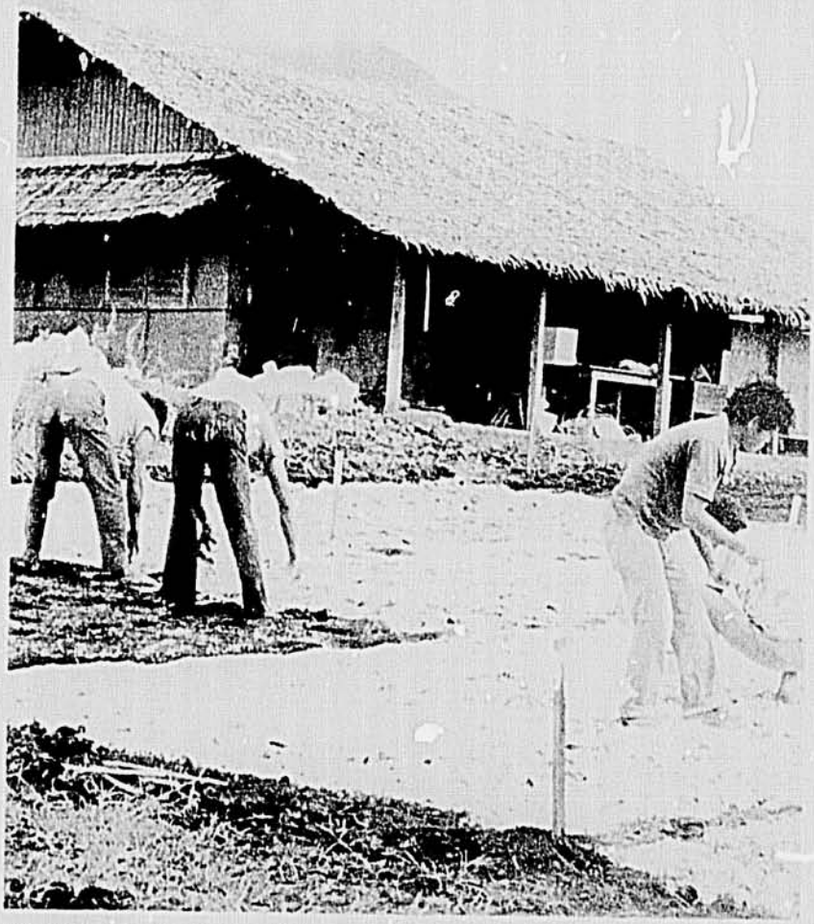


Fig. 13. As the level of potassium applied to soils of the Tropeptic Eutrustox increased, the yield did not increase; in fact, with the highest level of potassium applied, the yield decreased.



Superphosphate, at five different rates, was applied in 1976 at PUC, the Philippines, on the Hydric Dystrandepts in accordance with the transfer experimental design. The Project is not necessarily recommending such high application levels.

saturation and the high amounts of exchangeable calcium that were found to occur in soils of the Hydric Dystrandept network. Fig. 12 illustrates the relationship between KCl-extractable aluminum in reference to soil pH in the three soil families.

Soil Potassium

The Project found (see pages 38–39) that maize and soybeans planted on soils in Puerto Rico and Brazil (the Tropeptic Eutrustox network) generally did not respond to potassium (K) applications (Fig. 13). The Eutrustox soils have limited quantities of potassium-containing minerals that are expected to be depleted with continuous cropping. It did not appear this would happen during the life of the Project. Consequently, nitrogen (N) was substituted for potassium in the next series of experiments. This result parallels the findings in the lime experiments.

Soil Nitrogen

Since soil nitrogen is rapidly depleted in tropical soils when the land is cleared and continuously cropped, nitrogen is often the most limiting nutrient to crop growth. Nitrogen is also important in the nitrogen × phosphorus interaction that affects crop yields. The decision to include nitrogen as a variable resulted in the Project dropping soybeans as a test crop because they normally fix the nitrogen needed for growth.

Uncontrolled Variables

Weather variables, disease incidence, and crop variety adaptions are not reflected in the soil family names, although predictions for crop response need to incorporate these data; therefore, weather variables are measured at each experimental site. In addition, temperature, rainfall, relative humidity, solar radiation, wind direction, and wind speed are measured at each experimental site. In addition, insect and disease incidence and crop variety are being identified and rated within each soil family and compared between soil families.

Weather

Because climate is an uncontrolled variable, it is essential that significant climatic variables be measured at each experimental site so that their relationships to yield responses and therefore to the transfer of agrotechnology are clear. Air and soil temperature, relative humidity, solar radiation, wind speed, wind direction, and rainfall, are monitored at each site; pan evaporation is also measured at selected sites.

Solar Radiation

As the most important single energy source for plants to manufacture food through photosynthesis, solar radiation provides an index of the photosynthetic potential of a given site.

In general, the Tropeptic Eutrustox (Fig. 14) have higher ranges of solar radiation than the Hydric Dystrandepts (Fig. 15); therefore, grain yields are expected to be higher overall in the Tropeptic Eutrustox network. This is expected because the higher rainfall in the Hydric Dystrandepts implies more cloud cover, which intercepts incoming solar radiation for crop growth. Solar radiation is thus being measured at all sites.

Temperature and Relative Humidity

Trends in crop yields at different sites (pages 29-39) and in different soil families may be related, in part, to differences in maximum and minimum air temperatures (Figs. 16, 17) and the corresponding maximum and minimum relative humidity (Figs. 18, 19). On a

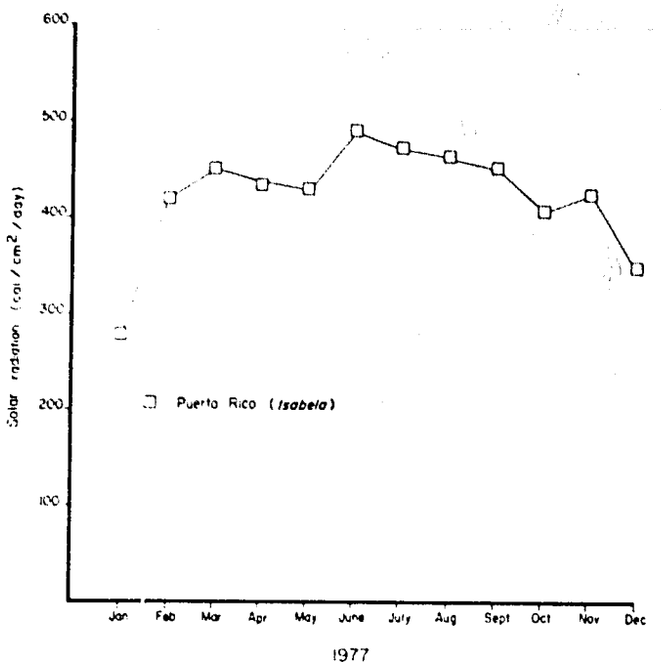


Fig. 14. The average monthly solar radiation was generally higher in the Tropeptic Eutrustox than in the Hydric Dystrandepts (compare Fig. 15).

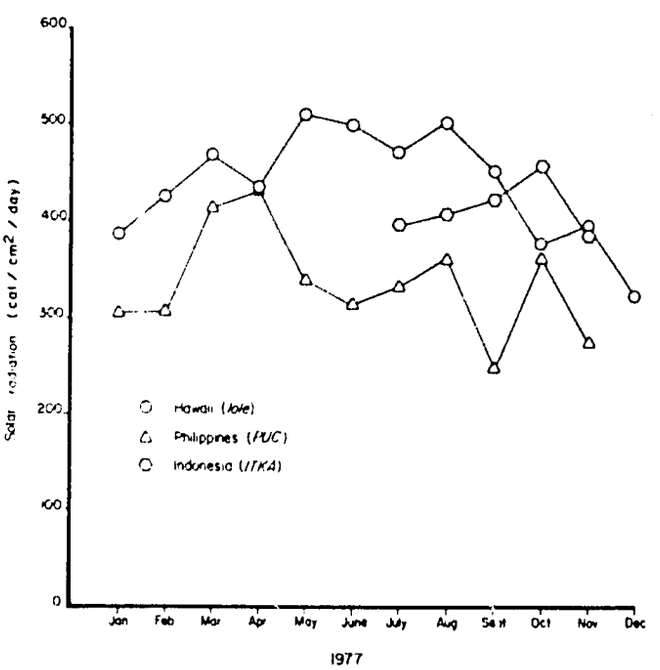


Fig. 15. In the Hydric Dystrandepts, the average monthly solar radiation has dipped as low as 250 cal/cm²/day, which indicates the crop yields may not be as good overall as in the Tropeptic Eutrustox.

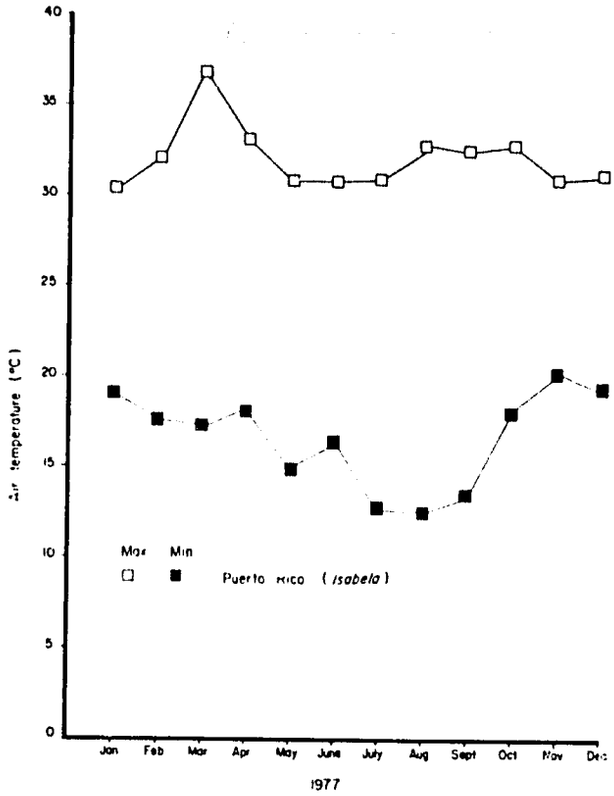


Fig. 16. Air temperatures obtained in the Tropeptic Eutrustox reflect the isohyperthermic temperature regime, which indicates that crops can be grown throughout the year with irrigation during the dry (-ust-) season.

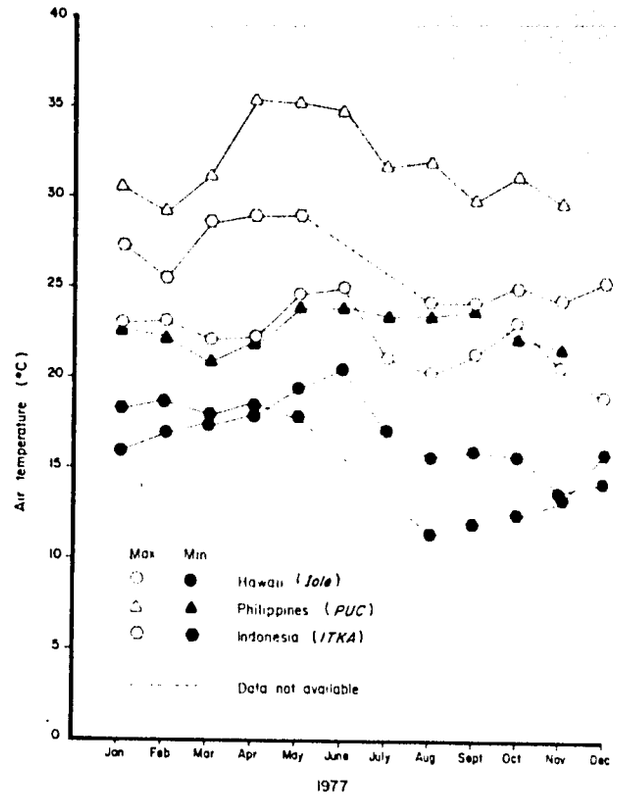


Fig. 17. For each of the Hydric Dystrandept sites, the difference between the maximum and minimum air temperature is smaller than in the Tropeptic Eutrustox site (compare Fig. 16).

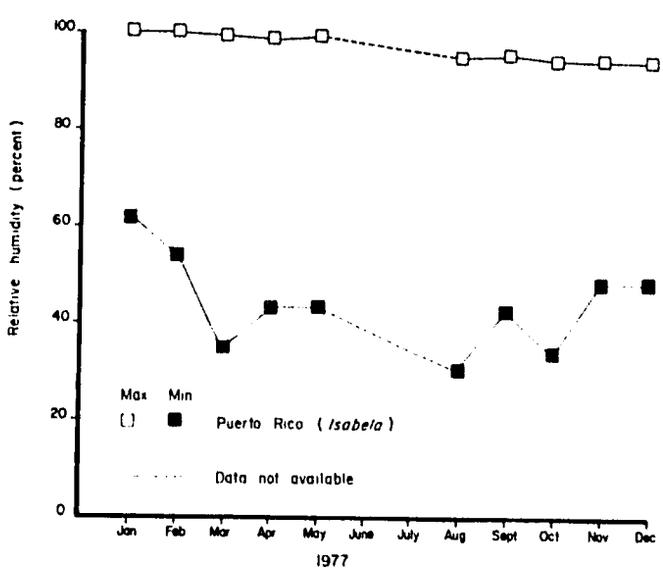


Fig. 18. The Tropeptic Eutrustox are hot and dry soils. The minimum relative humidity is generally lower than that in the Hydric Dystrandepts (compare Fig. 19).

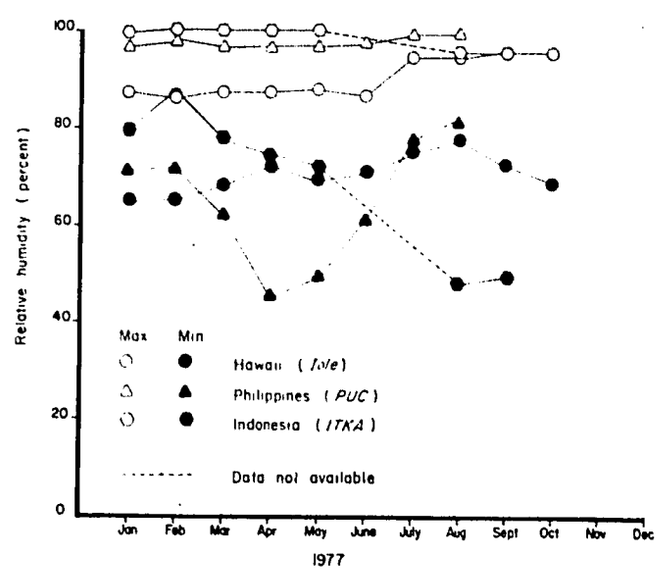


Fig. 19. The Hydric Dystrandepts are cool and wet soils.

Monitoring weather data at all sites is an integral part of the Project. This mechanical weather station at BRI, Davao, the Philippines, measures wind speed and direction, rainfall, temperature, and relative humidity.

Perhaps scale-some interpretation of crop adaptability and suitability (field potential, evaporation potential, and disease incidence can be made with a knowledge of the temperature regime of a given soil family. For instance, because of the higher maximum air temperature and solar radiation and lower minimum relative humidity at the Eutrustox sites in Puerto Rico, the Project expects higher grain yields due to the higher photosynthetic potential available. Because of the low minimum temperature, optimum conditions for dry-matter accumulation and storage in the plant itself are also expected.

Temperature and relative humidity are therefore being measured at all sites.

Wind Speed and Direction and Rainfall

Data on wind speed, air temperature, and solar radiation are being used to compute potential evaporation. This information will be useful in determining the water requirements for crops grown on sites of the three soil families. Since water is supplied to our crops at an optimum level by a drip irrigation system, rainfall is an additive component to our water budget. The influences of rainfall, wind speed and direction, and soil temperature on crop growth and development are being analyzed and compiled for presentation at a later date.

Crop Variety

Whether or not the yield potential of a particular soil is realized also depends on the crop and the variety of that crop grown. In the transfer experiments in both soil families, a variety of maize that is well adapted to the area is grown. This is done to avoid the complete loss of an experiment due to insect or disease attack on a variety that is not well adapted to that area. Another criteria used by the Project in selecting varieties for the transfer experiments is responsiveness to the

Because water is a limiting factor in growth for Tropentic Eutrustox, irrigation systems must be used. This rubber-lined reservoir was established in Jaiba, Brazil, before planting the first experimental crop.

Leaf spot disease (**above**) is a common problem in the cool, wet climate of the Hydric Dystrandepts, whereas downy mildew (**below**) is more prevalent in the warm humid climate of the tropical lowlands of the Tropeptic Eutrustox.

variables being tested, that is, phosphorus and nitrogen. Varieties are screened in experiments that have the appropriate fertilizer differentials (see pages 43–46).

Absolute yields achieved at a site depend on the variety grown. A comparison of varieties grown through each network can be made in the variety trials conducted at each primary site in both the wet and dry seasons (see pages 43–46). Variety tests with maize confirmed the environmental adaptability of a given cultivar in a given network. Yield results indicate that a universal variety for all the sites is not possible for a proper assessment of yield potential at all sites.

Disease Incidence

Although the yield potential of a particular soil is reflected in the soil family name to a great degree, the actual yields attained can be greatly influenced by diseases that can be devastating to crops. Therefore, the kind and severity of diseases are being recorded at all experimental sites.

On the Tropeptic Eutrustox sites, the Project found that soybeans were affected by anthracnose (*Colletotrichum dematium* var. truncata), which caused complete defoliation of the plants. On the Hydric Dystrandept sites, maize was affected by northern leaf spot (*Helminthosporium turcicum*), rust (*Puccinia sorghi*), and downy mildew (*Sclerospora maydis* [Rac.] Butler), and soybeans were affected by rust (*Phakopsora pachyrhizi*), *Cercospora* leaf spot, and powdery mildew (*Oidium* sp.). In some cases the diseases were contained with proper sprays so that damage was small, but in others damage was severe. Resistant varieties are being used wherever they are available.

An interesting observation that has been made on the Hydric Dystrandept sites in the Philippines and Indonesia is that although downy mildew is present in the area and susceptible varieties are being grown, no incidence of the disease has occurred in the Philippines and only minor incidence (less than 1 percent) has occurred in Indonesia. If this is substantiated in the future by additional data, this will imply that possibly the isothermic temperature regime is not favorable to the development and growth of the disease so that it is not a serious threat to maize. This would be transferable information based on the soil family.

To date, the Project has verified that accessory soil properties implied in the soil family taxonomic names are indeed inherent soil family characteristics, although these characteristics range narrowly from site to site within a family. In addition, the Project has successfully demonstrated that these soil family characteristics have specific inferences for management practices (see Table 3 and pages 18-28).

The yield responses and statistical analyses are being interpreted and evaluated; initially they suggest that agrotechnology can be transferred among various sites on soils of the same families throughout the tropical world. The results are not conclusive, however, because additional field experimentation is required for the degree of statistical certainty that is desired. With further testing, it is expected that the Project will confirm that soil management systems developed on a soil family in one region can be transferred to the same soil family in any other region.

The following list summarizes the findings to date in the test of the transfer hypothesis.

1. Soil Properties
   a. The Hydric Dystrandepts require higher applications of phosphorus than the Tropeptic Eutrustox because of both the lower sorption capacity and the relatively higher amounts of native or residual phosphorus in the latter.
   b. Nitrogen is generally limiting in tropical soils and was found to be very limiting in the two soil families under study.
   c. Experiments demonstrated that the Hydric Dystrandepts do not require lime and that the Tropeptic Eutrustox contain adequate amounts of potassium for several years. Lime and potassium are no longer being used as experimental variables.

2. Weather Variables
   a. Higher grain yields were obtained on the Tropeptic Eutrustox than on the Hydric Dystrandepts because of the higher solar radiation available in the former soil network.
   b. The Tropeptic Eutrustox also have higher average air temperatures and lower relative humidity than the Hydric Dystrandepts, resulting in more rapid crop growth.
   c. Crops grown on Tropeptic Eutrustox require irrigation whereas those grown on Hydric Dystrandepts require only supplemental irrigation.

3. Variety and Disease Incidence
   a. 'Pioneer X304' hybrids performed better than the other varieties throughout the Tropeptic Eutrustox network. To date, no single best-adapted variety has been identified for the Hydric Dystrandept network.
   b. Soybeans were found to be affected by anthracnose in the Tropeptic Eutrustox network but not in the Hydric Dystrandept network; in the Hydric Dystrandepts, but not in the Tropeptic Eutrustox, soybeans were affected by leaf spot, rust, and powdery mildew.
   c. Maize was affected by northern leaf spot, rust, and downy mildew in the Hydric Dystrandepts. Downy mildew did not occur in the Philippines and only slight incidence was found in Indonesia.

A summary of the results of the statistical test of the transfer hypothesis is found on pages 40-43.

STATUS OF FIELD EXPERIMENTATION

The network of experimental sites is shown in Table 10. The details of the numbers of experiments conducted in fiscal year 1976–1977 are presented in Table 11.

A total of 20 maize transfer and 16 soybean transfer experiments were completed on 9 Dystrandept sites, while a total of 6 maize transfer and 5 soybean transfer experiments were completed on 5 Eutrustox sites. It is expected that the full complement of experiments (2 each year on 9 sites in each network) will be carried out on the latter soil family in the coming year when the network is completed.

Table 10. Soil family network of experimental sites

Country	Location	Reference abbreviation	Site	Milestone[a] achieved
Hydric Dystrandepts–thixotropic, isothermic				
Hawaii	Niulii, Iole North Kohala, Hawaii	Iole	Primary	5
	Kukaiau Honokaa, Hawaii	KUK	Secondary	5
	Niulii, Halawa North Kohala, Hawaii	HAL	Secondary	5
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	5
	PLP Lembang, Java	PLP	Secondary	5
	Segunung Cipanas, Java	LPH	Secondary	5
Tropeptic Eutrustox–clayey, kaolinitic, isohyperthermic				
Puerto Rico	Isabela		Primary	5
	Isabela		Secondary	5
	Isabela		Secondary	2
Brazil	Paraná, Jaiba		Primary	5
	Bahia, Jaiba		Secondary	5
	Ceará, Jaiba		Secondary	5
Hawaii	Maunaloa, Molokai		Primary	2
	Waipio, Oahu		Secondary	3
Typic Paleudults–clayey, kaolinitic, isohyperthermic				
Philippines	Davao, Mindanao	BPI	Primary	3
	Davao, Mindanao		Secondary	1
Indonesia	Lampung, South Sumatra		Primary	1
Cameroon	Barombi-Kang Southwest Province		Primary	1

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

Table 11. Experiments completed through December 1977

Country	Crop	Transfer experiments	Variety experiments	Management experiments
Hydric Dystrandepts				
Hawaii	maize	9	1	1
	soybeans	6	1	–
Indonesia	maize	6	1	1
	soybeans	5	1	–
	Irish potatoes	–	–	2
Philippines	maize	5	2	4
	soybeans	5	2	2
	sorghum	–	–	2
Totals	maize	20	4	6
	soybeans	16	4	2
	Irish potatoes	–	–	2
	sorghum	–	–	2
Troceptic Eutrustox				
Brazil	maize	2	1	3
	soybeans	1	1	–
Puerto Rico	maize	4	3	1
	soybeans	4	–	2
Totals	maize	6	4	4
	soybeans	5	1	2

SUMMARY OF YIELD RESPONSES: TRANSFER EXPERIMENTS

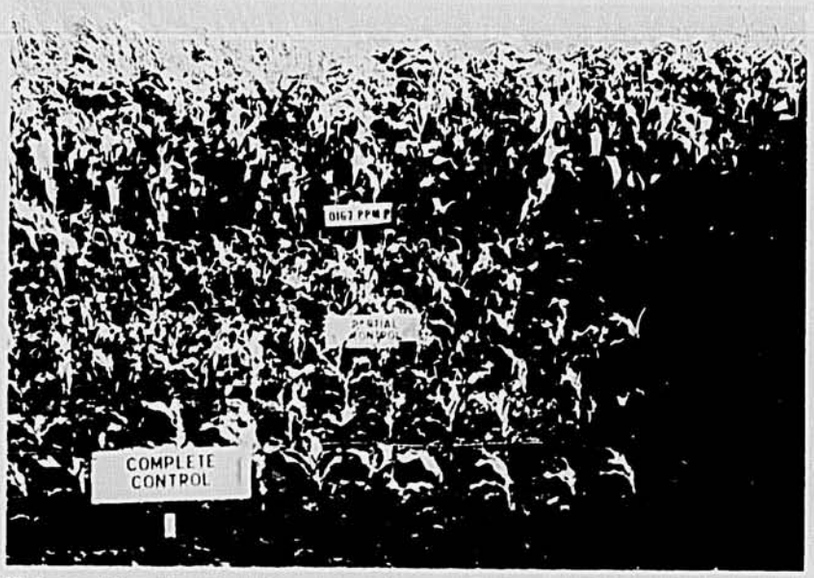
Hydric Dystrandept Network

The Project has effectively demonstrated that phosphorus must be applied on Hydric Dystrandepts in order to achieve reasonable yield response of maize. Throughout the network there was little or no response to higher levels of phosphorus above the first level of phosphorus applied. This was attributed to the high optimum phosphorus level established by the phosphorus-sorption method. Since rates of phosphorus applied vary with the amount of native or residual phosphorus in the soil at a specific site, alternative methods of analysis for soil phosphorus are being studied and will be reported at a later date.

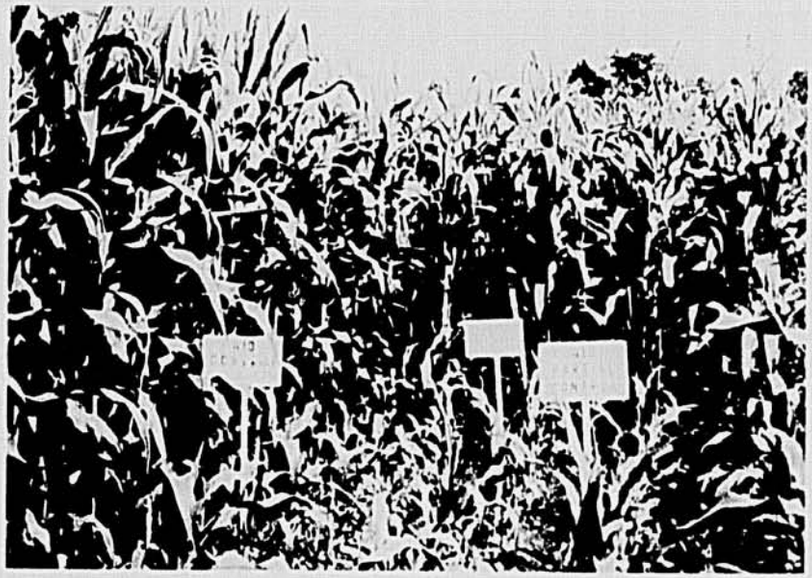
In Naga City, the Philippines, for example, maize was not grown to any significant extent on Hydric Dystrandepts because local farmers were not aware that these soils were nutritionally deficient in phosphorus. The visual growth response of maize to phosphorus in the transfer experiments effectively demonstrated the need for phosphorus application on these soils—information that was obtained through many years of research and experience in Hawaii on the Hydric Dystrandepts. These experiments also explained why a local practice of using chicken manure was more effective than commercially available urea or ammonium sulfate—nitrogen fertilizers that are commonly used by local farmers (see pages 50–51). All transfer experiments showed dramatic responses to phosphorus application with yields ranging from 0 with no phosphorus to more than 6 tons/ha with phosphorus.

All transfer experiments showed dramatic responses to phosphorus application.

The maize transfer experiments in Hawaii and Indonesia showed smaller responses to phosphorus due to residual amounts of available phosphorus from past management. Responses in Indonesia were also very small, due



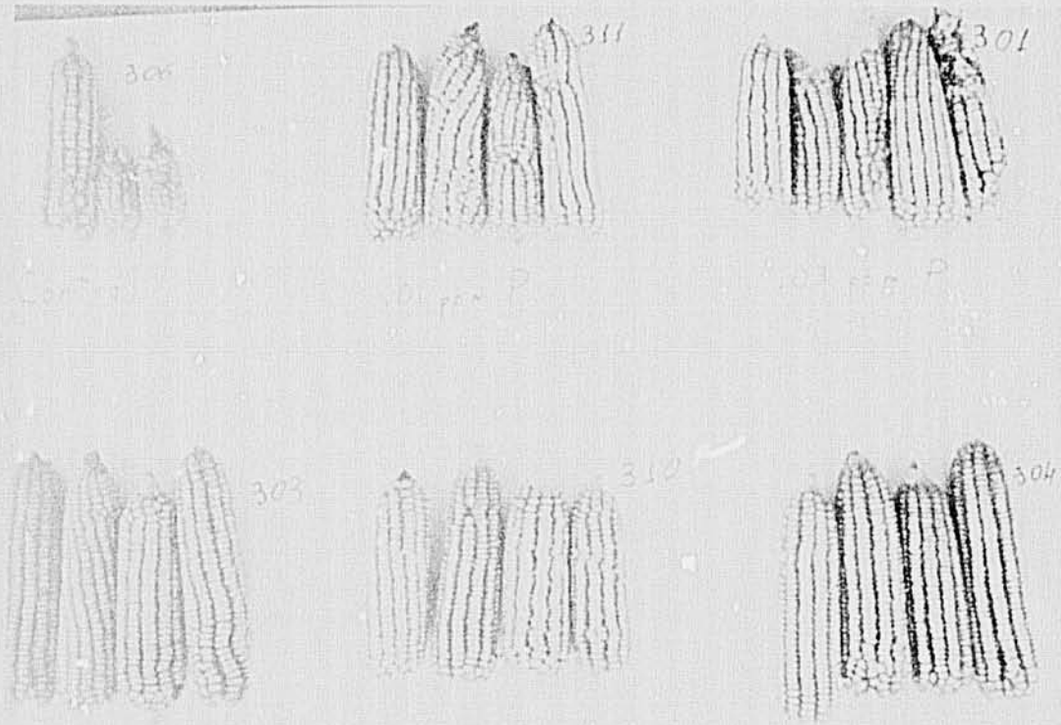
Kukaiau, Hawaii



Segunung, Indonesia

PUC, Philippines

Application of phosphorus on the volcanic ash soils of the thixotropic, isothermic Hydric Dystrandepts family gave the same crop response throughout this tropical soils network. At experimental sites in Hawaii, Indonesia, and the Philippines, maize yield improved markedly with even the slightest amounts of phosphorus added as fertilizer. The "control" plots received no fertilizer, and the "partial control" plots received all other nutrients except phosphorus. This response confirms the interpretation of the soil classification name in *Soil Taxonomy* (see Table 5).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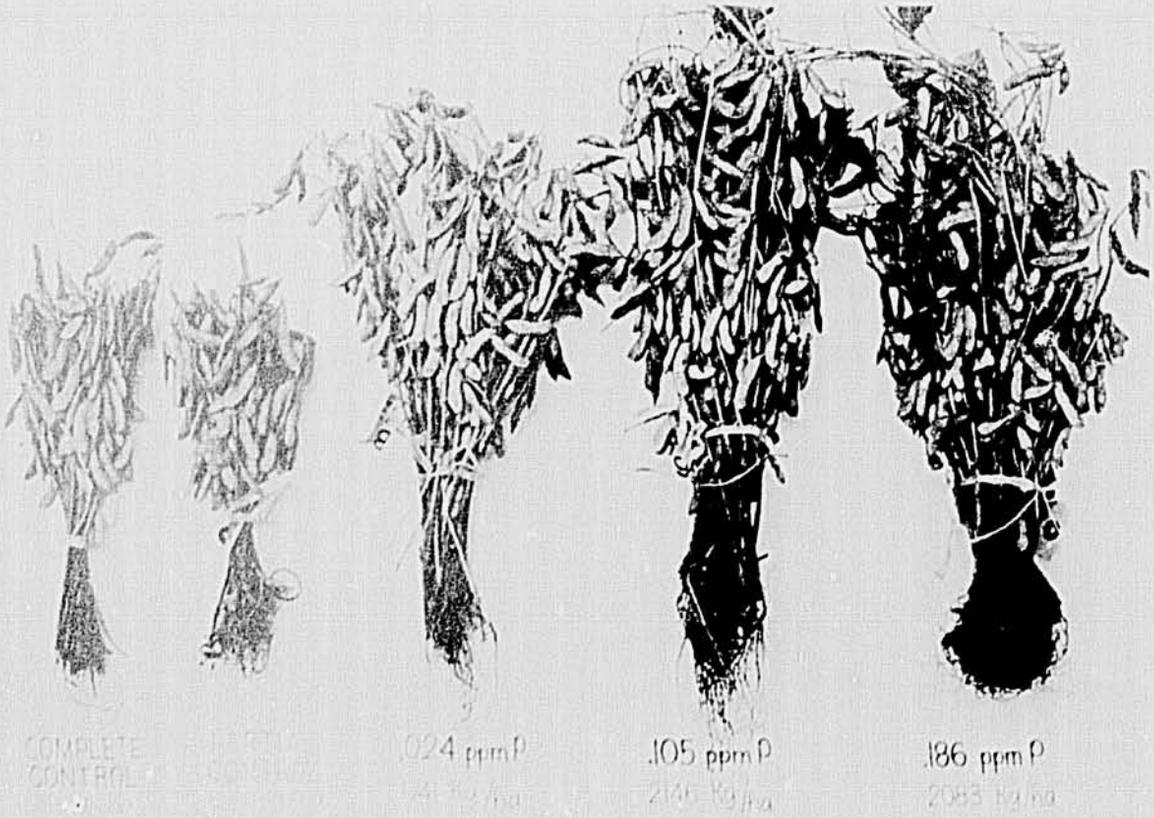
301
303
312
304


COMPLETE
CONTROL
.024 ppm P
.105 ppm P
.186 ppm P

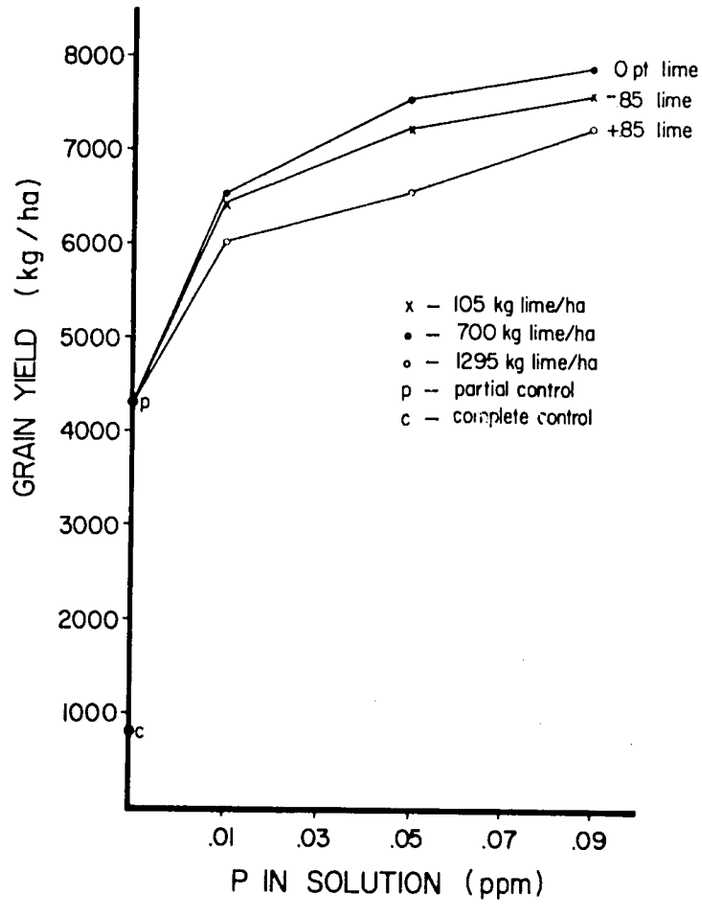


Fig. 20. The experiments at Halawa, Block A, in 1977 illustrate the overall findings in the Hydric Dystrandept sites: grain yields increased as phosphorus application increased, and there was little or no response to lime applications.

Surprisingly, no incidence of downy mildew was found in the Philippines, and less than 1 percent of the plants were infected in Indonesia.

largely to the use of a variety that was unresponsive to phosphorus application.

Application of lime generally resulted in little or no increase in yield. In some cases, in fact, higher applications of lime often resulted in a decrease in grain yield (Fig. 20). Soil pH ranged from 4.6 to 5.6, and KCl-extractable aluminum was generally 1.5 meq/100 g or less. These tropical soils are able to supply adequate amounts of calcium to crops, even though the pH is relatively low.

Table 12 shows the range of yields and responses to the optimum treatment in the Hydric Dystrandept network. Table 13 shows treatment means of all the experiments to date.

Application of lime generally resulted in little or no increase in yield.

Maize grain yield in the optimum treatment ranged from 1642 kg/ha at ITKA in Indonesia during the wet season to 10,232 kg/ha at Halawa in Hawaii during the dry season. The very low yield at ITKA was due to a severe wind and rainstorm that occurred during tasseling and is not indicative of the yield potential of maize on this soil family. The maize crop at the Halawa site received relatively higher amounts of solar radiation, and the diurnal temperatures in the unusually dry summer were conducive to good growth. This yield indicates the potential for maize production at the Halawa site in the dry season.

In Indonesia, grain yield of maize variety 'Bastar Kuning' generally did not reflect the imposed phosphorus or lime differentials in the three wet-season transfer experiments completed. The low grain yields were due largely to adverse weather conditions. The plants were healthier and taller with the higher applications of phosphorus and consequently were more susceptible to wind damage. Hence, another variety, 'Harapan', was selected for three dry-season transfer experiments because of its vigor and responsiveness to applied phosphorus.

Several attempts to plant during the Philippine wet season were constrained by strong winds and rain from typhoons. Crops that were planted showed a slower growth pattern. Plant height of maize ('UPCA Var. 1') at harvest during the wet season did not exceed 1.8 meters, while plants grew as high as 3.0 meters during the dry season. Marked response to phosphorus was observed in all transfer experiments with maize between treated and untreated plots. These responses were similar in each of the three sites, although at the PUC site, responses were larger with maize because without phosphorus application there was no grain yield.

Two varieties of maize known to be susceptible to downy mildew, a disease that is prevalent on maize throughout the tropics, were grown in the transfer experiments in Indonesia and the Philippines. Surprisingly, no incidence of downy mildew was found in the transfer experiments on 'UPCA Var. 1' in the Philippines, and less than 1 percent of the plants were infected in the transfer experiment using 'Harapan' in Indonesia. The Project believes the climatic environment of the isothermic regime of the Hydric Dystrandepts prevents the development of downy mildew; further tests are expected to confirm this.

The yield of soybeans varied among sites; the highest yield was achieved at the Kukaiau site in Hawaii where yields were generally 3000 kg/ha during the dry season. Lower yields were obtained at the PUC site in the Philippines and at the Iole site in Hawaii during the

Table 12. Summary of yields of partial control and optimum treatments[a] for all sites, Hydric Dystrandept network, 1976-1977 crop

Site	Block	Season	Fertilizer applied (kg/ha) P	Fertilizer applied (kg/ha) Lime	Yield (kg/ha) Partial control	Yield (kg/ha) Optimum	Increase (percent)
Hawaii–maize							
Iole	D	Wet	153	115	3587	4110	15
Kukaiau	A[b]	Dry	2113	600	4064	6136	51
	D	Dry	759	600	1846	3052	65
	C	Wet	618	204	4508	8122	80
	A	Dry	450	114	6769	7395	9
Halawa	A[b]	Wet	753	700	4729	5529	17
	B1	Dry	485	1278	8959	10,232	14
	D	Wet	160	405	4458	4762	7
	B2	Dry	446	803	6276	8854	41
Philippines–maize							
PUC	A[b]	Dry	658	525	0	4973	
	F1	Wet	145	1117	0	3458	
	F2	Dry	0	0	0	3246	
Palestina	A1	Wet	115	375	1188	3321	180
	C	Dry	197	413	3383	5035	49
	A2	Dry	0	0	1178	2985	
Burabod	A	Dry	217	465	976	2702	178
Indonesia–maize							
ITKA	A	Wet	283	283	2994	1642	-45
	K	Dry	683	2260	6442	7853	22
PLP	A	Wet	829	829	1248	1681	35
	D	Dry	646	151	3647	5485	50
LPH	A	Wet	395	600	3259	3602	10
	D	Dry	855	321	3129	7434	136
Hawaii–soybeans							
Iole	C	Wet	239	275	1286	1209	-6
Kukaiau	F	Dry	933	600	3234	3753	16
	E	Wet	1238	177	983	2069	113
	B	Dry	652	150	3151	2855	-9
Halawa	C	Dry	270	1530	2736	2955	8
	F	Dry	690	510	2620	2887	10
Philippines–soybeans							
PUC	B	Dry	658	525	379	1899	401
	E1	Wet	613	868	100	1527	1427
	E2	Dry	612	556	219	1303	495
Palestina	B	Wet	396	380	629	2049	226
	B2	Dry	0	0	1166	2022	73
Indonesia–soybeans							
ITKA	B	Wet	600	902	1598	1596	0
	J	Dry	894	2345	2616	3240	24
PLP	C	Dry	885	151	1148	2238	95
LPH	B	Wet			1337	2259	69
	C	Dry	1186	286	749	2674	257

[a]Optimum treatment applications of P and lime are listed in columns 4 and 5; partial control treatment consisted of application of all nutrients except P and lime.
[b]1975-1976 crop.

Grain yield data from the transfer experiments was determined throughout each network to test the transfer hypothesis. This weighing in occurred at ITKA, Indonesia.

Table 13. Mean yields (kg/ha) of transfer experiments conducted on Hydric Dystrandepts through December 1977 (average of three replications)

Treatment										
Coded P	Coded lime	Location/site								
Hawaii—Maize		IOLE-D W 76	KUK-A D 76	KUK-A D 77	KUK-C W 76	KUK-D D 76	HAL-A W 76	HAL-B D 76	HAL-B D 77	HAL-D W 77
+0.85	+0.85	4272	5953	8260	7826	3961	5716	10,308	8900	4860
+0.85	0	3904	6550	7421	7727	3384	6508	9737	8567	5080
+0.85	-0.85	4090	6512	7972	8142	3207	6140	9263	8955	4539
+0.40	+0.40	3859	5662	7875	7852	3041	5857	9892	8384	4957
+0.40	-0.40	3534	5949	7417	8092	3165	5728	9902	8388	5673
0	+0.85	3988	5768	6053	7808	3080	5545	9495	8385	4603
0	0	4110	6136	7395	8122	3052	5520	10,232	8854	4762
0	-0.85	4283	5764	8454	7578	2841	6062	9519	8442	5140
-0.40	+0.40	4200	6102	8157	6398	3058	5975	9894	8037	4893
-0.40	-0.40	3493	5916	7703	6733	2649	5792	9873	8914	5045
-0.85	+0.85	3554	5608	7752	6304	2988	5018	10,234	7540	5339
-0.85	0	3360	5217	7689	6701	3185	5202	9308	7947	4843
-0.85	-0.85	3311	5244	7761	6689	3339	5563	9683	8042	5102
Complete control		3385	4034	5813	3139	2817	3026	1724	1439	1977
Partial control		3587	4064	6769	4508	1846	4729	8959	6276	4458
Mean yield										
P treatments		3848	5875	7685	7383	3150	5741	9795	8412	4999
Controls		3486	4049	6291	3824	2331	3877	6341	3858	3218
Philippines—Maize		PUC-A D 76	PAL-A1 W 77	PAL-A2 D 77	PAL-C D 77	BUR-A D 77				
+0.85	+0.85	5218	3851	2751	5149	2672				
+0.85	0	5104	2830	2975	6266	3224				
+0.85	-0.85	5159	2902	2950	5323	2975				
+0.40	+0.40	5049	3878	2476	5320	2547				
+0.40	-0.40	5090	4148	2365	5530	3018				
0	+0.85	4510	3251	1988	5227	2951				
0	0	4973	3321	2985	5035	2702				
0	-0.85	5122	3024	2867	5574	2372				
-0.40	+0.40	4942	2890	2329	5606	1680				
-0.40	-0.40	4637	3624	2731	5229	2510				
-0.85	+0.85	4818	2917	3326	4942	798				
-0.85	0	4488	2344	1931	5180	1467				
-0.85	-0.85	4623	2149	2093	4939	758				
Complete control		0	1625	1654	3789	0				
Partial control		0	1188	1178	3383	976				
Mean yield										
P treatments		4902	3164	2598	5332	2283				
Controls		0	1406	1416	3586	488				

Indonesia–Maize		ITKA-A W 76	ITKA-K D 77	PLP-A W 76	PLP-D D 77	LPH-A W 76	LPH-D D 77
+0.85	+0.85	1759	8021	2377	6480	3269	8074
+0.85	0	1877	7909	1601	6160	3577	6914
+0.85	-0.85	1737	7693	1991	5406	3817	7588
+0.40	+0.40	2561	7281	1571	6301	4276	7483
+0.40	-0.40	2102	7804	1834	5998	3467	7594
0	+0.85	2106	7643	1943	5435	3742	7227
0	0	1642	7853	1681	5485	3602	7434
0	-0.85	1846	7755	1986	5980	2926	6910
-0.40	+0.40	1788	7503	2193	5338	3441	7160
-0.40	-0.40	1852	7484	1854	5229	3246	7521
-0.85	+0.85	2319	7049	1986	5139	4331	5565
-0.85	0	1784	7050	1379	5113	4405	6389
-0.85	-0.85	2493	7401	1716	4864	3622	5389
Complete control		2064	5975	764	2841	3597	1841
Partial control		2994	6442	1248	3647	3259	3129
Mean yield							
P treatments		1990	7573	1855	5610	3671	7019
Controls		2529	6208	1006	3244	3428	2485

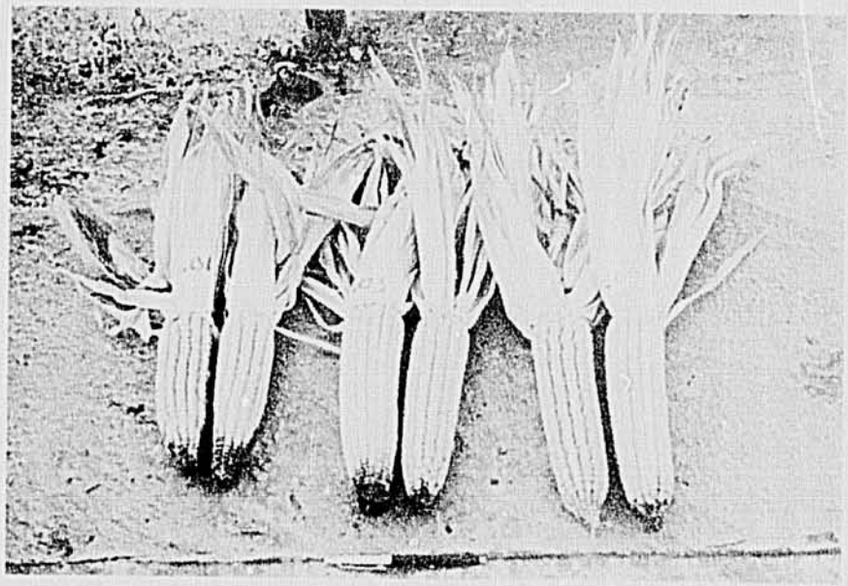
Hawaii–Soybeans		IOLE-C W 76	KUK-B D 77	KUK-E W 76	KUK-F D 76	HAL-C D 76	HAL-F D 77
+0.85	+0.85	1291	3351	2067	3392	3036	2989
+0.85	0	1317	2985	2024	3466	2722	2862
+0.85	-0.85	1166	3414	2208	3351	3027	2843
+0.40	+0.40	1417	3362	1997	3683	2794	2783
+0.40	-0.40	1620	2993	2165	3707	2749	2850
0	+0.85	1099	3310	2105	3618	3125	2948
0	0	1209	2855	2069	3753	2955	2887
0	-0.85	1259	3118	2180	3367	2856	2737
-0.40	+0.40	1383	3317	1968	3676	2756	2870
-0.40	-0.40	1515	3096	2033	3444	2910	2719
-0.85	+0.85	1371	3031	1835	3827	3090	2639
-0.85	0	1273	3059	1756	3494	3139	2795
-0.85	-0.85	1290	3118	1951	3686	2852	2758
Complete control		1321	2750	1052	3334	2326	2225
Partial control		1286	3151	983	3234	2736	2620
Mean yield							
P treatments		13[illegible]	3154	2028	3574	2924	2822
Controls		1304	2951	1017	3284	2531	2422

Philippines and Indonesia–Soybeans		PUC-B D 76	PUC-E W 76	PUC-E D 77	PAL-B W 76	PAL-B D 77	ITKA-B W 76	ITKA-J D 77	PLP-C D 77	LPH-B W 76	LPH-C D 77
+0.85	+0.85	1814	1721	1169	2223	2235	1390	3034	2327	2029	2720
+0.85	0	1782	1625	1348	2009	2006	1431	3269	2144	2075	2689
+0.85	-0.85	1848	1120	1461	2017	1996	1603	3298	2241	2029	2689
+0.40	+0.40	1708	2041	1161	2269	2071	1497	3421	2150	2257	2920
+0.40	-0.40	2013	1876	1297	2119	1983	1491	3288	2533	2049	2526
0	+0.85	1657	1792	1204	2113	2008	1744	2923	2017	2304	2959
0	0	1899	1527	1303	2049	2022	1596	3240	2238	2259	2674
0	-0.85	1748	1623	1346	2275	2127	1261	3191	2340	2236	2828
-0.40	+0.40	1725	1084	1326	2075	2039	1605	3203	2162	2066	2802
-0.40	-0.40	1663	1283	1214	2136	2014	1363	3510	2203	1882	2645
-0.85	+0.85	1701	992	1113	1818	1968	1276	2922	1912	2003	2310
-0.85	0	1860	757	1084	1629	1847	1433	2895	1591	1869	2435
-0.85	-0.85	1572	746	1097	1775	1800	1842	2927	1574	1828	2238
Complete control		313	183	229	589	1078	1395	2632	1249	1080	727
Partial control		379	100	219	629	1166	1598	2616	1148	1337	749
Mean yield											
P treatments		1768	1446	1240	2039	2009	1502	3163	2110	2068	2649
Controls		346	142	224	609	1122	1497	2624	1199	1208	738

Weather conditions at the sites affected yield levels achieved. Solar radiation is highest at the Hawaii sites, which also have the highest grain yield levels in the Hydric Dystrandept network.

wet season. The largest yield increase of the optimum over the partial control treatment was again found in the PUC site (226 to 495 percent), which coincides with the results with maize. Unlike maize, however, soybeans at PUC produced a small amount of grain without the addition of phosphorus or lime. The responses in Indonesia and Hawaii were variable, depending on the particular crop and season. Plant responses ranged from 6 percent at the Iole site in Hawaii during the wet season to 249 percent at the LPH site in Indonesia during the dry season. The yield increase at most sites appeared to be largely due to phosphorus, as was found with maize. For both crops, application of lime resulted in a small yield increase in some experiments, and higher amounts resulted in yield decreases in other experiments.

Weather conditions at the sites affected yield levels achieved to some degree (see pages 25–27). Solar radiation is highest on the average, at the Hawaii sites, which also have the highest grain yield levels. The Philippines and Indonesia have lower, somewhat comparable, levels of solar radiation, although levels in the Philippines are generally lower than in Indonesia. Maize yield levels were generally similar in the two countries. Both maximum and minimum temperatures were generally highest in the Philippines, while Indonesia had the lowest minimum temperature.



Yield results on maize from Kukaiau, Hawaii, showed that grain yield increased with higher applications of phosphorus (measured in ppm).

Tropeptic Eutrustox Network

In the Tropeptic Eutrustox network, response to the first phosphorus level over zero phosphorus was generally very marked, with a smaller response to the second phosphorus level (Tables 14 and 15). There was no additional response to higher levels of phosphorus. Application of potassium (K) did not increase yields in any of the Eutrustox experiments (see pages 24 and 59).

The range of maize yields with the optimum phosphorus and potassium treatment in the Tropeptic Eutrustox network was from 5806 kg/ha to 10,560 kg/ha at the primary site at Isabela, Puerto Rico. The yields at Jaiba, Brazil were similar to the average yields at Isabela. The response to the optimum treatments over the partial controls was between 18 and 58 percent for all maize experiments at Isabela; the response in Jaiba was 578 percent.

Soybean yields of the optimum treatments ranged from 1024 kg/ha at the primary site to 2606 kg/ha at the secondary site, both at Isabela, Puerto Rico. The yield increase of the optimum phosphorus and potassium treatments over the partial controls ranged from 8 to 60 percent in Puerto Rico, and the one soybean experiment conducted in Jaiba had a yield increase of 50 percent.

As in the Hydric Dystrandept sites, the yield responses in the Tropeptic Eutrustox sites were due almost completely to the phosphorus applied. There was no evidence of a response to potassium applications in any of the experiments.

Table 14. Summary of yields of partial control and optimum treatments[a] for all sites, Tropeptic Eutrustox network, 1976–1977 crop

Site	Season	Fertilizer applied (kg/ha) P	Fertilizer applied (kg/ha) K	Yield (kg/ha) Partial control	Yield (kg/ha) Optimum	Increase (percent)
Puerto Rico–maize						
Isabela, primary	Wet	300	125	8526	10,560	24
	Dry	171	125	6337	8557	35
Isabela, secondary	Wet	299	125	3694	5806	57
	Dry	234	125	5208	6138	18
Brazil–maize						
Jaiba, primary	Wet	97	100	1293	8772	578
	Dry	50	125	1568	4983	218
Puerto Rico–soybeans						
Isabela, primary	Wet	274	125	935	1024	10
	Dry	220	125	1287	2054	60
Isabela, secondary	Wet	234	125	2421	2606	8
	Dry	377	125	1037	1559	50
Brazil–soybeans						
Jaiba, primary	Wet	236	125	1208	1811	50

[a]Optimum treatment applications of P and K are listed in columns 4 and 5; partial control treatment consisted of application of all nutrients except P and K.

Table 15. Mean yields (kg/ha) of transfer experiments conducted on Tropeptic Eutrustox through December 1977 (average of three replications)

Treatment		Maize						Soybean				
		Isabela, Puerto Rico				Jaiba, Brazil		Isabela, Puerto Rico				Jaiba, Brazil
		1976		1977		1977		1976				1976
Coded P	Coded K	Wet	Wet	Dry	Dry	Wet	Dry	Wet	Wet	Dry	Dry	Wet
-0.85	-0.85	9,401	5907	5874	8161	6874	5505	1375	2551	1311	1546	1574
-0.85	+0.85	9,843	6402	6410	8257	8142	4654	734	2483	1194	1996	1795
+0.85	-0.85	10,375	6028	5772	8004	8545	7159	918	2628	1637	1765	1589
+0.85	+0.85	9,750	6114	6411	7302	7748	6360	1024	2836	1324	1833	1723
-0.40	-0.40	10,377	5967	6758	8082	7584	5982	1132	2804	1721	1944	1708
-0.40	+0.40	11,112	6260	6364	7607	7952	5289	954	2673	1499	1742	1848
+0.40	-0.40	11,287	6259	6400	7517	7588	6533	945	2927	1579	2155	2028
+0.40	+0.40	11,441	5801	7070	6984	7714	6438	756	2804	1451	2010	1967
0	0	10,560	5806	6138	8557	8772	5093	1024	2606	1559	2054	1811
-0.85	0	10,565	5501	5118	6134	6600	4943	928	2341	1399	1645	1887
+0.85	0	11,080	6365	5092	7085	7433	6434	722	2813	1637	1862	1932
0	-0.85	11,515	6414	5912	7408	6778	5177	1019	2873	1667	1626	1770
0	+0.85	11,134	6240	6605	8470	7748	6350	887	2792	1528	1927	1591
Complete control		6,530	3651	4165	4727	1141	1610	996	2867	1159	1508	1209
Partial control		8,526	3694	5208	6337	1293	1624	935	2421	1037	1287	1208
Mean yield												
P treatments		10,649	6082	6225	7659	7652	5423	955	2702	1500	1854	1786
Controls		7,528	3672	4686	5532	1217	2521	965	2644	1098	1398	1209

RESULTS OF A STATISTICAL TEST OF THE TRANSFER HYPOTHESIS

The success or failure of the Project rests heavily upon the development and application of a statistical test of the hypothesis of transferability. This is the means of showing scientifically that soils of the same family respond similarly to management.

Three statisticians met in 1977 to discuss an appropriate approach and to formulate a tentative statistic. In concurrence with a recommendation by AID's Research and Advisory Committee, R.L. Anderson at the University of Kentucky is conducting the theoretical studies needed to determine the method of prediction, to develop a valid test of the transferability hypothesis, to examine the statistical properties of the proposed test statistics, and to apply the test procedure to Project data.

It was found that a generalized equation could predict the yield response for any of the sites . . .

One test of the hypothesis was made using regression techniques to predict the yield response to phosphorus and lime at any of the Benchmark sites included in this study. It was found that a generalized equation could predict the yield response for any of the sites, provided terms reflecting the different average yields at the sites were included. Thus, a combined agrotechnology model describing the response to phosphorus and lime is considered transferable among sites of the same soil family.

Another approach to testing the hypothesis involved the estimation of a transfer equation from several sites and using it to predict yields on a different site. This is ultimately what is desired—that is, to transfer information from one site to another of the same soil family. This second test gave limited evidence that agrotechnology could be transferred between soils of the same family, but a more conclusive test awaits more yield and site variable information.

A detailed discussion of the statistical test of the transfer hypothesis follows.

This implies that within the range of experimental error there is no evidence that a different response surface model holds for each site.

An initial evaluation of the hypothesis of transferability used yield and climatic data from the thixotropic, isothermic family of Hydric Dystrandepts. Maize grain yield data selected for this test came from five experimental sites—three from Hawaii (KUK-A, KUK-C, and HAL-B) and two from the Philippines (PUC-A and PAL-C). (See Table 16 for data.)

The Combined Model Approach

One approach followed in the test of the transfer hypothesis was to calculate a quadratic response surface equation to describe the yield response to phosphorus and lime for each site using the model

$$Y = b_0 + b_1P + b_2L + b_3P^2 + b_4L^2 + b_5PL$$

where Y is the predicted maize yield (kg/ha); b_0 is the "intercept," the estimated yield when P and L are both zero in the coded values (this is the center of the design); b_1 to b_5 are regression coefficients for the respective variables; P is the coded value of the phosphorus differential; and L is the coded value of the lime differential.

If the transfer hypothesis is shown to be acceptable, then a separate response surface does not have to be estimated for each site, but one common response surface model will suffice. Thus, the regression coefficients in the equations for the individual sites should not be different from each other. The null hypothesis to be tested, therefore, was that the regression coefficients for all sites are the same.

The F statistic for testing the null hypothesis followed the general procedure of calculating (1) the response model sum of squares (SS) fitted separately for each site, and (2) the response model SS for all sites combined.

If the sum of the separate model SS is not much different from the combined model SS, the null hypothesis cannot be rejected. Since site variables affect yield levels, the appropriate intercept value (b_0) for each site should be included in the combined model response surface equation.

When the F test was applied to data from the five experiments, it was found that the null hypothesis could not be rejected. This implies that within the range of experimental error there is no evidence that a different response surface model holds for each site. Thus, it follows that the combined model response surface equation with the appro-

Table 16. Grain yield of five sites used in evaluation of the transfer hypothesis

Treatment		Site 1: PUC-A (May 1976 planting)				Site 2: Palestina C (PAL-C) (May 1977 planting)				Site 3: Kukaiau A (KUK-A) (August 1975 planting)			
Coded P	Coded lime	Rep 1	Rep 2	Rep 3	Average	Rep 1	Rep 2	Rep 3	Average	Rep 1	Rep 2	Rep 3	Average
-0.85	-0.85	4860	4258	4750	4623	5040	4809	4969	4939	4966	4887	5040	5244
0	-0.85	4868	5270	5228	5122	6204	5555	4964	5574	6309	6334	4649	5764
+0.85	-0.85	4743	5370	5363	5159	5214	5189	5566	5323	7931	5913	5692	6512
-0.40	-0.40	4107	4963	4840	4637	5021	4956	5710	5229	6156	5709	6192	5916
+0.40	-0.40	4930	5393	4947	5090	5710	6241	4640	5530	6339	5230	6277	5949
-0.85	0	5098	4257	4110	4488	4662	4761	6118	5180	5745	4983	4924	5217
0	0	5247	5483	4190	4973	5311	5009	4784	5035	6360	5979	6070	6136
+0.85	0	4372	5433	5506	5104	5652	6507	66[illegible]	6266	6179	6245	7226	6550
-0.40	+0.40	5060	5137	4629	4939	5681	5101	6036	5606	4890	6532	6883	6102
+0.40	+0.40	5367	5037	4742	5049	4984	5447	5530	5320	5728	5228	6031	5662
-0.85	+0.85	5190	5195	4068	4818	4622	5368	4837	4942	6049	5309	5466	5608
0	+0.85	4300	4657	4573	4510	4992	5387	5301	5227	4669	6102	6533	5768
+0.85	+0.85	4878	4270	6507	5218	5921	4856	4671	5149	5917	5924	6017	5953

Treatment		Site 4: Kukaiau C (KUK-C) (December 1976 planting)				Site 5: Halawa B (HAL-B) (July 1977 planting)			
Coded P	Coded lime	Rep 1	Rep 2	Rep 3	Average	Rep 1	Rep 2	Rep 3	Average
-0.85	-0.85	5935	7076	7056	6689	6823	8793	8510	8042
0	-0.85	7788	6974	7973	7578	8271	9195	7860	8442
+0.85	-0.85	7878	8411	8136	8142	8225	9918	8721	8955
-0.40	-0.40	5936	7214	7050	6733	8737	8157	9847	8914
+0.40	-0.40	8505	7728	8044	8092	8102	8957	8105	8388
-0.85	0	6353	7044	6706	6701	8689	6884	8268	7947
0	0	7468	8036	8862	8122	7881	8997	9683	8854
+0.85	0	7453	7599	8130	7727	8642	8680	8378	8567
-0.40	+0.40	6111	5588	7494	6398	7297	8083	8730	8037
+0.40	+0.40	7060	8870	7627	7852	7669	8530	8954	8384
-0.85	+0.85	6482	4908	7523	6304	7010	7714	7897	7540
0	+0.85	7132	7853	8438	7808	8374	8128	8652	8385
+0.85	+0.85	7684	7676	8117	7826	8639	9339	8722	8900

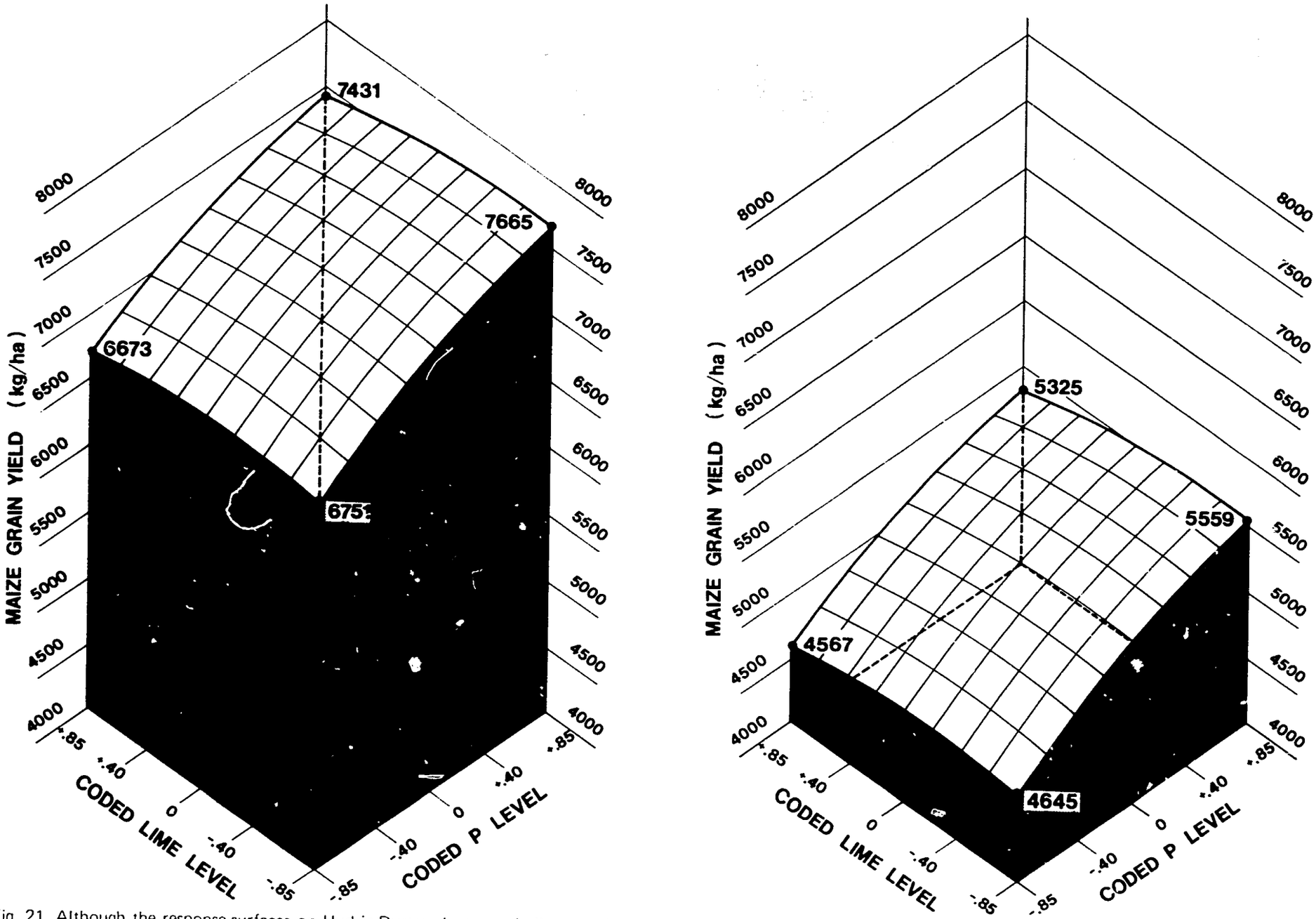


Fig. 21. Although the response surfaces on Hydric Dystrandepts are similar, the yield levels of maize in Hawaii were greater than those in the Philippines. This reflects the differences in climatic environment. We expect a similar response surface at our sites in Indonesia or any other Hydric Dystrandept. The magnitude of the response, however, depends on site variables.

priate intercept may be used for all five sites, and, in this sense, the response model describing the yield response of maize to phosphorus and lime is transferable among sites of the same soil family.

The combined estimated response surface equation is the following:

$$Y = I + .02P + .01L - .107P^2 - .107L^2 - 53.8PL$$
$$(.73) \quad (.71) \quad (.141) \quad (.141) \quad (.107)$$

Figures in parentheses are standard errors for the regression coefficients. The intercepts (I) were 5007 (PUC-A), 5437 (PAL-C), 5980 (KUK-A), 7487 (KUK-C), and 8517 (HAL-B).

Estimated response surfaces for the Philippines and Hawaii sites (Fig. 21) were calculated using this equation and the appropriate intercepts. A marked difference in yield level between the two countries is evident, along with the fact that the highest yields were attained with the highest phosphorus and lowest lime treatment combination. There was a similar marked response to phosphorus and a lack of response to lime in both countries.

The difference in the height (yield) of the fitted surfaces of the two countries reflects the difference in the intercept. The intercept integrates the effects of site variables such as temperature, solar radiation, and so on. Some of the experiments included in this test were installed before weather instruments were completely operational, so that complete weather data were not available for use. A preliminary equation that included average maximum daily temperature near the time of tasseling did not do as well as the equation with the individual intercepts in predicting yields for the individual sites. These differences in yield potential between sites will be described and tested more precisely when more complete data on uncontrolled site variables are available in the equation.

The Transfer Equation Approach

Another approach to testing the transfer hypothesis entailed determining whether or not a transfer function, estimated from one series of experiments, can be used in another area where experiments have not been carried out. This is really the major goal of the Benchmark Soils Project. To evaluate the transfer hypothesis with the five sites used, the transfer function (the combined response surface with the temperature site variable) on four sites was estimated and then yields were predicted for the fifth site. The theory is that if this "new" residual SS, called the transfer SS, has not increased over the residual SS obtained by a response surface estimated from the actual data for the fifth site, then agrotechnology can be transferred successfully. This ratio of the transfer SS to the residual SS is a newly-developed test that gave promising results for sites with values intermediate in the range of maximum daily temperatures.

These initial tests, then, have suggested that agrotechnology can be transferred between soils of the same family. A conclusive test of the transfer hypothesis awaits more yield and site variable data as well as additional work on the properties of the newly-developed statistic.

The difference in the height of the fitted surfaces . . . reflects the difference in the intercept.

SUMMARY OF RESPONSES: VARIETY EXPERIMENTS

Variety experiments are conducted in conjunction with the transfer experiments in order to compare crop response to treatment variables. The questions are "How do the phosphorus and lime or potassium applications affect crop yields of the variety or cultivar best adapted to the soil, locality, and the treatment variables within a given network?" and "How do factors such as the presence of different pests and diseases, local weather conditions, and other soil and climatic factors within the range of the soil family criteria affect the variety used?" Thus, varieties of maize were evaluated for both their suitability to the environment at the sites and their responsiveness to phosphorus and lime or potassium. (Nitrogen has now replaced both lime and potassium, see pages 23–24.)

In each country, the "best adapted" variety of maize is grown in the transfer experiments; these varieties are recommended by local research institutions. In addition, varieties used

In each country, the best adapted variety of maize is grown; these varieties are recommended by local research institutions.

Table 17. Best-adapted varieties or cultivars identified through December 1977 (wet- and dry-season trials)

Country	Maize	Soybeans
Hydric Dystrandepts		
Hawaii	'H610'	'Hill'[a]
		'TK-5'[a]
		'Kahala'[b]
Philippines	'UPCA Var. 1'	'Tainung 3'
Indonesia	'H6'	'Shakti'
	'Harapan'	'Orba'
Tropeptic Eutrustox		
Brazil	'Pioneer X304 A, B, C'	'Davies'
		'Bragg'
Puerto Rico	'Pioneer X304 A, B, C'	'Hardee'

NOTE: These results are not conclusive; further trials will be conducted as new varieties are bred, as Project time permits.

[a]Wet season only.
[b]Dry season only. Based on screening trial; no formal test was constructed.

In Puerto Rico, INTSOY made recommendations.

in transfer experiments throughout the soil network are included in the variety experiments during both the wet and dry seasons to determine if there is a single best-adapted variety within each soil family network. For comparative purposes, then, experiments on all the varieties are necessary; where there is doubt about the best adapted variety for a location, some preliminary variety experimentation may also be necessary.

Our tests to date indicate the varieties or cultivars in Table 17 to be the best adapted and most responsive to treatment variables. It appears that the 'Pioneer X304' hybrids are best adapted for use within the Eutrustox network and that, to date, there is no single best-adapted variety within the Dystrandept network. Maize variety tests will be continued to confirm the performance of selected varieties for the transfer experiments. Results will substantiate future recommendations in obtaining the maximum potential of the soils network for this crop in land-use planning.

In the variety trials, a split-plot design is employed, each variety being grown with phosphorus and lime or potassium treatments at two levels, optimum and −0.85. With all other controllable variables at or near optimum, this provides a measure of each variety's requirement for and capacity to respond to applied phosphorus and lime or potassium.

Maize Trials

Four variety trials have been conducted on the three primary sites of the Hydric Dystrandept network, one each in Hawaii and Indonesia and two in the Philippines. In the Tropeptic Eutrustox network, three variety trials were conducted in Puerto Rico and one in Brazil.

Hydric Dystrandept Network

In a wet season trial in Hawaii, the Hawaii transfer hybrid 'H610' outyielded all other entries, including the Philippines transfer cultivar 'UPCA Var. 1'. 'H6' and 'Harapan' were the most promising cultivars in Indonesia; although 'Bastar Kuning' gave comparable yield, it was not used in succeeding experiments due to its susceptibility to wind. Downy mildew did not occur in these experiments, even though varieties susceptible to the disease were included in the experiment. In the Philippines, no downy mildew was observed, and 'UPCA Var. 1' outyielded all other varieties for both seasons. Results are shown in Table 18.

Tropeptic Eutrustox Network

In Puerto Rico, hybrids 'Pioneer X304 A, B, and C' consistently ranked better than the locally grown, open-pollinated varieties ('Mayorabella' and 'Diente de Caballo'), which did not respond to phosphorus application and in which yields were lower. In Brazil, varieties were selected from a list of recommendations provided by the Centro Nacional de Pesquisa de Milho e Sorgo (CNPMS), and again the top varieties were 'Pioneer X304 A, B, and C'. Results are shown in Table 19.

Soybean Trials

A large number of soybean screening tests were installed throughout the Hydric Dystrandept network. A trial in Brazil in the Tropeptic Eutrustox network used INTSOY's standard test.

Hydric Dystrandept Network

Taiwan variety 'TK 5' outyielded all others in Hawaii in the wet season trials; 'Shakti' produced higher yields in Indonesia; and 'Tainung 3' and 'Orba' outyielded all others in the Philippines. Results are shown in Table 20.

Table 18. Summary of yields (kg/ha) of maize varieties for fertility treatments of phosphorus and lime throughout the Hydric Dystrandept network

Treatment						
Coded P	Coded lime	Variety				
Tacial—wet season 1976–1977		'H610'	'Pioneer 3068'	'H688'	'Waimea Dent'	'UPCA Var. 1'	'DMR Composite 2'
0	2	1783	3102	3142	2771	2814	2474
	0	3841	3361	2979	2760	2212	2000
2	0	3272	3281	3060	2766	2513	2237
Indonesia—dry season 1977		'H6'	'Bisi-18 Kuning'	'Hanpean'	'DMR Composite 1'	'Bima'	'H610'
0	2	2258	6380	6483	5651	4535	4687
	0	6762	5793	5961	5182	3821	3864
2	2	7761	6875	6726	6008	5181	5373
	0	7077	7305	7095	5923	5918	5205
0	0	6987	6669	6566	5691	4889	4782
Philippines—dry season 1976		'UPCA Var. 1'	'H788'	'H610'	'DMR-1'	'DMR Composite 1'
0	2	6205	5917	5594	5369	5846
	0	6587	5310	5862	5325	5230
2	2	6968	6753	5851	6739	5513
	0	6290	6216	5780	5895	5996
0	0	6462	6726	5722	5582	5621
Philippines—late dry (for early wet) season 1977		'DMR Var. 1'	'DMR Composite 1'	'H610'	'Pioneer'	'Bisi-18 Kuning'
0	2	5232	4784	4443	3533	1853
	0	4422	4754	5102	2863	2012
2	2	6346	5567	4807	5471	2495
	0	6273	5641	4941	4366	1478
0	0	5602	5181	4680	4058	1960

A drip irrigation system supplies the necessary water to this maize crop in both the transfer and the variety trials.

Table 19. Grain yield (kg/ha) in maize variety trials, Tropeptic Eutrustox network, 1976

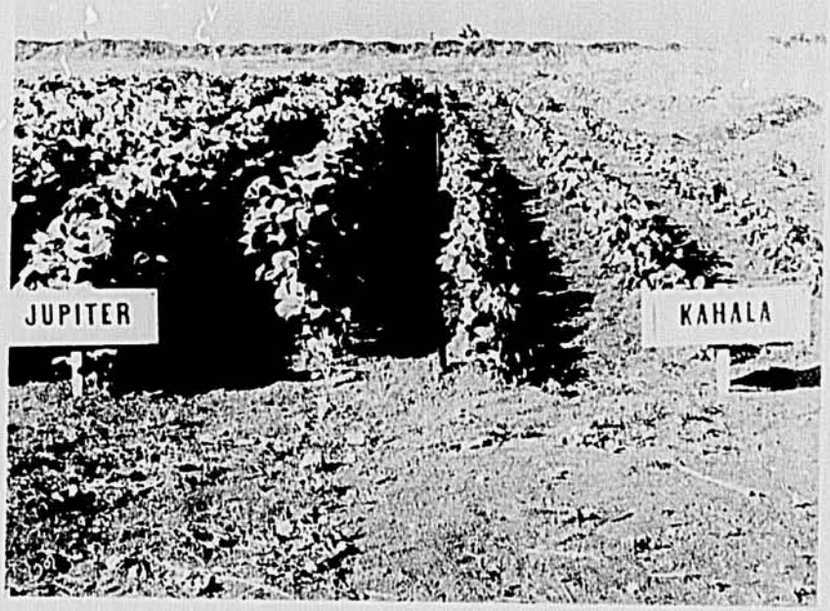
Jaiba, Brazil		Isabela, Puerto Rico	
Variety	Yield	Variety	Yield
'Pioneer X304 B'	7740	'Pioneer X304 C'	9782
'Pioneer X304 A'	7680	'Pioneer X304 B'	8957
'Pioneer X304 C'	7457	'Pioneer X304 A'	8349
'Pioneer X300 B'	7442	'H638'	8314
'Centibrasil 3'	7380	'Pioneer 105 A'	8186
'Cargill 318'	7222	'H652'	8019
'Cargill 111'	7217	'Pioneer X300 B'	7687
'Cargill 111 X'	7145	'H788'	7659
'Cargill 111 S'	7127	'UPCA-1'	7238
'Cargill 517'	7105	'H610'	7094
'Cargill 095 M'	7035	'INIA H507'	7058
'Pioneer X105 A'	7033	'Honduras H5'	7028
		'Diente de Caballo'	6966
		'Mayorbella'	6671
		'DMR'	6402
		'Oaxaca 179'	4670

Table 20. Summary of yields (kg/ha) of soybean varieties for fertility treatments of phosphorus and lime throughout the Hydric Dystrandept network

Treatment							
Coded P	Coded lime	Variety					
Hawaii—wet season 1976–1977		'TK5'	'Hill'	'Jupiter'	'Davis'	'Kahala'	'Kailua'
-0.85	-0.85	1070	968	1085	748	517	413
-0.85	0	1088	1080	863	817	559	477
0	-0.85	1061	1057	990	638	548	535
0	0	1355	1155	710	904	438	545
Overall mean		1124	1065	905	765	510	492
Indonesia—dry season 1977		'Orba'	'Shakti'	'TK5'	'B/66/7'	'Kahala'	'Jupiter'
-0.85	-0.85	2524	2302	2074	1983	1078	947
-0.85	0	3056	2377	1981	1963	1201	912
0	-0.85	2703	2279	2050	2020	1422	979
0	0	3183	2713	2103	2179	1468	1401
Overall mean		2867	2417	2052	2036	1293	1060
Philippines—(combined trials) dry season 1977		'Tainung 3'	'Orba'	'Clark 63'	'XVI-58'	'Jupiter'	'Kahala'	'TK5'
-0.85	-0.85	1586	1259	1236	1137	1140	1061	[illegible]
-0.85	0	1519	1168	1102	1200	1121	989	858
0	-0.85	1666	1239	1222	1224	1077	1022	930
0	0	1720	1333	1177	1093	1169	1040	995
Overall mean		1620	1250	1184	1164	1126	1012	919

Tropeptic Eutrustox Network

In Puerto Rico, 'Inputs' and 'Hardee' were recommended by INTSOY as the most adapted varieties. In Brazil, 'Davis' and 'Bragg' outperformed five other varieties; results are shown in Table 21.



Soybean variety testing occurred throughout the Hydric Dystrandept network in 1976–1977.

Table 21. Grain yield (kg/ha) in soybean variety trial, Jaiba, Brazil (planted Nov. 25, 1976)

Variety	Yield
'Davis'	4470
'Bragg'	4002
'Ransom'	3815
'Bossier'	3512
'Forrest'	3476
'Columbus'	3397
'Clark 63'	3261

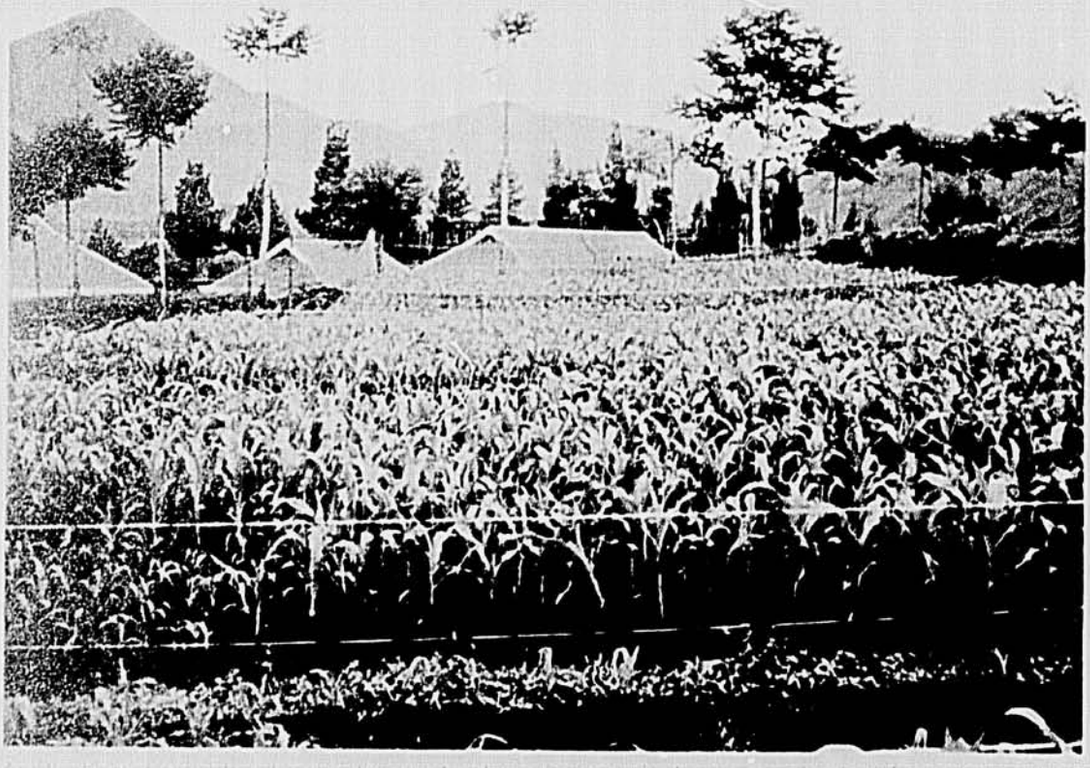
APPLYING TECHNOLOGY TO LOCAL NEEDS: RESULTS OF MANAGEMENT EXPERIMENTS

Management experiments are conducted at primary sites to study agronomic problems of local importance and to develop practices for local farmers with limited resources. The objectives of management experiments are (1) to provide information to local government agencies on ways to increase production by improved availability and utilization of resources, and (2) to provide basic information to local farmers with limited resources to improve crop yields at different levels of management. These tests should eventually lead to determination of the most economic and efficient agricultural practices for each country and information for subsequent soil interpretation and land capability classification.

Experiments carried out include tests to determine the limiting nutrients in a soil, the proper amounts of phosphorus to be applied at various band widths, the effects of organic manure, spacing of corn plants, residual effects of phosphorus, and irrigation, weed control, insect and disease control, and other necessary management practices required (Silva, in press). Results of these experiments have already been adopted by some local farmers (see pages 50–51).

As the Project progresses, the following three levels of management should become available as a result of Project activities.

1. Level 1: the combinations of management practices used most commonly by successful farmers for the soil under study.
2. Level 2: a combination of superior management practices followed by farmers who obtain yields of crops well above the average.
3. Level 3: the optimum combinations of management practices that can be



Application of agricultural technology to local requirements is shown in maize transfer experiments at PT. Pupuk Lembang, Indonesia, where crops were planted in terraces on volcanic slopes.

part 4

related activities

defined for full appplication of the current state of knowledge and techniques for crop production.

The management and transfer experiments now underway will help define levels 2 and 3; a farm survey to define level 1 should be begun by the Project in 1978. It is expected that the Project will demonstrate that management systems implemented on one soil in one region can be transferred to the same soil in any other region.

The information derived will provide decision-makers with alternatives for the agricultural development planning policy of their region or country.

Whereas the procedures for conducting the transfer experiments must be identical at all sites, the design of the management experiments is flexible, allowing the Project to respond to host-country priorities and to local farmer needs. A philosophic framework for the management experiments was developed at the first annual coordination meeting of the University of Hawaii and University of Puerto Rico Projects in 1976. Details of the management research experiments are developed by each participating country.

The management experiments described indicate the wide array of transferable information that is being generated by the Project. These experiments may not only have immediate impact for the in-country small farmer, but they may also carry greater impact for small farmers living on similar soils in other tropical countries.

Additional management experiments—such as fertilizer placement, responses to fertilizer phosphorus derived from varied sources, and others—are planned. The value of management experiments will be fully realized when the results are combined with soil-resource data for purposes of soil-survey interpretation and land classification. The information derived will provide decision makers with alternatives for the agricultural development planning policy of their region or country.

The soil classification and characterization data, crop yield data, and climatological data will be processed by methods of multivariate analysis to determine the desired land potential, land capabilities, and transferability information. Local yield data and land-capability information, where they exist, will be included in the data base to improve the quality of yield predictions at various levels of the soil classification to cover a larger group of soils than will be represented by the Benchmark Soils Project network. Where similar soil indexes of production capabilities are determined by analysis, the information will be translated directly through the soil linkage, as a first approximation to production targets for these soils occurring in other tropical and subtropical lands.

Table 22. Maize response (kg/ha) to residual phosphorus, Hydric Dystrandept network

Treatment		Hawaii (HAL-A) ('H610')		Philippines ('UPCA Var. 1) PUC-A		PAL-A	
Coded P	Coded lime	Transfer Wet 1975–1976	Residual Dry 1977	Transfer Dry 1976	Residual Wet 1977	Transfer Wet 1977	Residual Dry 1977
+0.85	+0.85	5716	7223	5218	2049	3851	2751
+0.85	0	6508	7889	5104	2121	2830	2975
+0.85	-0.85	6140	7567	5159	1987	2902	2950
+0.40	+0.40	5857	7063	5049	2014	3878	2478
+0.40	-0.40	5728	7244	5090	2452	4148	2365
0	+0.85	5545	6564	4519	1937	3251	2110
0	0	5529	7547	4973	1992	3321	2985
0	-0.85	6062	7236	5122	2093	3023	3200
-0.40	+0.40	5975	7904	4939	1979	2890	2329
-0.40	-0.40	5792	7320	4637	1760	3624	2731
-0.85	+0.85	5018	6030	4818	1666	2917	3326
-0.85	0	5202	6558	4488	1595	2344	2264
-0.85	-0.85	5563	6438	4623	1721	2149	2093
Complete control		3026	804	0	0	1625	1653
Partial control		4729	4295	0	0	1810	1178
Mean yield							
P treatment		5741	7122	4902	1951	3164	2658
Controls		3878	2550	0	0	1718	1415

Residual Phosphorus

After the transfer experiments were completed on the Hydric Dystrandept network, experiments in those same blocks were installed to test crop response to residual phosphorus. These experiments were expected to demonstrate the continuous availability of phosphorus for subsequent crops—that is, that the initial large cost of phosphorus fertilizer can be amortized over several plantings. These expectations were confirmed, and the experimental findings can have immediate impact on local small farmer practices.

The response of maize to residual phosphorus in the Philippines and Hawaii (Fig. 21), as expected, was similar to that of the transfer experiments. The grain yield of the residual crop in Hawaii (HAL-A), however, was greater than the yield of the transfer crop, whereas the yields of residual crops in the Philippines (PUC-A, PAL-A) were lower than the yield of the transfer crop (Table 22). These differences were attributed to the differences in season—more precisely, to the greater amounts of solar radiation in the dry season. The smaller difference in yield observed in PAL-A was due to a "wet" dry season.

The plantings of the second experiment at PUC, the Philippines, indicated that low applications of the Kon-o-mono, which contains phosphates, were sufficient to yield more growth than application of chemical fertilizers with high phosphate.

Table 23. Grain response (kg/ha) to residual phosphorus experiments on Hydric Dystrandepts in the Philippines

Treatment		Soybeans ('TK-5')				Sorghum ('Cosor 2')	
		PUC-B		PAL-B			
Coded P	Coded lime	Transfer Dry 1976	Residual Wet 1977	Transfer Wet 1977	Residual Dry 1977	PUC-A Dry 1977	PUC-B Dry 1977
+0.85	+0.85	1815	437	2223	2235	1358	3385
-0.85	0	1781	442	2009	2007	1325	3544
+0.85	-0.85	1848	454	2017	1996	1505	3632
+0.40	+0.40	1768	477	2269	2071	1629	3441
-0.40	-0.40	2013	414	2119	1983	1463	2844
0	+0.85	1857	410	2113	2008	1613	3327
0	0	1898	394	2049	2022	1440	2881
0	-0.85	1748	390	2275	2127	1318	2983
+0.40	+0.40	1725	404	2075	2039	1401	2642
-0.40	-0.40	1663	420	2177	2014	1370	3011
+0.85	+0.85	1702	424	1818	1968	1085	2966
-0.85	0	1860	309	1629	1847	1267	2861
-0.85	-0.85	1572	320	1775	1809	1226	2211
Complete control		313	64	589	1078	0	485
Partial control		380	89	629	1166	0	857
Mean yield							
Treatment		1770	407	2042	2009	1385	3056
Control		346	76	609	1122	0	671

The small farmer with limited resources can realize relatively large gains in yield by applying small amounts of nitrogen and phosphorus. Close planting within rows reduced yields markedly.

This effect of weather on yield was reflected in similar soybean experiments in PUC-B and PAL-B (Table 23). A third, or second residual, planting with sorghum in former maize (PUC-A) and soybean (PUC-B) transfer experiment blocks resulted in a trend in grain yield similar to the trend in the transfer experiments. The greater grain yield in PUC-B was due to the higher rates of phosphorus applied to the preceding transfer experiments on soybeans in those fields.

Similarly, Irish potatoes were planted on a former soybean transfer block at the LPH site in Indonesia. The trend (Fig. 22) in tuber yields was similar to that of soybeans. Only small amounts of nitrogen (46 kg/ha) and potassium (40 kg/ha) were applied to the rain-fed potato crop.

Limiting Nutrients

In another type of management experiment designed to identify limiting plant nutritional factors, maize growth and grain yield (Fig. 23) showed that phosphorus and nitrogen were the two most limiting elements at the PUC site.

The severity of the yield limitation from lack of phosphorus is indicated by the ten-fold increase in yield with the application of 30 kg P/ha. Yields increased markedly as nitrogen and phosphorus were increased to the maximum tested (106 kg N/ha and 120 kg P/ha), which gave grain yields of 6000 kg/ha. Maximum yields for this soil were not achieved, as indicated in Fig. 23 by the increasing yield response curves at the highest levels of nitrogen and phosphorus. Information provided by this experiment suggests that the small farmer with limited resources can realize relatively large gains in yield by applying small amounts of nitrogen and phosphorus.

Nutrient Source

A commonly available source of fertilizer containing a sufficient supply of nitrogen and phosphorus is chicken manure. A maize experiment (Table 24) comparing inorganic nitrogen and phosphorus fertilizer with chicken manure showed that yields from application of chicken manure were comparable with those from application of low amounts of nitrogen and phosphorus fertilizer. This sim-

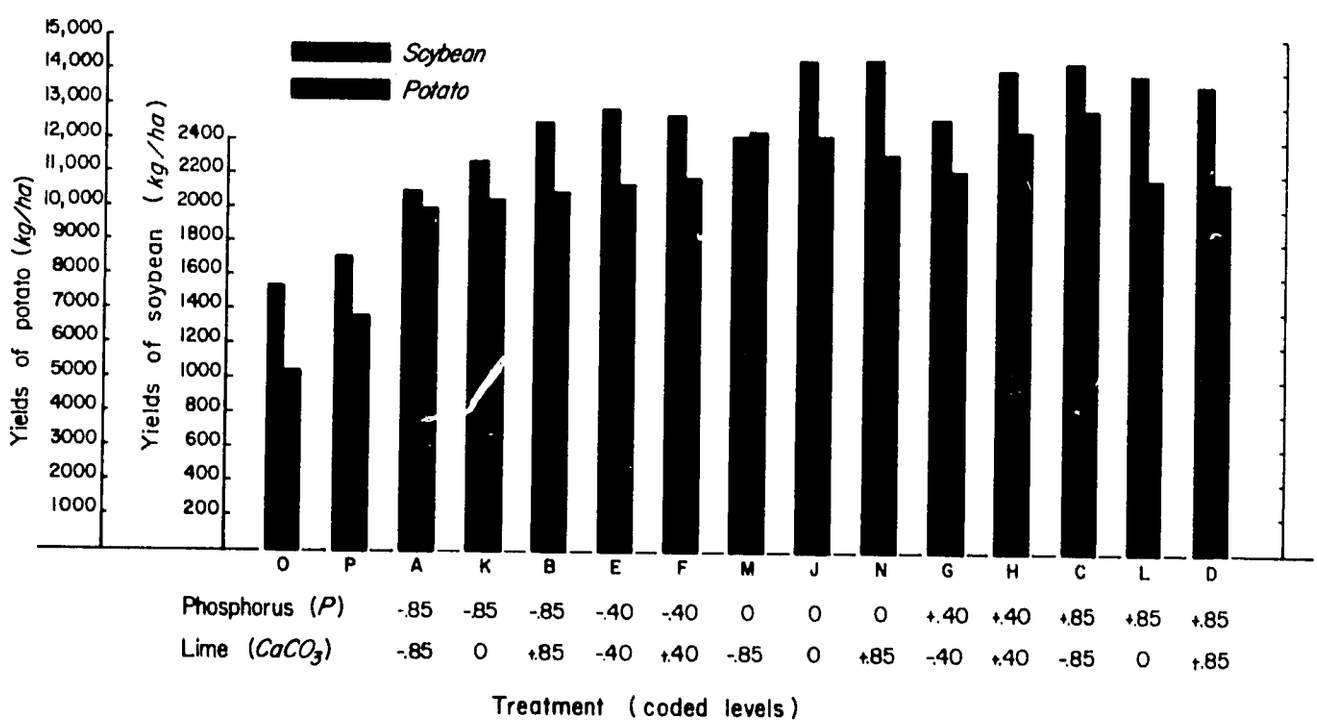


Fig. 22. When phosphorus is applied during one year, its effects last for several more years. Residual phosphorus from previous transfer experiments on soybeans was sufficient for high yield of potatoes the next year at LPH in Indonesia.

ple demonstration convinced the Philippine Union College (PUC), owner of the primary site, to plant about 7 ha of corn using chicken manure obtained from the college poultry farm to raise feed for the chickens. Maize is generally not grown in the area because of very poor yields without phosphorus fertilizer.

Solar Radiation and Plant Density

Maize grain yield in the Tropeptic Eutrustox network is generally greater than that obtained in the Hydric Dystrandept network because of the isohyperthermic temperature regime in the former and the isothermic regime in the latter (the isohyperthermic regime implies the availability of more direct sunlight, see pages 25–27).

To determine the optimum planting density of maize for the most efficient utilization of incoming solar radiation in the Tropeptic Eutrustox network, a plant population and variety experiment with maize was designed and planted in Jaiba, Brazil. Maize grain yields were found to be highest with plant populations of 40,000 to 60,000 plants/ha with row spacings of 50 and 75 cm (Fig. 24). Close planting within rows, however, resulted in crowding, which reduced yields markedly in variety 'Cateto Colombia' and less markedly in variety 'Piranão'. In fact, 'Piranão' appears to thrive in a high plant population with close planting except at the closest plant spacing.

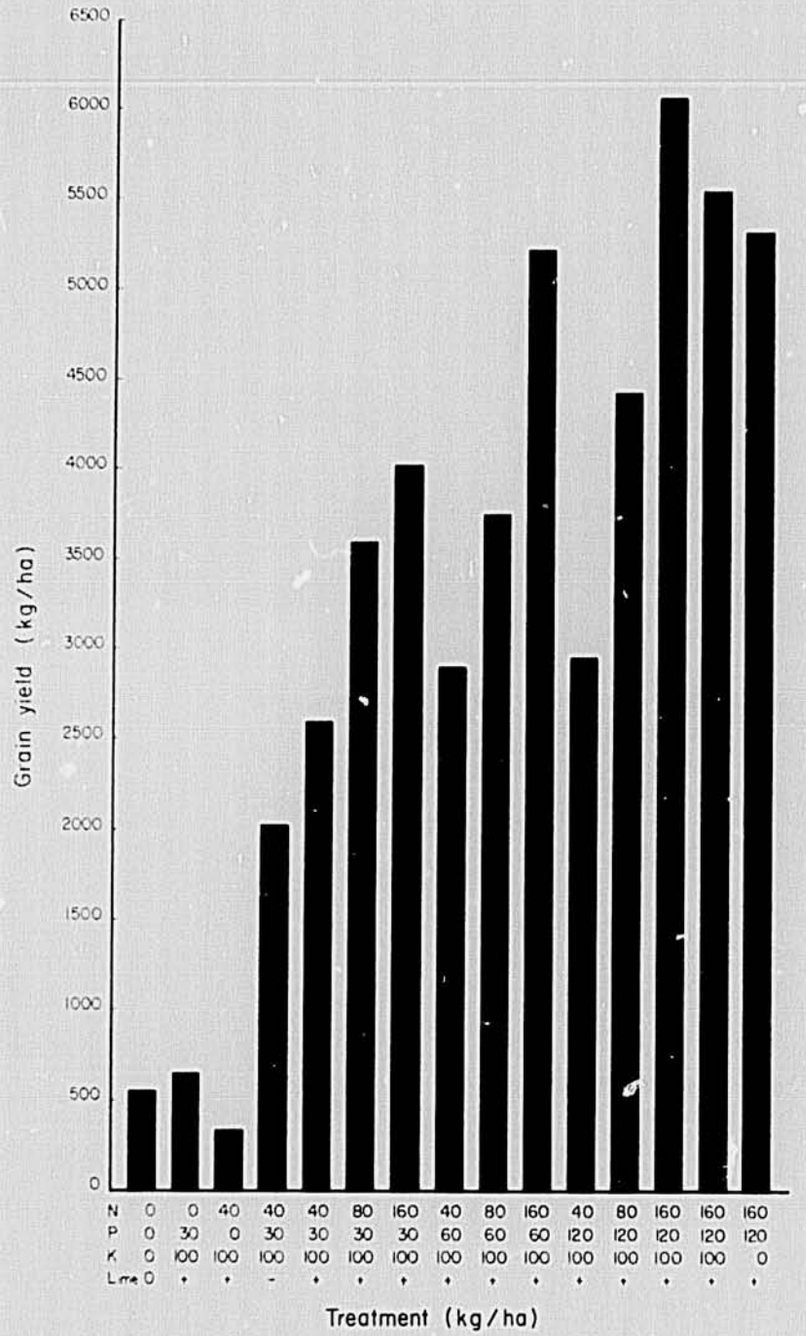
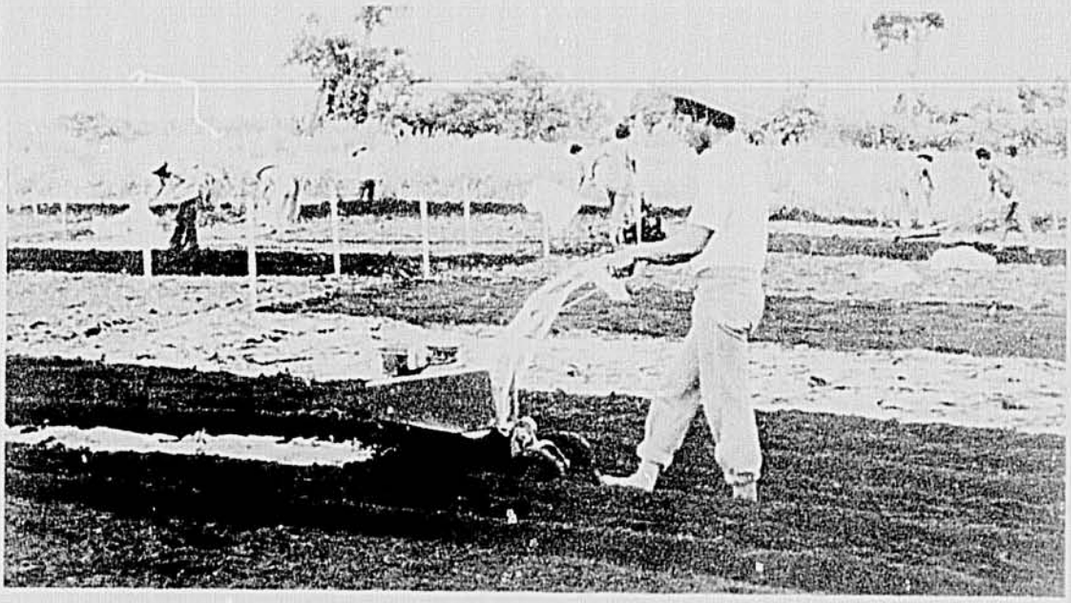


Fig. 23. The variables that affect yield the most are nitrogen and phosphorus; lime and potassium did not contribute to greater crop growth in these experiments at PUC in the Philippines.



Fertilizing and rototilling (here at the Palestina site, the Philippines) are two of the management practices required before planting. The Benchmark Soils Project experiments currently in progress will help determine the quantity and type of fertilizer required for crops on each soil family.

Table 24. Sources of phosphorus, maize management experiment, PUC site, 1976

Treatment				Mean grain yield (kg/ha)
Inorganic (kg/ha)				
N	P	K	Lime	
50	0	50	600	49
50	50	50	600	860
50	50	50	0	1232
100	50	50	600	747
50	100	50	600	849
Organic (tons fresh weight)				
Chicken manure (2 tons)				1029

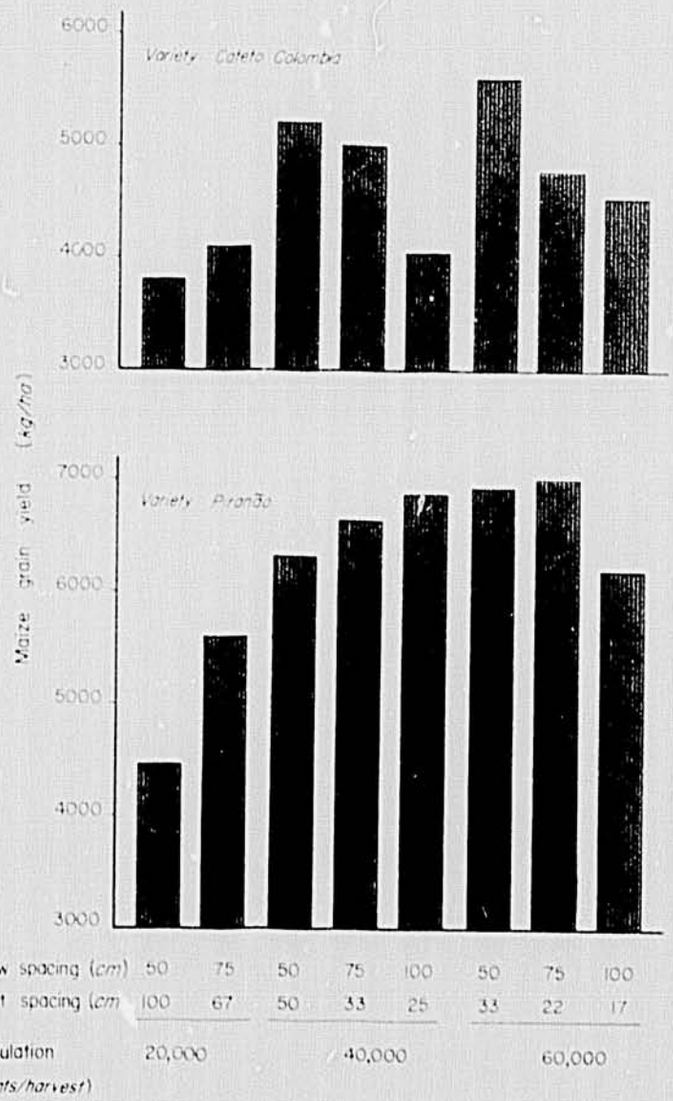


Fig. 24. A maize variety trial was conducted on the Tropeptic Eutrustox at Jaiba, Brazil, to determine the optimum planting density to best utilize the available sunlight.

DEMONSTRATING THE USEFULNESS OF SOIL CLASSIFICATION TO SOIL INTERPRETATION AND LAND CLASSIFICATION

The fine art of agroproduction technology transfer hinges on the international adoption of a standard soil classification system based on uniform standards, to enable communication and exchange of information by means of a common technical language. *Soil Taxonomy*, the system of soil classification developed by the Soil Conservation Service of the U.S. Department of Agriculture, is the most comprehensive and widely accepted system today.

This system, however, requires further refinements in the classification of soils of the tropics, where information is largely incomplete. The Benchmark Soils Project is assisting in gathering soils data and increasing information exchange within a network of typical soils. Because of the Benchmark Soils Project approach, the value of soil classification and *Soil Taxonomy* to host-country cooperators is becoming increasingly evident.

Training courses in soil resources inventory and the transfer of agrotechnology (see page 56) were held in the Philippines in May and June 1977, organized by the Benchmark Soils Project and Cornell University, under the auspices of the Consortium on Soils of the Tropics (CST), in cooperation with the Philippine Council for Agriculture and Resources Research (PCARR) and the Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA). In addition, in association with CST, USAID, and the Benchmark Soils Project, the Servicio Nacional de Levantamento e Conservacao de Solos (SNLCS) of the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) and the Empresa Brasileira de Pesquisa Agropecuária de Minas Gerais (EPAMIG) hosted an international workshop on soil classification in Brazil in June 1977. A similar workshop is planned

Effective agroproduction technology transfer hinges on the international adoption of a standard soil classification system.

All these workshops are concerned with the application of Soil Taxonomy to tropical soils.

Based on clayey, kaolinitic, isohyperthermic Typic Eutrustox are suitable for production of pineapple, sugarcane, and [illegible] grown extensively in the State of Hawaii. Similar soils that occur elsewhere in the world can be used just as [illegible]

for August 1978 in Malaysia and Thailand. All these workshops are concerned with the application of *Soil Taxonomy* to tropical soils.

In-Country Workshops

The utilization of concepts developed by BSP is being initiated in both Indonesia and the Philippines.

In-country workshops on soil classification are planned for January 1978 in the Philippines by PCARR and for May 1978 in Indonesia by the Soil Research Institute (SRI) with the involvement of the Benchmark Soils Project. The utilization of concepts developed by the Benchmark Soils Project for effective land-use planning is being initiated in both Indonesia and the Philippines.

For example, in Indonesia, the Soil Research Institute established its own experimental site on a soil family in the Ultisol order in Lampung, South Sumatra in the latter part of 1977 using Benchmark Soils Project concepts and methodology. Analyses are underway to characterize the soil in Sumatra and identify the family. Currently, there is an ongoing resettlement program to distribute the population center from Java to Sumatra, and to ease the trauma of transmigration, there is an urgent need to determine and transfer knowledge of the management practices best suited for the Ultisols. Indonesians have learned that the farming practices used on the Andepts in Java cannot be transferred to the Ultisols in Sumatra. This application of Benchmark Soils Project concepts on soils other than the three test families demonstrates the importance of soil classification to needs of individual countries. Similar activities will likely be extended to other important soil families in Indonesia. The SRI has a key role in identifying the soils at nine agricultural stations that are established or to be established in Sumatra.

Indonesia already knows the farming practices used in the Andept soils in Java cannot be transferred to the Ultisol soils in Sumatra.

A technical committee was organized in 1977 under the leadership of D. Muljadi, Director of SRI. It is composed of scientists in agrotechnology, associated either directly or indirectly in the dissemination of scientific findings in Indonesia. The group comprises members representing various areas of agricultural research, agricultural planning and plan implementation, agricultural extension and training, and food technology, and the Soil Research Institute. The objectives of the committee are: (1) to coordinate and disseminate scientific findings among the allied scientific bodies in Indonesia; (2) to actively participate in agrotechnology transfer within Indonesia; (3) to discuss and suggest management and variety experiments to be undertaken at the primary sites in Indonesia; (4) to make periodic visits to Benchmark Project sites and gather first-hand information on management-level experiments; (5) to participate in the monitoring of agroclimatic data; and (6) to establish a close link with the activities of the Benchmark Soils Project within and outside the borders of Indonesia. The Technical Committee met twice during 1977—in May at the Soil Research Institute, Bogor, and in September at the primary site of the Institut

Senior students in soil fertility and management at Bicol University, College of Agriculture, visited the Benchmark Soils Project site at PUC, the Philippines, in February 1977.

Theologia Keguruan Advent (ITKA), Cisarua. Members of the committee had a chance to view the actual performance of both maize and soybean crops. The members agreed that experimental findings obtained thus far will go a long way in creating a positive impact on the local small farmers and decision-makers.

To ensure a correlation of the Indonesia soil classification system to *Soil Taxonomy* and the continuing use of *Soil Taxonomy* to interpret soil surveys of Indonesia, SRI has ordered 50 copies of *Soil Taxonomy* for distribution to agencies and institutions involved in agricultural research and development.

In addition, the Bureau of Soils in the Philippines has made plans to utilize the concepts of the Benchmark Soils Project to make recommendations on land utilization and management to the national government. Currently, soil surveys are being conducted throughout the Philippines. Key and extensive soils will be identified prior to implementation of field research activities.

Soil Data Bank

To extend the concept of transference of agrotechnology on the basis of the soil family in *Soil Taxonomy* to other potential users, the Benchmark Soils Project, in association with the Consortium on Soils of the Tropics (CST) and the Hawaii Agricultural Experiment Station (HAES), has expanded their Soil Data Bank to include soils of experimental locations in the tropics.

The Benchmark Soil Data Bank is a computerized system of data storage and retrieval that can be used to perform standard statistical analysis for interpreting soils data for different uses. Soil descriptions are stored either as a text or in a coded form, and chemical and physical data are stored as numbers. These data, as well as derived or calculated data, can all be easily and quickly retrieved.

To date, nearly 20 institutions and organizations have submitted a number of soil profiles with soil descriptions for characterization and classification by Project analytical laboratory personnel. In addition, several organizations have furnished laboratory data and soil descriptions for inclusion in the Soil Data Bank.

One of the objectives of the Project is to be a "storage house" of soils and soil-related data of the important agricultural research stations of the tropics. The Project, furthermore, will furnish the participants the soil classification names, according to *Soil Taxonomy*, of their soils. The data will be reproduced in a standard format similar to that in the Soil Survey Investigation Reports published by the Soil Conservation Service, USDA. The information can then be used for soil interpretations for agricultural or nonagricultural uses.

The Data Bank can serve as a focal point in establishing an effective network of research stations throughout the tropics. For the first time, this allows participants—scientists or planners—to share and exchange data of mutual interest.

PCARR, the Bureau of Soils, and the Soil Science Society of the Philippines are planning a three-day national conference-workshop on "Soil Resources Inventory for Countryside Development" for January 18–21, 1978 in Manila. A major component of the workshop is the use of *Soil Taxonomy* in development planning. Group sessions will identify the need for soil resources inventory for farmers, researchers, and planners, and proposals will be sought for soil resources inventory programs to support development planning. This activity, as well as Indonesia's own soil management experiments, utilizes the concepts of the Benchmark Soils Project.

The Data Bank can serve as a focal point in establishing an effective network of research stations throughout the tropics.

DISSEMINATING PROJECT INFORMATION FOR UTILIZATION

Contacts with the tropical world and the international agricultural community were established through the sponsorship of training programs, workshops, and coordination meetings; attendance at international workshops and conferences relevant to Project concepts

and objectives; publications of current Project developments; and linkages with research projects, programs, and institutions. Graduate students are supported in part by the Project, and their graduate programs are geared toward eventual use of Project concepts in their respective countries.

Training Programs

The course provided intensive training in soil classification and soil survey.

Two training courses were held at Los Baños, the Philippines, from May 9 to June 4, 1977, under the auspices of the 211(d) grant of Cornell University, the Benchmark Soils Project of the University of Hawaii, the Philippine Council for Agriculture and Resources Research (PCARR), the Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA), the University of the Philippines at Los Baños, the Bureau of Soils of the Philippines, and the United States Agency for International Development (AID). The course on "Soil Resources" provided intensive training in soil classification and soil survey for assessing soil resources; the course on "Utilization of Agrotechnology Transfer for Country Development" provided intensive training in the use of soil classification and field experimentation for soil survey interpretation and agrotechnology transfer. Both courses combined lectures and work sessions with field trips. Instructors were from the University of the Philippines at Los Baños, Cornell University, the University of Hawaii, SEARCA, the International Rice Research Institute (IRRI), and FAO/UNDP. The 42 participants came from Brazil, Indonesia, Malaysia, the Philippines, Thailand, and Puerto Rico. The University of Hawaii provided funds for attendance by six participants each from the Philippines and Indonesia; the University of Puerto Rico supported one each from Puerto Rico and Brazil. PCARR supported several participants from the Philippines and provided funds for supplies and field trip transportation. SEARCA provided logistical support and assistance in obtaining dormitory facilities and classrooms and in accounting of expenditures. Nine copies of *Soil Taxonomy* were used by the Benchmark Soils Project as reference teaching materials. At the completion of the course, these copies were distributed to the College of Agriculture and the Department of Soils Science at the University of the Philippines at Los Baños; Central Luzon State University; the College of Agriculture and the Department of Soils at Mindanao State University; Visayas State College of Agriculture; PCARR; the Bureau of Plant Industry; and the National Irrigation Authority.

Five graduate students—from the Philippines, Peru, Liberia, and the United States—are currently involved in programs related to various activities associated with the Project. Supporting agencies include the Benchmark Soils Project, the National Science Foundation, the East-West Center, AID, and the International Potato Center (CIP). Graduate students have key roles in data collection, organization, and analysis. In the Project extension, funds were allocated to support two graduate students per cooperating country.

About 50 people from seven countries participated in the training programs on soil resources, soil classification, field experimentation, and the transfer of agrotechnology, sponsored in part by the Benchmark Soils Project, which were held at Los Baños, the Philippines, in 1977.

Conferences and Workshops

Workshop on Experimental Design

The "Workshop on Experimental Designs for Predicting Crop Productivity with Environmental and Economic Inputs" was held at the University of Hawaii in May 1974 and attended by 38 participants from the United States and abroad in the fields of agricultural economics, statistics, soil science, and agricultural research in tropical countries. Fourteen papers were presented. This initial workshop by the Benchmark Soils Project was devoted to the discussion of the research methodology and the experiment designs to be employed by the two Projects. Position papers by the Universities of Hawaii and Puerto Rico provided the framework for discussion of various aspects of the approach and design of the experiments to be implemented.

ICRISAT Seminar

A seminar entitled "The Uses of Soil Survey and Classification in Planning and Implementing Agricultural Development in the Tropics" was held at Hyderabad, India, under the auspices of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in January 1976. Contributions to the seminar were compiled and gathered under the title *Soil Resource Data for Agricultural Development*, edited by L.D. Swindale, to be published by the Hawaii Agricultural Experiment Station with funding by AID as a hardcover book.

Fertilizer INPUTS Project Meeting

The Benchmark Soils Project was invited to participate in the "Review Meeting of the Fertilizer INPUTS Project" sponsored by the East-West Center in Honolulu in 1976. Participants representing Africa, Asia, and Pacific basin countries agreed that the soil family concept would be an appropriate means of extending information from the INPUTS project to other locations as well as among cooperators within the project. Adoption of this concept will provide a basis for future comparison of results. Several participants provided soil characterization and classification data for use in classifying their soils at the family category of *Soil Taxonomy*. The information provided was combined with those obtained from participants of the ICRISAT seminar and placed in the Soil Data Bank for storage, retrieval, and dissemination.

South Pacific Regional Meeting

At the request of AID, L.D. Swindale of the Benchmark Soils Project participated in the "Regional Technical Meeting on Soil Science and Land Use" in Suva, Fiji in 1976. Particular interest was expressed by the Fiji government in the concepts of the Benchmark Soils Project, and members of the meeting agreed that governments with important soils in the soil families covered by the Benchmark Soils Project should consider taking part in the program to draw from the wide range of knowledge now becoming available from other parts of the world, and that the concept of a regional Benchmark Soils Project on soils important to the region should be accepted as the basis for a follow-up soils- and land-use program. Governments should be requested to support this work.

The Fiji government expressed particular interest in the concepts of the Benchmark Soils Project.

CLAMATROPS Conference

F.H. Beinroth, H. Ikawa, and L.D. Swindale attended the CLAMATROPS conference in Kuala Lumpur, Malaysia, August 15–20, 1977. The conference, organized by the Malaysian Society of Soil Science, allowed scientists from tropical areas to participate in discussions on the classification and management of tropical soils. Swindale presented a paper entitled "The Benchmark Soils Project—An Innovative Approach to Agrotechnology Transfer," coauthored by Swindale, J.A. Silva, and Beinroth.

Participants agreed that the soil family concept would be an appropriate means of extending information to other locations.

Hilly Land Development Workshop

A.A. Briones and B.G. Cagauan, Jr., participated in the International Workshop on Hilly Land Development held in Legaspi City, the Philippines, August 3–6, 1977, and presented a paper entitled "The Soil Family as a Basis for Extension of Agrotechnology in Hilly Lands." This workshop was attended by delegates from Korea, Indonesia, Malaysia, Taiwan, Thailand, Hawaii, and the Philippines. During the three-day workshop, participants

The problems of hilly land development closely parallel the research activities on upland soils by the Benchmark Soils Project.

proposed various research programs to study the problems of hilly land development, which closely parallels the research activities on upland soils by the Benchmark Soils Project. Fifteen delegates visited the Benchmark Project site at Naga City and were briefed on Project methodology and its implications for hilly land development.

Brazil Soil Classification Meeting

Benchmark Soils Project personnel H. Ikawa and G. Uehara participated in an international soil classification workshop in Brazil in June 1977 to examine *Soil Taxonomy* as it relates to soils of the tropics. The workshop was cosponsored by the University of Puerto Rico, AID, and Servicio Nacional de Levantamento e Conservacao de Solos (SNLCS) of EMBRAPA (Brazil) and attended by 64 soil scientists from Africa, Asia, Oceania, North America, and South America. The workshop was a major success because all participants agreed to use the language of *Soil Taxonomy*. The workshop clearly demonstrated that a common knowledge base is essential for effective communications and agrotechnology transfer. For this reason, the Benchmark Soils Project supports the concept of a single international soil classification system.

A common knowledge base is essential for effective communications and agrotechnology transfer.

Annual Coordination Meetings

Two Project coordination meetings have been held: one at the University of Puerto Rico, Mayaguez, August 17–20, 1976, and the other at the Philippine Village Hotel, Manila, the Philippines, August 9–13, 1977. These meetings provided the opportunity for Project personnel to report progress and discuss problems of preceding years and to develop improved methodologies and approaches for experiments. In addition to Project personnel, representatives from FAO/UNDP, the University of the Philippines at Los Baños, SEARCA, the Philippines National Economic Development Authority (NEDA), the Philippine Bureau of Soils, ICRISAT, the International Institute of Tropical Agriculture (IITA), and AID Manila and Washington and the Research Advisory Committee attended the meetings in the Philippines.

Publications

Quarterly Report

The Benchmark Soils Project Quarterly was first printed in March 1977 to disseminate information on Project activities and on the progress of Project planning to in-country cooperating government agencies and institutions, local AID missions and other interested parties. Combining contributions from Project personnel in Brazil, Hawaii, Indonesia, the Philippines, and Puerto Rico, the quarterly is produced and printed by Hawaii Project personnel for worldwide distribution.

The Benchmark Newsletter in the Philippines has been temporarily discontinued due to the workload of Project activities at both Naga City and Davao. A newsletter written in Indonesian is being planned for distribution in that country.

Soil-Resource Data for Agricultural Development

The book entitled *Soil-Resource Data for Agricultural Development* is expected to be in print by August 1978. This book is the end-product of the seminar on the "Uses of Soil Survey and Classification in Planning and Implementing Agricultural Development in the Tropics" held in Hyderabad, India in 1976.

Proceedings on the Workshop on Experimental Design

The proceedings of the workshop on experimental design held in Honolulu in 1974 are undergoing final editing and should be available for distribution in late 1978. Delays in publishing the results of the workshop were due primarily to the transcribing and editing of the discussion sessions, which were subsequently deleted. The significant and salient points of the discussion sessions were reported in a "Report of the Workshop on Experimental Designs for Predicting Crop Productivity with Environmental and Economics Inputs" by J. A. Silva and F. H. Beinroth (Hawaii Agr. Exp. Sta. Dept. Paper 26).

LINKAGES WITH COOPERATING AGENCIES AND ORGANIZATIONS

Official and unofficial linkages are considered an essential element of the Benchmark Soils Project. In the course of site selection, contacts were established with numerous institutions and individuals in LDC's and in the U.S. These have already been mentioned in the previous section on the network of experiment sites (see pages 14–17). The following are status reports of collaborative linkages.

International Institute of Tropical Agriculture (IITA)

A memorandum of agreement between the Benchmark Soils Project, University of Hawaii, and the International Institute of Tropical Agriculture (IITA), Nigeria, was approved by both parties in March 1977. William K. Gamble, Director of IITA, agreed to have Frank Moormann, Pedologist, and A.R. Juo, Soil Chemist, assist the Benchmark Soils Project in locating suitable sites on a family of Ultisols in Cameroon. Joseph M. Menyonga, Chief of the Institute of Agricultural and Forestry Research in Ekona, Cameroon, was consulted by both parties before signing the agreement. Moormann also enlisted the services of G.W. van Barneveld, Manager of the FAO Soil Science Project in Ekona, to assist in conducting a reconnaissance soil survey for possible experimental sites. Soils in the area near Barombi-Kang in the Cameroons have been tentatively classified as clayey, kaolinitic isohyperthermic Typic Paleudults. The mineralogy of the control section was confirmed by X-ray analysis from samples sent to Hawaii. Site selection will commence in early 1978. A new agreement with IITA to assist in the implementation of site establishment and to allow B.T. Kang to serve as a resource agronomist was initiated in June 1977. Kang was invited to attend the second annual coordination meeting in the Philippines to discuss preliminary negotiations of the agreement and to review the agronomic activities of the Project.

Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG)

EPAMIG is the Project's principal cooperator in Brazil. In coordination with the national research institutions, EMBRAPA, EPAMIG is responsible for all aspects of agricultural research in the state of Minas Gerais. The president of EPAMIG, H. Mattana Saturnino, fully concurs with the principles and approach of the Project and realizes the potential benefits for the agricultural development of the state of Minas Gerais. Saturnino was personally involved in initial negotiations between EPAMIG and the University of Puerto Rico. The administration and staff of EPAMIG have given the Project excellent cooperation.

The administration and staff of EPAMIG have given the Project excellent cooperation. Viable linkages were developed with the AID 211d and INTSOY programs.

Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA)

The Project has established very effective working relationships with the Servicio Nacional de Levantamento e Conservacao de Solos (SNLCS) of EMBRAPA. SNLCS has expressed interest in getting more directly involved in the Project, and informal contacts are maintained with the EMBRAPA administration in Brasilia.

International Soybean Program (INTSOY)

Since soybeans were used as an indicator crop in the early experiments, viable linkages were developed with UPR's AID 211(d) soybean grant and the AID-sponsored INTSOY program. Superior working relationships exist between INTSOY's plant breeder stationed in Puerto Rico, E.H. Paschal II, which resulted in joint field research of mutual benefit.

East-West Center

The Benchmark Soils Project has continued to provide information and assistance to the INPUTS (Increasing Productivity Under Tight Supplies) program of the East-West Center in Honolulu. To avoid site-specific re-

search, project investigators recommended to Saleem Ahmed, Research Associate responsible for INPUTS, to have all cooperators classify their soils so that experimental results obtained can be compared with or utilized at other locations with similar soils. The Benchmark Soils Project has agreed to assist in the classification of these soils. Soils and plant data from key experiment stations of some of these tropical countries may be added to the Benchmark Soil Data Bank.

The Benchmark Soils Project has agreed to assist in soil classification.

Hawaii NifTAL Program

A collaborative experiment between the Benchmark Soils Project and the NifTAL project (ta-C-1207, Nitrogen Fixation by Tropical Legumes) at the University of Hawaii was installed at the Iole primary site in September 1977. The experiment seeks to obtain a field evaluation of the relative effectiveness of selected Rhizobium strains in comparison with (1) a standard strain; (2) application of nitrogen (urea); and (3) an uninoculated control. The test crop was the soybean cultivar 'Jupiter', which was used in the transfer experiments at each of the Hawaii sites.

Consortium on Soils of the Tropics (CST)

The Project is closely linked to and complemented by the 211(d) grant AID/csd-2857 entitled "Classification and Microbiology of Tropical Soils." Under this grant, efforts are made to identify and evaluate the advantages and deficiencies of *Soil Taxonomy* relative to tropical soils. This state-of-the-art study is carried out with assistance from the sister universities comprised in the Consortium on Soils of the Tropics (CST). It will also be determined which systems of soil classification are currently used in the tropical countries and how these systems relate to *Soil Taxonomy*. It is anticipated that the grant will create a keener awareness of the advantageous attributes of *Soil Taxonomy* among LDC soil scientists. This awareness should expedite the utilization of project results in nonparticipating LDCs.

It will be determined which systems of soil classification are used in tropical countries and how they relate to the Soil Taxonomy.

Missions

Brazil. Effective rapport has been developed with the AID Mission in Brasilia. Although under no obligation to do so, the Mission provided the Project with valuable cooperation and support, which greatly facilitated Project implementation in Brazil.

Indonesia. Project linkage with the AID Mission in Indonesia is through a formal Implementation Agreement signed in April 1976 between AID, SKI, and the University of Hawaii, covered under the AID Assistance to Agriculture Project No. 497-11-110-189. W.C. Tappan of AID/Jakarta, the contact man, was always in constant coordination with Project activities. He has been responsible for making the necessary arrangements for tax-free entry of Project supplies and equipment to Indonesia.

Philippines. The AID Mission in the Philippines facilitated clearances for travel of project personnel by Lane Holdcroft, Assistant Director for Agricultural Development, and William McCluskey, Agriculture Advisor, working closely with PCARR. In Naga, Don Wadley, Assistant Director for Rural Development, has been in close contact with the Project and has had the opportunity to get a field tour and orientation of the primary site. Occasional arrangements for transportation have been made by him for Project guests who visit the Naga operations.

Other Countries. Linkages with local AID Missions or offices will be established as the Project moves along to establish other sites. The AID office for regional development at Yaounde, Cameroon will be contacted for assistance once the plans for Project establishment are finalized.

Other Linkages

Informal linkages further exist with the International Center for Maize and Wheat Improvement (CIMMYT), FAO of the United Nations, the Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM), the Soil Conservation Service of the USDA, and the University of Ghent, Belgium.

IMPLICATIONS OF THE BENCHMARK SOILS PROJECT TO AGRICULTURAL DEVELOPMENT IN THE TROPICS

The Benchmark Soils Project is laying the groundwork to establish relationships between production and land use for the benefit of planners. This will be realized in the later stages of the Project when sufficient soil and crop data are available. The land evaluation criteria proposed by the FAO (A Framework for Land Evaluation, FAO, 1976) will be used by the Project.

The FAO system depends on formulating relationships between crop requirements and land qualities. The land qualities themselves can be extracted from soil surveys based on a comprehensive soil classification system such as *Soil Taxonomy*. Examples of land qualities are the water-supplying capacity of land, the nutrient supply, the energy (sunlight and temperature), erodability, accessibility, and so on.

The water-supplying capacity of land, for example, might take into account such land characteristics as slope, soil texture, soil depth, and soil mineralogy as well as rainfall intensity and distribution. It is also possible to integrate socioeconomic factors into the relationship between crop production and land suitability. Socioeconomic factors are expected to play an increasingly crucial role in land evaluation as the mismatch between the water-supplying capacity of land and the crop requirements become greater. In the final analysis, the planner will judge land use on the basis of social and economic benefits.

International agreement on three issues will facilitate agrotechnology transfer and planning for the world's food production. These issues are:

1. Adoption of a standard international soil classification system for making and interpreting soil surveys;
2. Adoption of a standard framework for land evaluation; and
3. Adoption of a standard method of displaying land classes for planners and decision-makers.

A newly-cleared transmigration area in Sumatra has soils classified as Ultisols, and transmigrated farmers need information on managing these soils, which are very different from the Andepts found in their native island of Java.

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An overview of the organization of the Benchmark Soils Project is shown in Fig. 25.

personnel

Brazil

Agronomists:	Christopher E. Seubert
	Mervyn L. Olson
	Umbemar Silveira Dias
Research Aides:	Narbal de Sá
	Marcos A.C. Torres
Field Foreman:	Delcino C. Jorge
Secretary:	Carolyn Seubert

Hawaii

Principal Investigator:	James A. Silva
Soil Scientist:	Goro Uehara
Associate Soil Scientist:	Haruyoshi "Ike" Ikawa
Project Associate:	Gordon Y. Tsuji
Hawaii Agronomist:	Alan R. Hurdus
Training Coordinator:	Bernardino G. Cagauan, Jr.
Editor/Publications Specialist:	Cynthia L. Garver
Data Analyst/Computer Specialist:	Clement P.Y. Chan
Administrative Aide:	Jill D. Kosaki
Secretary:	Annette E. Chang
Laboratory Technicians:	Ada E. Chu
	Dwight T. Tanoue
Agricultural Technicians:	
Hawaii	William K.Y. Wong
	James Couttie
	Lawrence Pasco
	Rendell S. Hirano
	Richard M. Uehara
Molokai	Thomas R. Hill
Oahu	Stephen B. Thomas
Graduate Assistants:	Crisanto R. Escano
	David J. Harris
Consultants:	Foster B. Cady
	Wayne H. Hudnall
	Tung-Ming Lai
	Alberto T. Valmidiano

Indonesia

Project Leader:	Rajasuri George Manuelpillai
Project Coordinator:	I Putu Gedjer Widjaja-Adhi
Farm Managers:	Ir. M. Aljabri
	Ir. Didi Ardi S
	Ir. Sholeh
Secretary/Typist:	Ratna Julia
Research Aides:	Murdani Diredja
	Dadin Suhendra
	Anda Suhandi
	Arman P.H.
	Udin Hasaunudin
	Lulus Sunario
	Seno Widiaksana
Driver, Benchmark Vehicle:	Abdul Rachman

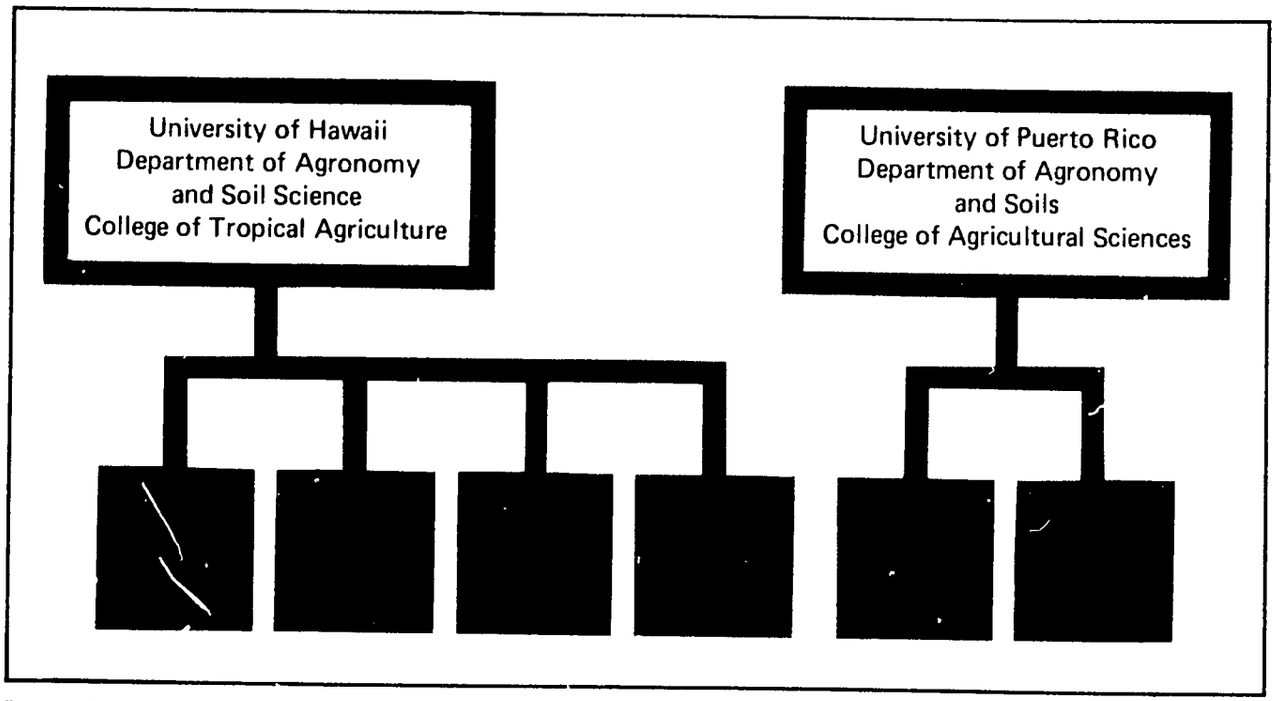


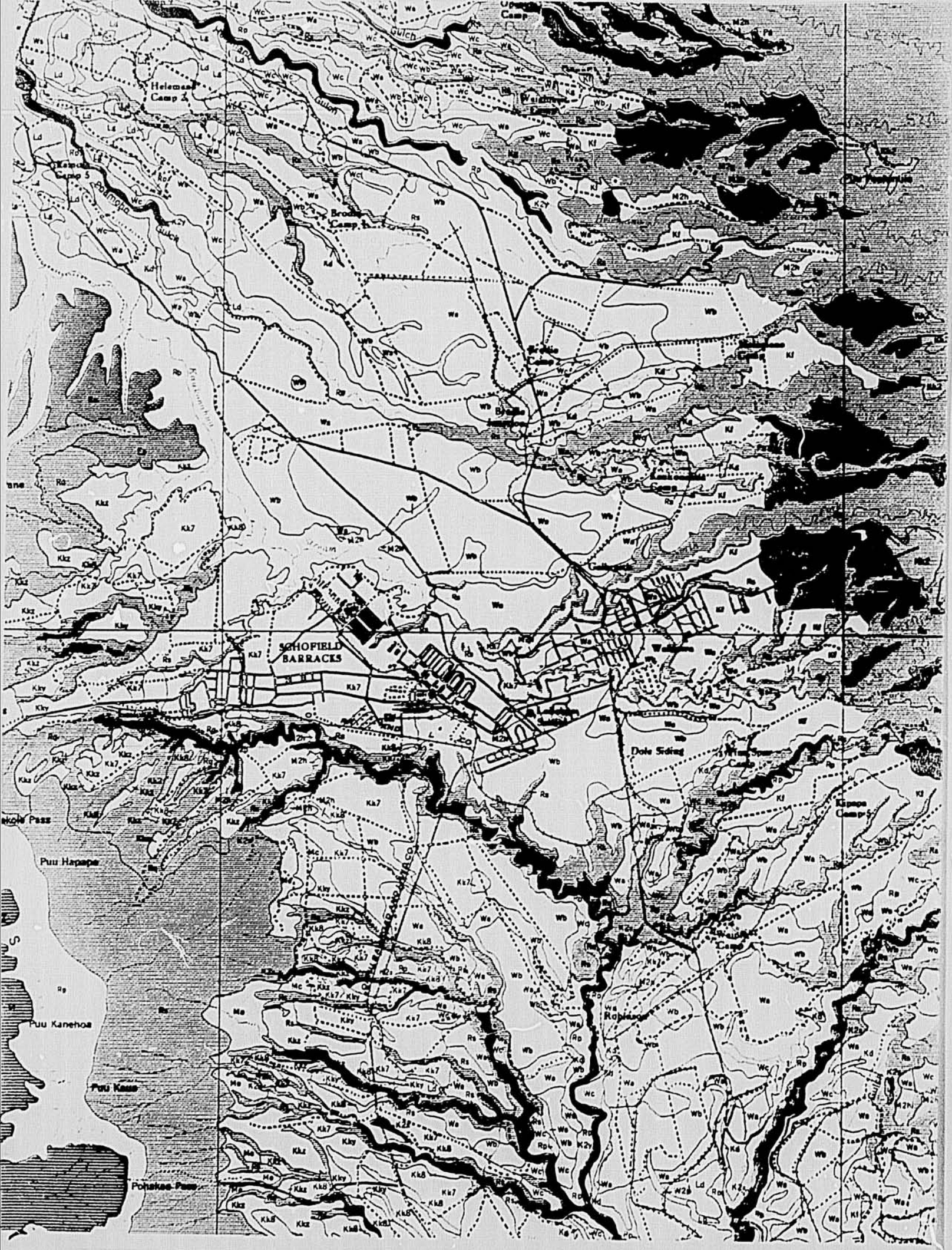
Fig. 25. Country and institutional organization of the Benchmark Soils Project.

Philippines

Project Leader:	Martin E. Raymundo
Co-Project Leader:	Aurelio "Olo" A. Briones
Assistant Co-Project Leader:	Amado R. Maglinao
Field Operations Coordinator:	Perfecto "Pec" R. Vicente
Liaison Officer (Davao):	Pedro O. Sagrado
Farm Manager (Davao):	Israel M. Clemente
Administrative/Fiscal Assistant:	Penafrancia "Anchie" P. Pago
Secretary (Davao):	Julieta I. Bravo
Clerk Typist (Naga):	Nydia Saavedra
Research Assistant (Naga):	Alberto Borromeo
Research Aides:	Rogelio C. Arco (Naga)
	Jaime N. Gibe (Davao)
	Cristino Modino (Naga)

Puerto Rico

Headquarter Staff (Mayaguez)	
Principal Investigator:	Friedrich H. Beinroth
Senior Agronomist:	Gene L. Spain
Laboratory Staff:	Luis Carlos Sarmiento
	Lillian Costa Mayoral
	Juan A. Vega Lopez
Consultants:	Jack Keller
	Larry A. Nelson
Graduate Assistant:	Arturo Orquera
Administrative Aide:	Elsie Gonzalez Sanchez
Secretary:	Ingrid A. Velez Ramos
Isabela Site Staff	
Agronomists:	Jose Badillo Feliciano
	Stevan P. Nightengale
Research Aides:	Faret Mercado Badillo
	Luis Calduch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Dole Siding
Puu Hapapa
Puu Kanehoa
Puu Kaua
Pohakea Pass
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Helemano Camp 5
Brodie Camp 1
Brodie Camp 2
Brodie Camp 3
Kipapa Camp 5
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On the cover: Soil classification is the first step in applying the principles of the Benchmark Soils Project and in transferring agrotechnology throughout the tropics. Soil pits were dug at Cibodas, Indonesia, and the soil was classified as the thixotropic, isothermic family of Hydric Dystrandepts.

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