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Benchmark Soils Project
Progress Report 2
Jan. 1978–June 1979

Development of the Transfer Model and Soil Taxonomic Interpretations on a Network of Three Soil Families

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BENCHMARK SOILS PROJECT

Dear Friend:

The Benchmark Soils Project is an internationally based research project testing and demonstrating that agroproduction technology can be transferred from one location in the tropics to another based on the soil family classification in Soil Taxonomy. Early results of the research conducted to date on the transfer hypothesis indicate that this is true.

This second Progress Report of the Benchmark Soils Project presents the results of BSP research from January 1978 through June 1979. (Results of previous research are found in Progress Report 1, available from the addresses on the back cover.) Emphasis is on the verification of the hypothesis that soils belonging to the same family, according to Soil Taxonomy, have a homogenous set of characteristics that can be used to predict crop response and performance under specified levels of management. Experimental results are presented only to the extent needed for the statistical and taxonomic interpretations.

Tests to demonstrate the validity of the transfer hypothesis are addressed from two viewpoints. First, an interpretative approach is used to predict crop yields by matching soil family characteristics to crop requirements. Second, actual yields are analyzed by a statistical model developed to test the transfer hypothesis. We have not reiterated at length the basic rationale of the Project or the generalities on research strategy and experimental methodology; for more detailed information on these aspects, various publications of the Benchmark Soils Project can be reviewed (see Appendix 3).

While the immediate objective of the Benchmark Soils Project is to test scientifically the hypothesis of the transfer of agroproduction technology based on information contained in the soil family name, the ultimate goal of the Project is to ensure that the world will be able to feed itself. In the next quarter of a century, the world will have 2 billion more people to feed. There is little doubt that there is enough land and proper technology to produce enough food to meet the anticipated population increase; but there is considerable doubt as to whether the food will be produced where it is most needed or be distributed in an equitable manner. Research efficiency needs to be met, and agroproduction technology transfer is one way to achieve research efficiency.

Agrotechnology transfer as a means to meet the world's food demand will require international coordination. A common soil classification system used by participating agencies and countries is essential, and a uniform procedure for making and interpreting soil surveys based on a common system of classification must be employed. International cooperation in these areas will render decision-making for national and global food strategy easier and more accurate.

We invite additional input and participation by organizations and country leaders throughout the tropics. Your comments and suggestions will be appreciated.

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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.

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

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Development of the Transfer Model and Soil Taxonomic Interpretations on a Network of Three Soil Families

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All reported opinions, conclusions, and recommendations are those of the authors (contractors) and not those of the funding agency or the United States government

Highlights of Progress

Establishment of a Network of Benchmark Soil Families

Three soil families from upland areas that have the potential to be productive under appropriate management practices were selected to test the hypothesis of agrotechnology transfer.

- Detailed soil surveys were conducted in nine countries, and a network of three soil families has been established on 23 experimental sites in Brazil, Cameroon, Hawaii, Indonesia, the Philippines, and Puerto Rico.
- The network of Hydric Dystrandepts is fully operational; field operations are in progress on all nine sites.
- The network of Tropeptic Eutrustox was completed with the addition of a site in Puerto Rico; experiments are in progress on all eight sites.
- The network of Typic Paleudults is nearing completion with site establishment and field operations in Indonesia and the Philippines; a memorandum of understanding was approved in Cameroon, and field operations are expected to begin in Cameroon by 1980.

Development and Successful Test of a Statistical Model for Agrotechnology Transfer

Initial statistical tests on the Hydric Dystrandepts were released in 1978 and in 1979, suggesting that the hypopthesis of agrotechnology transfer from one location to another on the basis of the soil family will very likely be verified and that crop response can be predicted.

- A total of 78 transfer experiments were conducted on the three soil families from Jan. 1978 to June 1979 to generate data for statistical tests of the transfer hypothesis.
- The statistical test of the transfer model combines data of experiments from different countries and sites on one family and predicts the yield response of maize at another site of the same soil family.
- Early tests of the model on the Hydric Dystrandepts were successful.
- The Project demonstrated that there is a similarity of response to phosphorus in soils that are widely separated but are within a common soil family.

—Phosphorus was required on Hydric Dystrandepts to achieve acceptable maize yields, and response to nitrogen was generally marked throughout the Hydric Dystrandept network, especially at the highest phosphorus rates.

—On the Tropeptic Eutrustox, the transfer experiments produced the highest yields to date: 12 metric tons/ha. Less phosphorus is required for acceptable maize yields on the Tropeptic Eutrustox than on the Hydric Dystrandepts.

—Yields on the Typic Paleudults were comparable to those of the Hydric Dystrandepts with marked response to nitrogen and phosphorus, especially on the Indonesia sites.

Demonstration of Soil Taxonomic Considerations

A nonstatistical approach to agrotechnology transfer through soil taxonomic considerations was completed, and is compiled in this Progress Report, as an example of predicting crop performance through Soil Taxonomy. It was demonstrated that the quantitative determinations for soil and environmental characteristics used in Soil Taxonomy lend themselves to evaluating criteria for land qualities for specific land use.

- The Project confirmed the expectation that the cool and wet environment of the Hydric Dystrandepts limits the available photosynthetic energy for crop production.
- The Project confirmed the expectation that the Tropeptic Eutrustox yields would be highest of the three soil families because of the energy available in the warm and dry environment inferred by the temperature and moisture regimes defined in Soil Taxonomy.
- The Project confirmed the expectation that the yields of the Typic Paleudults would be lower than the Tropeptic Eutrustox. The Typic Paleudults have a warm and humid environment.

Compilation of Crop and Soil Management Information

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

- A total of 14 variety trials were conducted on primary sites of all three soil families.
- Results on the Hydric Dystrandept network indicate that the best-adapted local variety, not a universal variety across sites, provides the best assessment of yield potential at a specific site.
- Results on the Tropeptic Eutrustox network indicate that a common variety exists for all sites across the network.
- A total of 32 management experiments were conducted on all three soil families.
- Nitrogen and phosphorus were found to be the most limiting nutrients for maize, and phosphorus and potassium, as well as molybdenum, were limiting nutrients for soybeans (Hydric Dystrandepts).
- Residual fertilizer experiments effectively demonstrated that phosphorus application is effective for several crops, and thus the net cost of fertilizer per crop is reduced (Hydric Dystrandepts).
- Addition of farmyard manure or corn stover with applied phosphorus produced higher yields than either organic material alone (Hydric Dystrandepts).
- Initial results from placement studies show promise for developing simplified fertilizer application techniques to maximize return from small phosphorus applications on soils with high phosphorus fertilizer requirements (Hydric Dystrandepts).
- Plant population or density reduction reduced grain yield per unit area but increased yield components, such as grain weight per plant and number of ears per plant (Tropeptic Eutrustox).

Development of a Framework for a Model Crop and Soil Data Bank

The crop and soil data bank was enlarged to include a weather data file. A combination of the three files is being systematized to provide a framework for the development of an interpretation data file.

Establishment of a Network of Cooperating Countries and Agencies

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

- The Project has entered into cooperative agreements with five agencies/institutions and established linkages with three international agricultural research centers.
- Project personnel participated in planning and organizing the international conference on the Operational Implications of Agrotechnology Transference Research that was held at Hyderabad, India, by ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) in October 1978.
- Project personnel were invited to assist in planning the February 1981 conference on Soils with Variable Charge to be held in New Zealand under the auspices of the International Society of Soil Science and the New Zealand Soil Bureau. A full day at the symposium has been set aside for the Benchmark Soils Project.
- Project personnel organized the Second International Soil Classification Workshop in Malaysia and Thailand, August–September 1978, under a special grant from the U.S. Agency for International Development.
- PCARR (Philippine Council for Agricultural Resources Research) and SRI (Soil Research Institute), cooperating agencies in the Philippines and Indonesia, convened Advisory Committees to provide guidance in the conduct of regional programs by the Project and to serve as a bridge between host-country scientists and planners.

Promotion of Awareness and Utilization of Project Concepts

Dissemination of results of research and the theories and implications of the Project, through participation in conferences and through publications, has stimulated interest in the Project and catalyzed utilization of the concepts in various areas.

- The mailing list for Project publications now numbers over 1400 people in more than 50 countries.
- Expressions of interest have been received from a number of countries, including Haiti and Rwanda.
- Brazilian officials of EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária) asked Project personnel for assistance in establishing a strategy to utilize the Benchmark Soils concept in Brazil. They visualize the linkage of a national network with an international network of soils.
- Indonesia envisions over 200 in-country agricultural development centers. Centers have already been established in Central and West Java, integrating various agricultural disciplines to test food crops for suitability for local farmers. The Centers are situated on benchmark and extensive soils of a particular area.
- SRI (Soil Research Institute) has also initiated a national Benchmark Soils network with the establishment of an experimental farm in South Sumatra, which has been operational since early 1978. SRI has been conducting soil surveys in Sumatra to identify soils on which nine agricultural research stations are to be situated; these stations may become part of a national Benchmark Soils network.
- A joint proposal for the classification of Philippine soils and the use of a Soil Taxonomy for agrotechnology transfer was prepared by Philippine Project personnel and representatives from BSP-cooperating agencies, the Bureau of Soils and PCARR (the Philippine Council for Agriculture and Resources Research) and the University of the Philippines, Los Baños.

Development of Training Packages for Soil Taxonomy and Agrotechnology Transfer

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

- Thirteen selected soil surveyors representing each of the designated agricultural sectors of the Philippines attended a workshop on Soil Taxonomy, its use and implications to agrotechnology transfer, developed and sponsored by the Benchmark Soils Project. A similar workshop is planned for 1980 in Indonesia and for 1981 in Cameroon.
- The immediate impact of the workshop was the support expressed by the Philippine government agencies for a coordinated plan for the participants to systematically classify soils at the experiment stations in each region according to Soil Taxonomy.
- Seven graduate students are sponsored by the BSP at the University of Hawaii; upon completion of their studies, the students will provide continuing utilization of the Project concepts and adaptation to future national needs.

Purpose and Scope

Rationale, Intent, and Perspectives

Since agricultural experimentation is both expensive and time-consuming, it is necessary to reduce site-specific research and capitalize on agricultural experience gained elsewhere. The underlying rationale of the BSP is that soil and crop management knowledge is directly transferrable in the tropics on the basis of the soil family as defined in Soil Taxonomy. The basic assumption is that information obtained from a soil family in one country can be applied to sites on the same soil family in the same or another country. Early results of the research conducted to date on the transfer hypothesis indicate that this is true. The ultimate objective is the development of a model of agrotechnology transfer based on soil interpretation and land classification to assist in ensuring adequate and equitable food production throughout the tropical world.

Recent events, especially the World Population Conference held in Bucharest in 1973 and the World Food Conference held in Rome in 1974, have brought the food and population problem of the Third World into sharper focus and new prominence. It is obvious that efforts to confront the steadily worsening food situation, especially in the tropical world, must consider the fact that fossil fuel shortages are no longer vague predictions but a reality, and that marked increases in the production of agricultural commodities will be restricted in many areas by the high cost of chemical inputs and by limitations in the environment. It is becoming evident that to meet the required food production growth rates for the developing market, the productive capacity in LDCs (less-developed countries) must be expanded by increases in both the yields per unit area and in the acreage of cultivated land.

"Soil Taxonomy describes procedures for identifying similar soils in similar environments on a global scale."

Time has shown 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 agrotechnology transfer 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 Contract No. AID/ta-C-1108 with the University of Hawaii in 1974 and Contract No. AID/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 1979, steps were taken to establish sites in Cameroon (Fig. 1). The network encompasses three soil families that are of importance in the tropics: the thixotropic, isothermic family of Hydric Dystrandepts; the clayey, kaolinitic, isohyperthermic family of Tropeptic Eutrustox; and the clayey, kaolinitic, isohyperthermic family of Typic Paleudults (Table 1; *see* Progress Rep. 1, 1978).

The concept in question is whether agrotechnology can be transferred from one tropical region to another tropical region on the basis of Soil Taxonomy at the soil family level of classification. To test the transfer hypothesis, a series of crop production and soil management experiments are being conducted in all three soil families.

The thrust of the Project is the acceleration and reduction of cost of agricultural planning and development in the less-developed countries (LDCs) through the process of agrotechnology transfer. Thus, the Project is testing an innovative approach to agrotechnology transfer in the tropics and developing a methodology designed to assist LDCs in effectively and appropriately utilizing their land resources for increased and better quality food production. As a result of Project research, these countries will bypass 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 (Fig. 2). The challenge is to increase food production to match the rising population pressure in a timely manner.

If proven correct, the concept will have a profound effect on food production in the world: millions of dollars worth of research information produced by thousands of man-year efforts will be available for immediate tapping; costs of site-specific trials all over the world will be saved; and a worldwide network of expertise to expedite and provide needed information for development will be established.

The basis for the Benchmark Soils Project is the soil family, as defined in Soil Taxonomy (Soil Survey Staff, 1975), which contains the

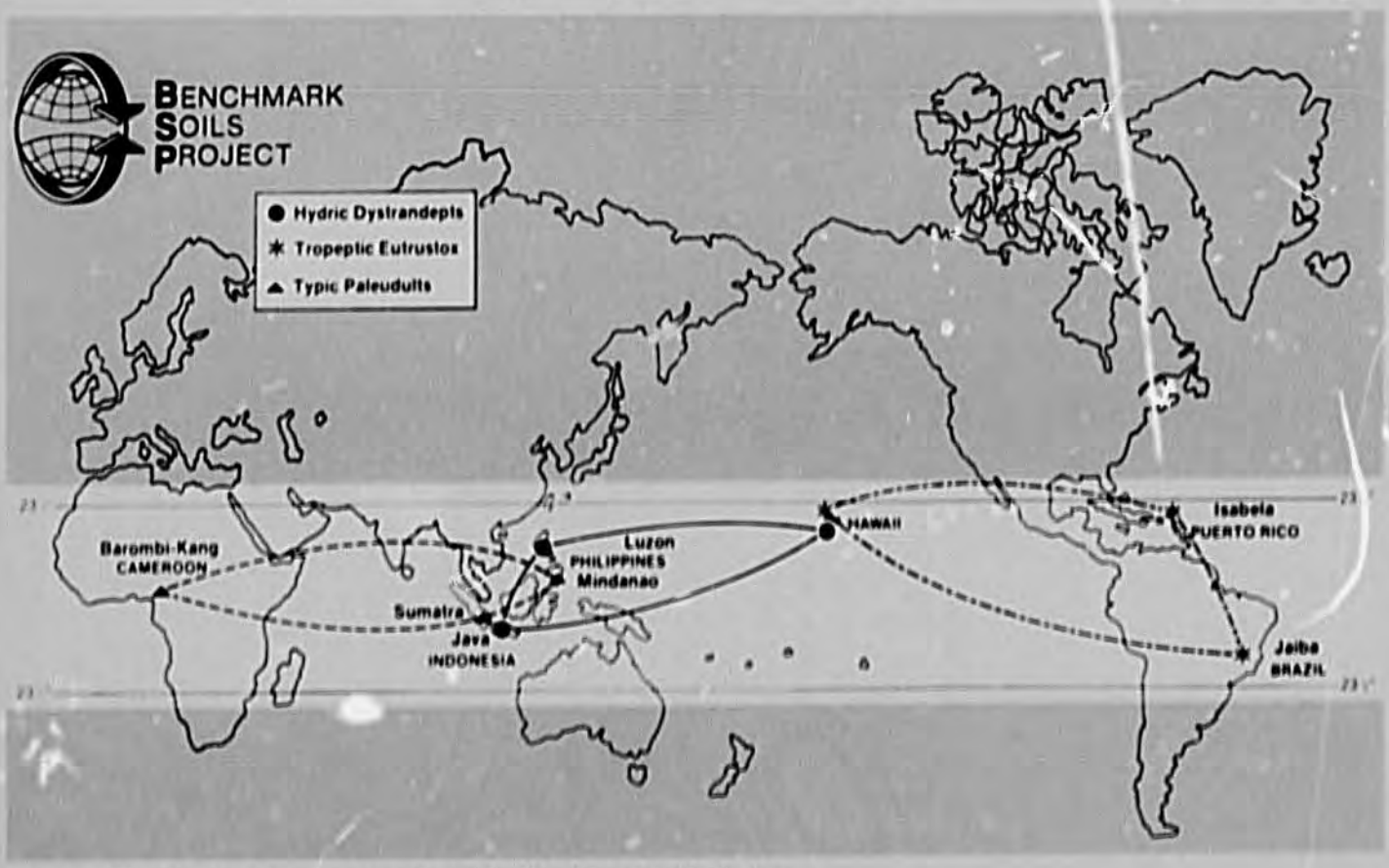


Fig. 1. The three soil family networks in the Benchmark Soils Project.

Table 1. Soil family network of experimental sites

Location	Site	Reference abbreviation	Type of experiment	Milestone[a] achieved
Soil Family A: thixotropic, isothermic Hydric Dystrandepts				
Hawaii	Niulii, Iole, North Kohala, Hawaii	IOLE	Primary	5
	Kukaiau, Honokaa, Hawaii	KUK	Secondary	5
	Niulii, Halawa, North Kohala, Hawaii	HAL	Secondary	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, Lemu[illegible]g, Java	PLP	Secondary	5
	Segunung, Cipanas, Java	LPH	Secondary	5
Soil Family B: clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox				
Puerto Rico	Isabela	ISA	Primary	5
	Isabela	ISA-2	Secondary	5
	Isabela	ISA-3	Secondary	5
Brazil	Paraná, Jaiba	PAR	Primary	5
	Bahia, Jaiba	BAH	Secondary	5
	Ceará, Jaiba	CEA	Secondary	5
Hawaii	Maunaloa, Molokai	MOL	Primary	5
	Wairio, Oahu	WAI	Secondary	5
Soil Family C: clayey, kaolinitic, isohyperthermic Typic Paleudults				
Philippines	Davao, Mindanao	BPI	Primary	5
Indonesia	Lampung, South Sumatra	NAK	Primary	5
	Lampung, South Sumatra	BUK	Secondary	5
	Lampung, South Sumatra	BPMD	Secondary	5
Cameroon	Barombi-Kang	CAM	Primary	3
	Southwest Province	CAN	Secondary	3

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

criteria for identifying similar soils in similar environments on a global scale. The book's publication in 1975 made it possible and profitable to assemble soils information in a systematic and standardized way for soil interpretation and land-use planning on a global scale. Its wide acceptance and its comprehensive and quantitative nature make Soil Taxonomy a powerful tool for agrotechnology transfer within and among tropical countries.

"The Project is developing a methodology designed to assist in effective and appropriate utilization of land resources."

The soil family was selected as the basis for the transfer 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 (Table 2). Thus, the soil family name constitutes a condensed scientific statement that integrates the knowledge about a soil with its environment (see Ikawa, 1978). Soils classified in the same family, therefore, should have nearly the same management requirements, a common response to cultural practices, and a similar potential for crop production.

The primary research objectives of the Benchmark Soils Project are to test the hypothesis that soil management and crop production knowledge can be directly transferred among

tropical countries at the soil family level of Soil Taxonomy and to establish that the behavior of tropical soils and their potential for food production under various levels of management inputs can be predicted on the basis of soil taxonomic units.

Implicit in these objectives are the substantiation of the value of soil survey and classification for land-use planning and the testing of the validity of the established taxonomic criteria. For a limited number of soil families, the Benchmark Soils Project is further attempting to indicate management alternatives that conform to the economic decision-making environment of small farmers in tropical LDCs.

An operational model for the statistical test of the transfer hypothesis has been developed by the Benchmark Soils Project, which appears to confirm what soil taxonomists have believed but have never verified—namely, that similar soils respond and perform alike.

Official linkages exist between the Project and host-country cooperating agencies:

- Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG), Brazil
- Office National de la Recherche Scientifique et Technique (ONAREST), Cameroon
- Philippine Council for Agriculture and Resources Research (PCARR), Philippines
- Soil Research Institute (SRI), Indonesia
- University of Hawaii (UH), USA
- University of Puerto Rico (UPR), Puerto Rico

Collaboration and informal linkages also exist with Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA); the International Institute of Tropical Agriculture (IITA); the International Soybean Program (INTSOY); the Consortium on Soils of the Tropics (CST); the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT); the Fertilizer INPUTS Program (Increasing Productivity Under Tight Supplies) of the East-West Center; the Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM); the International Fertilizer Development Center (IFDC); the Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA); the Hawaii NifTAL Program

Food crops are now being grown in South Sumatra in areas that were previously used only for tree crops such as rubber and cloves.

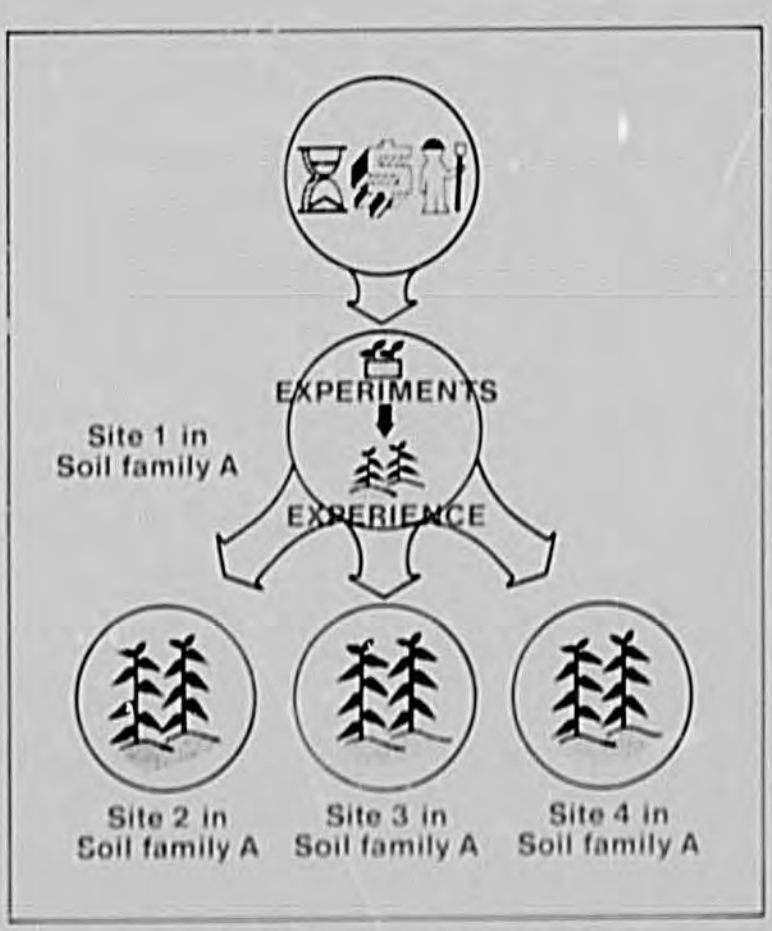


Fig. 2. As a result of Project research, and with the verification of the transfer hypothesis, the major constraints of time, money, and manpower will be minimized as planners begin to use soils and crop data gathered elsewhere.

Table 2. Criteria for classifying soils using Soil Taxonomy (in worksheet format)

Keys and differentiae		Soil taxa
Diagnostic horizon: _____	=	**Order:** _____
Moisture regime:		
mean annual rainfall:[a] _____		
mean monthly rainfall:[a]		
Jan _____ Jul _____		
Feb _____ Aug _____		
Mar _____ Sep _____		
Apr _____ Oct _____		
May _____ Nov _____		
Jun _____ Dec _____	=	**Suborder:** _____
Base status:		
Total bases: _____		
Cation exchange capacity: _____	=	**Great group:** _____
Temperature regime:		
mean annual temperature:[a] _____		
mean monthly temperature:[a]		
Jan _____ Jul _____		
Feb _____ Aug _____		
Mar _____ Sep _____		
Apr _____ Oct _____		
May _____ Nov _____		
June _____ Dec _____	=	**Subgroup:** _____
Mean annual soil temperature at 50-cm depth: _____		
Soil texture: _____		
Soil mineralogy: _____		
estimated percentage of		
kaolinite _____		
halloysite _____		
oxides _____		
montmorillonite _____		
chlorite _____		
others _____	=	**Family:** _____
Location: township, village, barrio, desa	=	**Series:** _____

[a]Over a 30-year period or the maximum period available.

(Nitrogen Fixation by Tropical Legumes, Contract No. AID/ta-C-1207); the Soil Conservation Service of USDA; FAO of the United Nations; and various AID Missions.

Agrotechnology transfer as a means to meet the world's food demand does require international coordination, and an international coordinating body must be formed to fulfill this need. The role of the coordinating body should be to enable the countries with probable food deficits to exploit the full agricultural development capability of the world. To achieve this goal, this body must ensure that (1) a common soil classification system is used by all participating agencies and countries, (2) a uniform procedure is employed for making and interpreting soil surveys based on a common system of classification, (3) international soil correlation and quality control is maintained in soil surveys and land evaluation, (4) a uniform and reliable procedure is employed for developing crop performance data, and (5) a means of storing, retrieving, and displaying crop performance data is established. These initiatives will promote economy of thought and action and will render decision-making for national and global food strategy easier and more accurate.

Although widespread in the tropics, downy mildew has been found to have negligible effect on crops in a cool, isothermic temperature regime. In areas with isohyperthermic temperature regimes, such as this site at Java, Indonesia, an entire crop can be destroyed by downy mildew. Here, affected plants are weeded out to prevent further infection.

Research Strategy

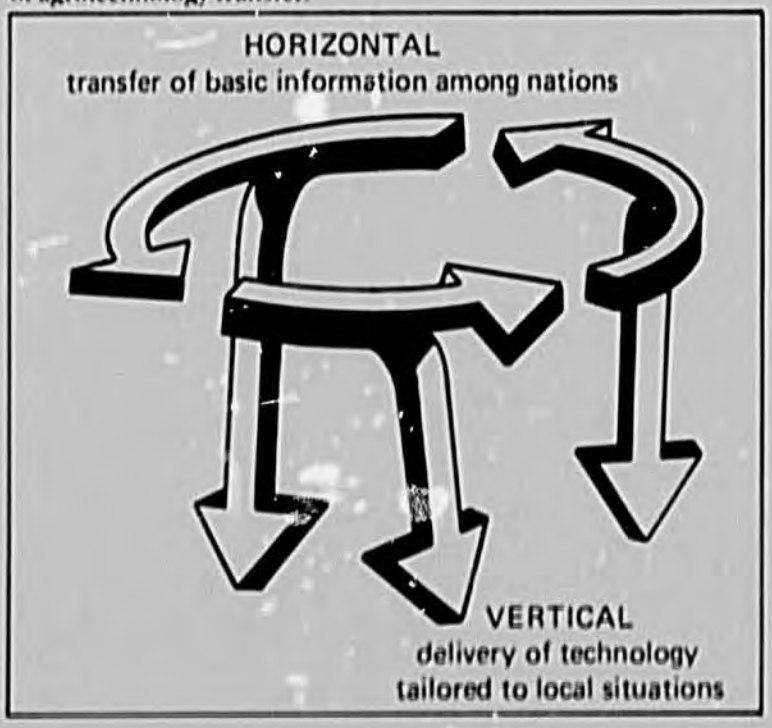
Effective technology transfer hinges on horizontal information exchange among nations and vertical delivery of appropriate technology to the farmer. Two kinds of experiments, transfer and management, are conducted throughout the networks to meet these needs. Variety trials, a third type of experiment, are conducted to evaluate suitability and compare crop response to treatment variables. Rigidly controlled, standardized procedures and guidelines are followed for field operations, data collection, and data processing. Weather parameters are monitored at all sites. The statistical test of the hypothesis of transferability of agrotechnology among soils of the same family is the pivot around which all the activities operate.

The strategy of the test of the hypothesis is to conduct a series of identical experiments in phases of the same soil family and to monitor crop performance. The research design and methodology were developed in concurrence with the recommendations of the Workshop on Experimental Design in 1974 (Silva and Beinroth, 1975).

Horizontal vs. Vertical Transfer

Two components are essential to the process of transfer: a horizontal component that delivers basic information and technology to and among nations, and a vertical component that delivers technology tailored to local situations to the farmer (Fig. 3). In the Benchmark Soils Project, two types of experiments, one for horizontal and the other for vertical technology transfer, are 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," or vertical transfer, experiments are designed to digest horizontally transferred information and render it socially and economically appropriate for local assimilation.

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



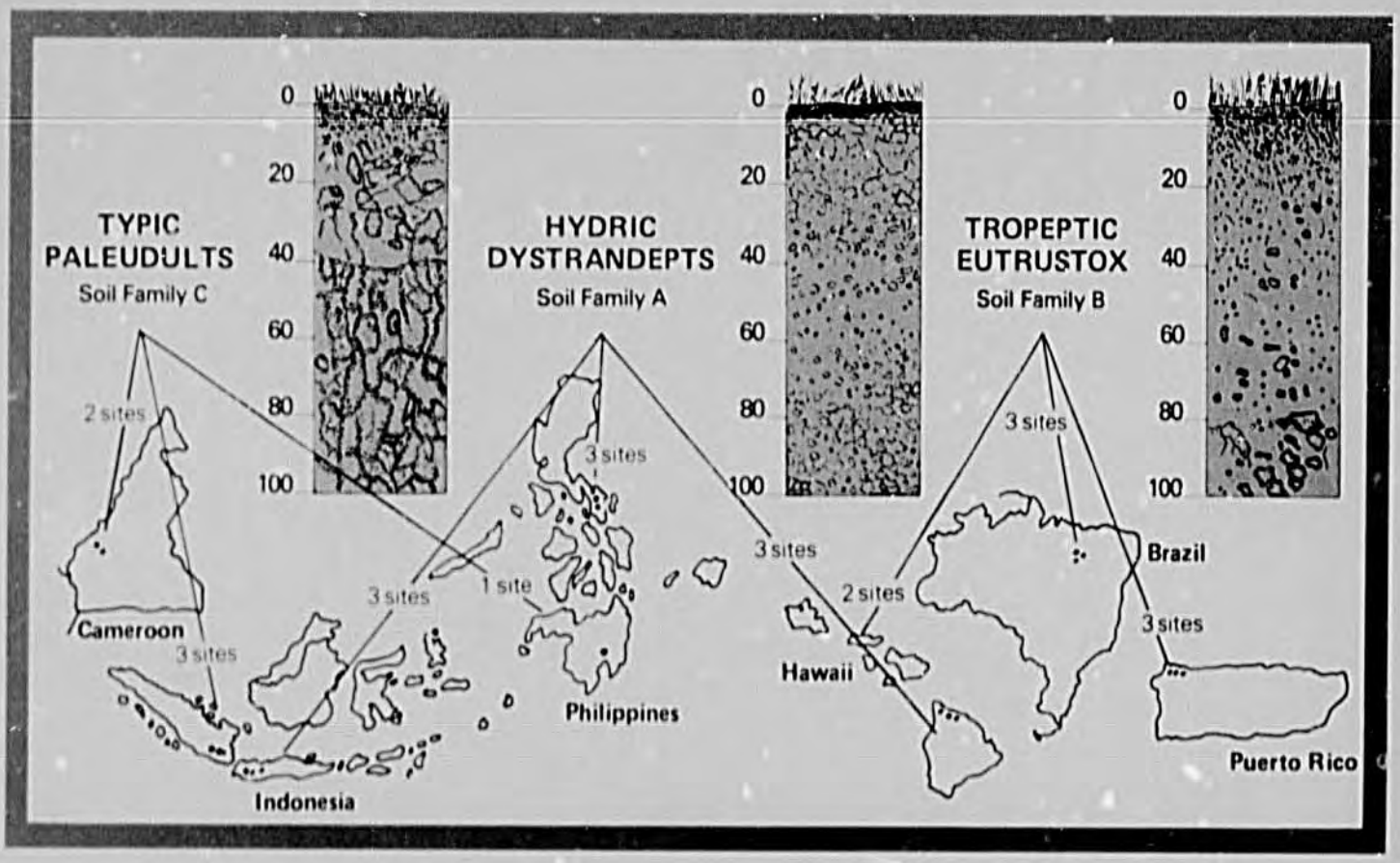


Fig. 4. Linkages among cooperating countries in the Benchmark Soils Project currently include 21 experimental sites operational in three soil families. The two sites each in Cameroon and the Philippines will be operational by early 1980.

Network of Soil Families

Three soil families from upland areas that have the potential to be productive under proper management practices were selected to test the hypothesis: the thixotropic, isothermic Hydric Dystrandepts; the clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox (which is the link between the Hawaii and the Puerto Rico Projects); and the clayey, kaolinitic, isohyperthermic Typic Paleudults.

"Management experiments are designed to digest horizontally transferred information for local assimilation."

Establishing the network required, for each cooperating country, a combination of negotiation, soil survey and classification, and training. This included conducting a library search of soil survey information for a particular country, contacting the country soil surveyor, and conducting a preliminary soil survey at the potential site in the country. As appropriate soil families were identified, drawing up an agreement with the country was necessary to permit detailed soil surveys at the proposed sites. The Project soil classification specialist surveyed areas which were probably in the appropriate families and collected soil samples. Soils were characterized by laboratory analysis and classified into appropriate families on the basis of field and laboratory data. As appropriate families were identified, a long-term memorandum of agreement was negotiated with the cooperating country for use of the site and joint participation in the Project. For each cooperating country, a project leader was trained in Hawaii in the agronomic methods to be followed and then assigned to head the country project on location. The site was cleared and tilled with machine and hand labor, and storage facilities were constructed.

The network of experimental sites includes three soil families with a minimum of eight experimental sites per family (Fig. 4).

Experimental Variables

The experimental variables (phosphorus and nitrogen) were selected by the Project for three major reasons: (1) they are controllable; (2) they are important to the test plant—in this case, maize; and (3) they are 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. A full discussion of the variables is found in Progress Report 1 (1978) and in the section Soil Taxonomic Considerations.

Experimental Design and Monitoring

There are two types of experimental sites, designated primary and secondary sites, and three kinds of experiments, referred to as transfer, management, and variety experiments (Table 3). The conduct of these experiments requires installation, maintenance, data collection, and analysis and interpretation. Short-term activities include collecting crop response data on soils belonging to the same family and collecting soils and climatic data to explain crop responses. Long-term activities include testing whether these crop responses are similar among similar soils, and, if the test is affirmative, developing a scheme by which management practices (agrotechnology) can be transferred between other similar soils anywhere in the world.

Transfer Experiments

At each primary site (one on each soil family in each country), all three kinds of experiments are generally installed. Secondary sites, which are relatively smaller and used primarily for transfer experiments, differ from primary sites in that they exhibit variations in soil properties within the range permitted by the soil family definition (see Ikawa, 1978).

Each site is completely instrumented for collection of weather data. The following weather parameters are continuously monitored by a battery-operated mechanical weather station: air temperature, relative humidity, rainfall, wind run and wind direction. Solar radiation and soil temperature at 5-, 10-, 20-, and 50-cm depths are recorded.

Standardized experimental procedures are followed to assure comparability of results throughout the network. An extremely detailed set of guidelines was developed and is continuously revised so that laboratory and field experiment procedures can be as nearly identical as possible. All field operations—such as land preparation, pest control, irrigation, cultivation, and harvesting—are considered, as well as field plot designs and data collection at all sites.

Field experimentation entails the following procedures. Proper planting materials are obtained, and the experiments are planted after the treatments have been applied. During crop growth, adequate plant protection is provided in the form of insect, disease, and weed control. Plant samples are collected at tasseling, a critical stage of growth, to monitor the nutrient status of the crop. Diseases and insects are identified, and the extent of damage is rated. Phenological characteristics are recorded periodically. Adequate irrigation is provided throughout the crop growth. Crops are harvested, and important yield parameters are measured. Quality of the crop, such as its nutritional value, is obtained in selected cases. Soil samples are collected after harvesting and analyzed to assess residual soil nutrients.

"Emphasis is on the verification of the hypothesis that soils of the same family have a common and predictable response to management practices."

Table 3. Experiments in the Benchmark Soils Project three soil family networks

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

Experimental yield results, with all related data on controlled and uncontrolled variables (*see* pages 30–35) are analyzed in conjunction with the Project statistical consultants with the ultimate objective of statistically testing the transfer hypothesis and developing a model of agrotechnology transfer (*see* pages 36–38). Three approximations will be made on all three types of experiments. The three approximations will be used to indicate three possible levels of testing—i.e., two years of testing for the first approximation, which is considered minimum for field research; four years of testing for the second approximation, which would considerably increase the reliability of the results; and five years of testing, which would optimize the reliability of the results. Data is stored in the Benchmark Data Bank. Data analysis includes recording data on punch cards and carrying out regression and variance analysis. Interpretation and display of data is being accomplished, and the transfer hypothesis is being tested.

The approach taken by the BSP is shown schematically in Fig. 5. The statistical approach is unique for this kind of experimentation; it in itself is expected to be a significant contribution to scientific research (Ehrenreich, personal communication).

Variety Experiments

Variety trials are conducted to compare crop response to treatment variables. In addition, it was decided to use the "best adapted local variety" as the test crop in the transfer experiments. Experiments with all the "transfer" varieties from other BSP country networks will be necessary in several places on primary sites for comparative purposes. Split-plot designs will be used for these experiments. Where there is doubt about the best adapted variety for a location, some preliminary variety experimentation may also be necessary.

Management Experiments

Management experiments on maize are being installed at the primary site on each soil family in each country. The objectives of these experiments are (1) to provide information to local governments on ways to increase production by improved availability and utilization of resources; and (2) to provide basic information to local farmers with limited resources to indicate how they can increase their yields. Some management variables that are being investigated include plant density and spacing, irrigation, multiple cropping, residual phosphorus, phosphorus placement, and major nutrient requirements. Details of the management experiments and other research to be conducted are worked out with each participating country.

There is an annual meeting of principal staff for the purposes of Project design, coordination, and evaluation, and an annual meeting of Project leaders and appropriate contractor staff of each institution.

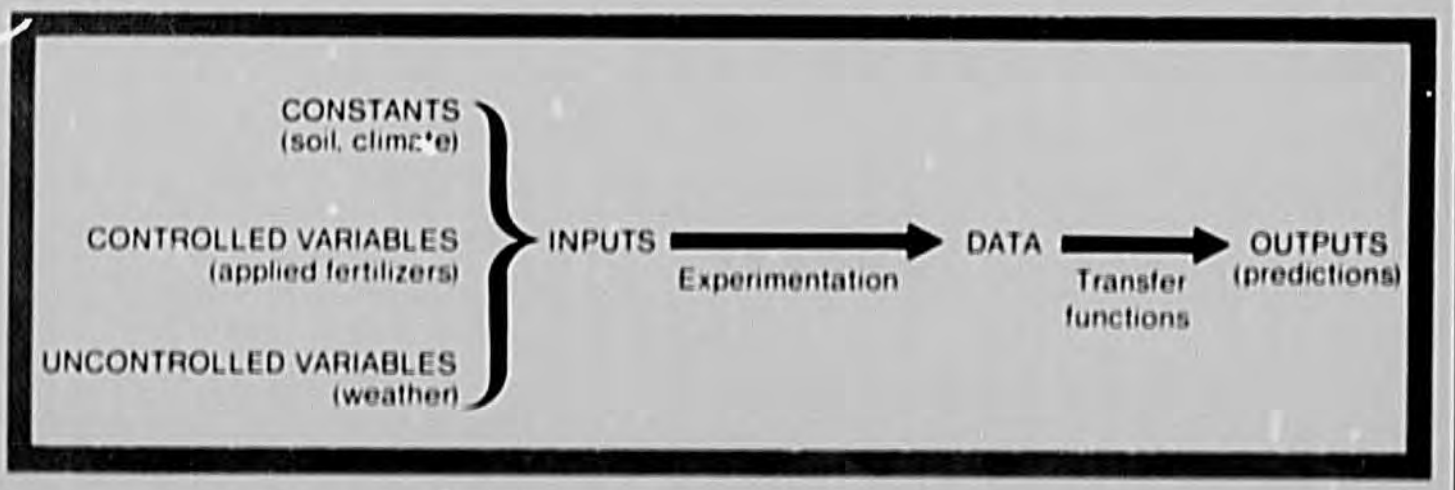


Fig. 5. The schematic approach to testing the transfer hypothesis is unique to the experimental design of the Benchmark Soils Project.

Research on Agrotechnology Transfer

Predicting Crop Performance and Management Inputs from Soil Family Characteristics

Through proper use of Soil Taxonomy, predictions may be made about soil behavior *from* soils on which research has been conducted or on which experience is available *to* soils for which experience is lacking. Since soils in the same family require essentially the same management practices, maximum production results obtained in one soil family can be used as production targets for all soils belonging to the same or similar soil families. For this reason, the information implicit in the taxonomic name of the three soil families under study in the Benchmark Soils Project has been interpreted to determine their suitability and potential for crop production and to outline the required management practices for optimum crop growth. One objective of the Benchmark Soils Project is to demonstrate that the interpretations derived from the soil family name can be used to transfer agroproduction technology. Following is a discussion of the salient land qualities that have been found to affect the crop performance and yield potential of the three soil families of the Benchmark Soils Project.

Publication of Soil Taxonomy in 1975 filled a critical void; for the first time it became possible and profitable to assemble soil information in a systematic and standardized way for soil interpretation on a global scale. Soil Taxonomy is rapidly becoming the unofficial international language, and its comprehensive and quantitative nature makes it a powerful tool for agrotechnology transfer within and among developing nations.

The Benchmark Soils Project is the first comprehensive effort to scientifically substantiate the efficacy of soil classification as it relates to predicting the behavior of soils, identifying their best use, and estimating their productivity —all of which are incorporated in the term agrotechnology transfer. But the validity of this concept has been assumed for some time; in the foreword to the FAO-UNESCO Soil Map of the World (FAO, 1974), for example, it is stated that one objective was "to supply a scientific basis for the transfer of experience between areas with similar environments. . . (for) . . . with the tremendous amount of knowledge and experience gained in the management and development of different soils throughout the world, the hardship perpetuated in some areas by methods of trial and error is no longer justified."

Soil Taxonomy recognizes that soils have many properties that have causal relationships to soil behavior. Those properties with the greatest number of covariant or accessory characteristics are selected to define and separate the various classes and categories. Classes of the system are defined in terms of soil properties, but there is a tendency to place more weight on soil properties of agricultural relevance, particularly at the lower categoric levels. Because soil properties control soil behavior, taxa of Soil Taxonomy therefore should reflect behavioral patterns.

Like most taxonomic systems, Soil Taxonomy is a multicategoric system. Each category is an aggregate of taxa, defined at about the same level of abstraction, with the smallest number of classes in the highest category and the largest number in the lowest category. In order of decreasing rank, these categories are order, suborder, great group, subgroup, family, and series.

Soil families are differentiated within a given subgroup, primarily on the basis of soil characteristics that provide classes having relative homogeneity in properties important to plant growth and indicative of soil-water-root relationships. Soils classified in the same family, therefore, should have nearly the same management requirements, a common response to cultural practices, and a similar potential for crop production. This assumption is basic to the Benchmark Soils Project and a test of its validity is the principal concern of the Project.

The validity of this assumption can be examined in two ways: (1) by collection of experimental data (see pages 29–40), or (2) by interpretation of pedologic data. Interpreted data are less expensive and easier to obtain, and they can substantially reduce development costs by alerting planners to soil limitations and enabling them to exploit soil potentials. One purpose for assembling high-quality pedologic and climatologic data is to enable a soil interpreter to predict from them reasonably accurate soil and crop performance data.

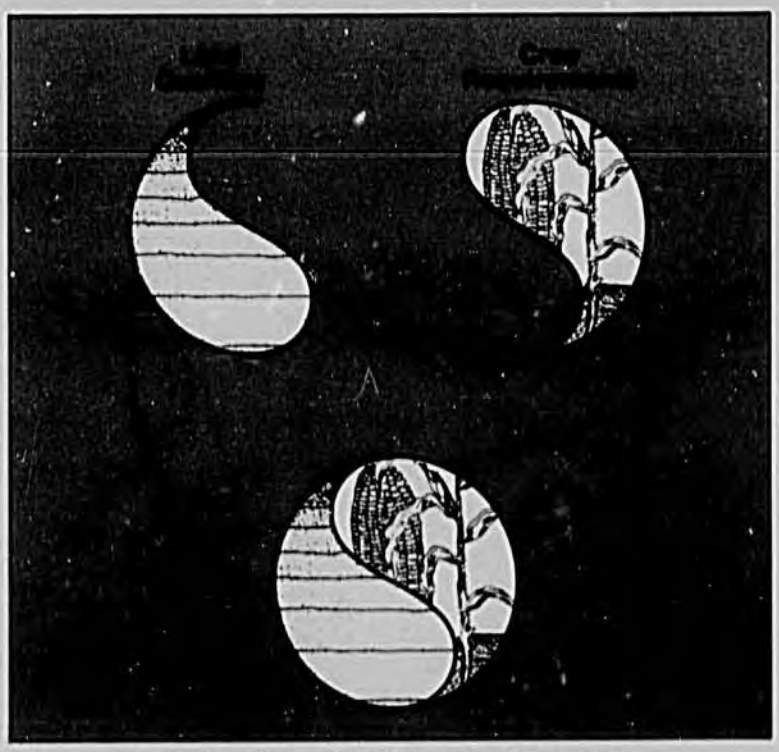


Fig. 6. Matching land qualities determined from soil taxonomic considerations to crop requirements is a means of predicting crop performance in an agroenvironment defined by a soil family.

Land Qualities as the Synthesis of Soil Characteristics

A key element in obtaining interpreted performance data is to match land qualities to crop requirements (Fig. 6).

A land quality is a complex attribute of a soil unit as it appears in the landscape. Normally, a land quality defies direct measurement; it is usually arrived at through the synthesis of a number of individual soil characteristics (interpretation of pedologic data) and their interactions with each other. Erosion hazard, for example, is a land quality that results from the interaction of slope angle, slope length, permeability, soil structure, rainfall intensity, and other characteristics. Because it is the aggregate of such interactions that controls crop performance and soil management, it is preferable to evaluate soils in terms of land qualities rather than in terms of individual soil and land characteristics. In the following discussions, land qualities of importance to maize production and the concomitant soil management requirements are estimated from the differentiae defining a soil family and the accessory properties of the taxon.

"Interpreted data are less expensive and easier to obtain, and they can substantially reduce development costs."

About 20 land qualities related to crop production and management are recognized; however, not all of these are relevant for the soils under consideration. The discussion of land qualities here, therefore, is restricted to moisture availability, energy availability, nutrient availability, soil toxicity, workability and

trafficability of the land, soil erodibility, and climatic hazards.

Moisture availability (water-supplying capacity) is related to several soil characteristics, including soil moisture regime, particle-size class, temperature class, mineralogy, structure, rooting depth to physical or chemical barriers, and slope (runon and runoff). The interaction of soil characteristics with the amount, seasonal distribution, and variability of rainfall results in the water-supplying and storage capacities of the soil.

"Agricultural development will be accomplished through interpretation of information in Soil Taxonomy. The BSP will demonstrate, scientifically, the feasibility of doing this."

Energy availability is largely a function of temperature and solar radiation. Energy supply is closely related to the temperature and moisture regimes. Land in perudic and udic moisture regimes, for example, generally receives lower solar radiation than land in ustic or aridic moisture regimes. Land in thermic and mesic temperature regimes has longer summer day lengths than land in isohyperthermic or isothermic temperature regimes.

Nutrient availability is the most complex land quality because pronounced interactions occur between other land qualities and nutrient supply. For example, when soil fertility is low, crops such as coffee, tea, cocoa, and black pepper perform better under shade than in direct sunlight. Shading helps to optimize growth when a crop is under partial water or nutrient stress. Nutrient uptake is also strongly influenced by oxygen stress. Thus, crop performance and nutrient uptake is not related to nutrient content in a simple way. Only the two essential macronutrients—nitrogen and phosphorus—are being considered in the Benchmark Soils Project approach. More generally, soil characteristics such as cation-exchange capacity, base saturation, organic-matter content, mineralogy, weatherable mineral content, temperature, pH, and particle-size class are used to assess soil nutrient supply.

Soil toxicity is associated with extreme soil acidity or alkalinity. In acid soils aluminum and manganese toxicities are common, whereas

Overcrowded living conditions at Ekona, Cameroon (left) and a fishing village near Madras, India (right) exemplify the LDC needs that are the main thrust of the BSP. Because similar soils occur in Africa and Asia, it is possible that people in both these areas could use similar farming methods to increase crop yields.

in alkaline soils boron toxicity is sometimes encountered. Predictions of soil toxicity require careful interpretation of additional factors such as mineralogy, organic-matter content, and salt content.

Soil workability and trafficability are related to the rheologic properties of soil. Soil workability and trafficability indicators can be extracted from particle-size class, mineralogy, plasticity index, slope, depth to physical barriers, wetness (moisture regime), and temperature regime (permafrost). In organic soils, workability and trafficability is directly interpretable from the soil taxa.

Soil erodability can be predicted from particle-size class, mineralogy, structure, slope angle, slope length, rainfall (moisture regime), estimated permeabilities, and aggregate stabilities.

Climatic hazards include adverse weather conditions, such as wind, hail, frost, and excessive temperatures. This is the least reliable land quality, but rough estimates can be made from temperature and moisture indicators in the soil taxa.

Complex relationships of land qualities influence crop performance and require careful study by agronomists, crop physiologists, and agricultural climatologists. Extension specialists who make soil management recommendations do so from their knowledge and experience about the soil and crop in question. The quality of their recommendations varies with the amount of experience, knowledge, and skill. A skilled specialist predicts performance with a high degree of accuracy. But the process remains an art; it needs to become a science so that people with less experience can consistently derive high-quality interpretations.

In the final analysis, the transfer of agroproduction technology for planning agricultural development will be accomplished through interpretation of information organized and condensed in Soil Taxonomy. The purpose of the Benchmark Soils Project is to demonstrate scientifically the feasibility of doing so. This section of this report compares estimated maize performances derived from soil interpretations with those obtained by experimentation on a network of Benchmark soils.

Effect of Salient Land Qualities on Crop Performance and Soil Management Requirements

Table 4 equates the taxonomic name of each family with the inherent soil family characteristics.

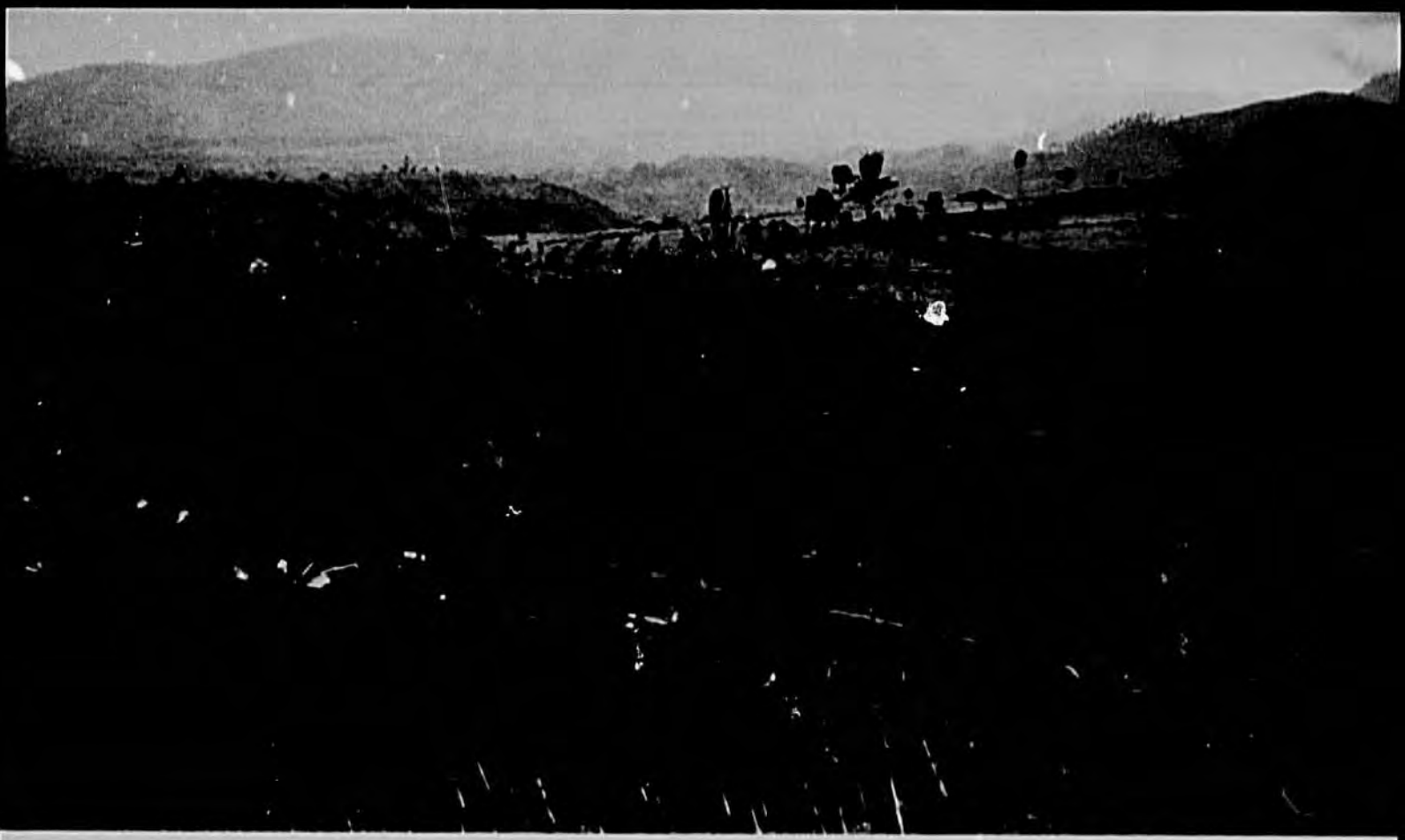
Thixotropic, Isothermic Family of Hydric Dystrandepts

INTERPRETATION OF LAND QUALITIES

These soils require supplementary irrigation during the dry months but are well-suited for

Table 4. Soil family properties as they relate to the taxa in Soil Taxonomy

Taxonomic name	Inherent soil family characteristics
Thixotropic, isothermic Hydric Dystrandepts	
thixotropic	High surface activity of colloids.
isothermic	Cool soil temperatures (15–22°C).
Hydric	Moist humid soils.
Dystr-	Low base saturation (≤ 35%).
-andept	Low bulk density (≤ 0.85 g/cm^3).
Clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox	
clayey	More than 35% clay in the subsoil.
kaolinitic	Dominated by low active clay.
isohyperthermic	Warm soil temperatures throughout the year (mean > 22°C); small difference between summer and winter temperatures (< 5°C).
Tropeptic	Moderate structure; less than 125 cm deep, or both.
Eutr-	Moderately enriched with nutrients; medium to high base saturation (≥ 50%).
-ust-	Pronounced dry season (dry for more than 90 cumulative days/year).
-ox	Presence of oxides of iron and aluminum; low cation-exchange capacity.
clayey, kaolinitic, isohyperthermic Typic Paleudults	
clayey	More than 35% clay in the subsoil.
kaolinitic	Dominated by low active clay.
isohyperthermic	Warm soil temperatures throughout the year (mean > 22°C); small difference between summer and winter temperatures (< 5°C).
Typic	Typical or central concept.
Pale-	Deep old soils with low nutrient supply.
-ud-	Humid soils.
-ults	Low base saturation (≤ 35%).



Hydric Dystrandepts are nonerosive soils. This quality is related to the high aggregate stability and high water intake rate of this soil.

rainfed agriculture. Because of the frequent cloud cover associated with frequent rains and cool temperatures, the energy supply is reduced for biological activity. Crops such as maize require longer periods to reach maturity, and the yield potential is lower than in soil families with higher temperature regimes, longer daylengths, and drier moisture regimes. Although cool temperatures and low solar radiation cause potential yields to be lower, low temperatures protect maize from downy mildew, and uniform distribution of rainfall makes irrigation unnecessary, both of which reduce the risk and cost of producing maize.

"Hydric Dystrandepts are easily tilled and highly prized for their excellent physical properties."

Phosphorus deficiency is the most frequently encountered soil limitation for maize production in this soil. While phosphorus deficiency is common in many soils in and out of the tropics, the inordinate amount of phosphorus needed to correct the deficiency renders this problem unique to the thixotropic families. This soil has a high affinity for phosphorus so that fertilizer phosphorus is "fixed" and rendered unavailable to plants. Thixotropic families are generally high in organic nitrogen; even so, maize responds to fertilizer nitrogen, indicating that the organic nitrogen is not easily mineralized to ammonia or nitrate nitrogen. Although soil fertility is a serious limitation to maize production, correction of nutrient deficiency is relatively easy, and the potential for crop production becomes moderately high when this limitation is removed.

Thixotropic families of Hydric Dystrandepts require large quantities of lime to raise the pH; but, because of the high buffering capacity, which resists pH change, liming to achieve high soil pH is not recommended. Overliming is costly and frequently results in reduced maize yields in this soil family. A soil pH of 5.2 is generally adequate for maize production on Hydric Dystrandepts if calcium exceeds 2 meq/100 grams soil.

Hydric Dystrandepts are easily tilled and highly prized for their excellent physical properties. The soil compacts readily under applied pressure but resists natural compaction and consolidation during drying. Compacted traffic lanes recover good tilth after tillage.

Intensive cultivation on steep slopes is common on Hydric Dystrandepts, attesting to the nonerosive feature of this soil. This soil will erode if abused, but, all factors being equal, Hydric Dystrandepts must be considered one of the least erodable soils. Because of their good tilth and ease of workability, Hydric Dystrandepts are ideal soils for producing root crops in typhoon-prone areas.

ESTIMATED CROP PEFORMANCE AND SOIL MANAGEMENT PRACTICES

In the isothermic, thixotropic family of Hydric Dystrandepts, climate in general and energy supply in particular limit maize yields to an average of about 6000 kg/ha per crop. Under subsistence farming methods, performance of maize on this soil is about 2000 kg/ha. Unimproved varieties cultivated with little or no fertilizer are the main reasons for current low yields. Low farm incomes prevent farmers from acquiring and applying the full amount of fertilizers necessary to achieve potentially higher yields. Greater efficiency of fertilizer use can be obtained by placing fertilizers in narrow bands instead of broadcasting. Heavy fertilizer applications, particularly of phosphorus, can be justified even for the low-income farmer on the basis of the residual effects of applied phosphorus. Phosphorus fertilizer applications should be treated as a capital cost, because a single heavy application brings returns on investments for 5 to 10 years. Banks and lending agencies should be informed of this point.

Although maize can be grown profitably on the isothermic, thixotropic family of Hydric Dystrandepts, this soil should be reserved for intensive, continuous cropping of high-value crops. For this soil, crops better suited than maize are vegetable crops and Irish potatoes.

Clayey, kaolinitic, isohyperthermic Family of Tropeptic Eutrustox

INTERPRETATION OF LAND QUALITIES

The small amount of plant-available water (10 mm/10 cm soil) in combination with a high potential evapotranspiration means that even a few rainless days may create drought conditions, especially for shallow-rooted crops; irrigation is recommended during that time. Abundant energy is available to Eutrustox throughout the year. Isohyperthermic Eutrustox receive high amounts of solar radiation (about 120,000 to 140,000 g cal/year), resulting in higher temperatures. This means that these soils have high yield potentials because of the high available energy.

Because of its susceptibility to leaching, nitrogen is deficient in most cultivated

Tropeptic Eutrustox are ideal soils for intensive mechanized agriculture. Gentle slope, good internal drainage, high soil strength, stable structure, and low activity clays contribute to excellent trafficability in this soil.

Eutrustox; only in virgin Eutrustox with epipedons of mollic properties is sufficient nitrogen available for several crops. Thus, in general, nitrogen is a consistently limiting factor for crop production on Eutrustox. The amounts of phosphorus available depend on past management and on the nature of the parent rock, both of which cannot be inferred from the taxon name. Qualitative statements can be made, however, about the degree of phosphorus fixation in the soil. The Eutrustox of the clayey, kaolinitic family have a low-to-moderate phosphorus-fixation capacity. Combined with the weakly acid character of this soil, Eutrustox require moderate amounts of phosphorus fertilizers to produce maximum maize yields.

"With adequate irrigation and fertilizer applications, Tropeptic Eutrustox constitute some of the most productive soils in the tropics."

Potassium can be inferred to be present in these soils in sufficient quantities so as not to severely limit plant growth. The presence of small amounts of potassium reflects the fact that Eutrustox are not subject to strong leaching; however, because of the low cation-exchange capacity of Eutrustox, the absolute amounts of potassium retained in the soil are small and may be depleted under prolonged cropping. Since there are no or few primary minerals that could weather to release bases, potassium fertilization is required for sustained crop production. Because the Eutrustox of the BSP network are at least 125 cm deep and there are no chemical barriers to root growth, the plants can utilize the nutrients and moisture stored in a large volume of soil. Thus, with adequate irrigation and fertilizer applications, members of this family constitute some of the most productive soils in the tropics.

Due to past management practices, the surface soil of this family may have a pH of less than 5, in which case corrective measures need to be taken to avert toxicities.

Eutrustox are readily workable due to the high degree and stability of soil aggregates; upon drying, however, the surface soil has a tendency to harden. Tillage operations, therefore, are best performed when the soil has a moisture content midway between field capacity and wilting point. The high infiltration rates and permeability of Eutrustox allow field work to begin shortly after heavy rains. Trafficability of Eutrustox is excellent. Also, the level topography associated with Eutrustox is favorable for mechanized crop production.

Surface runoff occurs only under conditions of extremely high intensity rainfall. The high water permeability of Eutrustox and the level topography further reduce the erosion hazard. In an isohyperthermic soil temperature regime, frost is nonexistent and hail is extremely rare. Storms and torrential rains, however, may cause severe hazards to crop production. These conditions cannot be inferred from soil classification but can be estimated from the general air circulation pattern of the area where the soil occurs. For example, about every 25 years the island of Puerto Rico experiences hurricanes whose centers pass over the land area. In addition, severe storms with wind velocities of up to 150 km/hour accompanied by large quantities of high-intensity rainfall occur in Eutrustox areas. In the case of the Eutrustox of Puerto Rico, there is a probability of total crop loss once every 25 years and the possibility of severe crop damage once every 5 years.

ESTIMATED CROP PERFORMANCE AND SOIL MANAGEMENT PRACTICES

The preceding discussion of land qualities clearly conveys that the limited moisture availability, as indicated by the ustic soil moisture regime, is the most severe constraint of Eutrustox for year-round maize production. Thus, irrigation is absolutely necessary during the dry season. Because of the limited availability of stored water in Eutrustox, irrigation is also desirable in the wet season to avoid moisture stress caused by short dry spells. While sporadic irrigation in the wet season is essential to ensure high yields, reasonable yields can be obtained without irrigation, particularly if there is no moisture stress during the time of tasseling and pollination. This is possible because in the Eutrustox there are no barriers to root growth, and plants can thus draw upon the water stored in a large volume of soil. Maize yields of up to 10,000 kg/ha can be obtained under rainfed conditions in seasons with well-distributed rainfall.

For soil fertility, of course, nitrogen is needed. Because nitrogen is subject to rapid leaching in the highly permeable Eutrustox, several applications are desirable. The application of low to moderate amounts of phosphorus are predicted on the basis of land qualities. Potassium is predicted to be a nonlimiting nutrient in Eutrustox when the soil is first cultivated, but owing to the absence of weatherable minerals to supply potassium, potassium deficiencies can be anticipated after several years of intensive cultivation.

Assuming that the moisture and fertility constraints indicated above are effectively overcome and pests and diseases are controlled, the Eutrustox have a high potential for crop production. Maize grain yields under optimum conditions of management can be expected to be in the range from 5000 to 7000 kg/ha. Yields during the dry season when more solar energy is available may be 1000 to 2000 kg/ha higher. With irrigation, at least two crops of maize and one short-term crop can be obtained on soils of this family.

Clayey, kaolinitic, isohyperthermic Family of Typic Paleudults

INTERPRETATION OF LAND QUALITIES

With an udic moisture regime and with a well-distributed, annual rainfall pattern, the Udults generally have adequate moisture available for crop production throughout the year. In addition, because of the clayey particle-size class, the subsoil has a high moisture-storage capacity. The Udults are more likely to be situated in locations where there is greater cloud cover than are soils associated with an ustic moisture regime of a similar temperature regime. Less radiant energy is thus available, and lower yields are expected in these soils.

Because these soils are highly leached of bases and have little or no weatherable minerals, crop responses to phosphorus, nitrogen, lime, and the macro- and micronutrient fertilizers are virtually assured. Moderate amounts of fertilizer phosphorus in comparison to the Dystrandepts are required. Subsoil acidity and low fertility are the major constraints to crop production in this soil. Since they are leached of bases, these soils require nutrients such as potassium, calcium, and magnesium.

Typic Paleudults are acid and infertile soils, but under proper management, maize thrives in the BSP experiments in South Sumatra. This experiment, a collaborative effort of BSP and IFDC, shows the control plants (no P) in the foreground and the plants with applied P in the background.

Although extractable aluminum is not expected to be high in the Paleudults with low activity clays, it nevertheless may range from 1 to 3 meq in the upper portions of the argillic horizons. Maize is not as sensitive to aluminum as are soybeans or cotton; however, it is more sensitive than crops such as pineapple or tea.

Soil workability varies with surface textures. In clayey families, deep tillage is often necessary to promote deep rooting. However, if acid, infertile subsoil is brought to the surface during deep tillage, lower yields can occur without proper management. To avoid this problem, subsoil

Table 5. Effect of land qualities and management inputs on estimated grain yield of maize for three soil families

Soil family	Land qualities							Predicted maize grain yields (kg/ha)	
	Moisture availability	Energy availability	Nutrient availability	Soil toxicity	Soil workability and trafficability	Soil erodibility	Climatic hazards	Low inputs	High inputs
Soil Family B: Tropeptic Eutrustox clayey, kaolinitic, isohyperthermic	Moderate	High	Moderate	Low	Good	Low	Low	4500	9000
Soil Family C: Typic Paleudults clayey, kaolinitic, isohyperthermic	High	Moderate	Low	Moderate	Fair	Moderate	Moderate	3000	7000
Soil Family A: Hydric Dystrandepts thixotropic, isothermic	High	Moderate	Low	Low	Good	Low	Moderate	2000	6500

ripping is recommended. Correction of subsoil acidity remains a serious problem in this soil.

Unlike the Hydric Dystrandepts, Typic Paleudults on steep slopes are subject to erosion, and reestablishment of vegetation is very difficult because the exposed subsoil is extremely infertile. Soil conservation practices should be an integral part of Paleudult management.

Isohyperthermic families of Paleudults are free from hazards of frost and hail but may encounter problems with high winds (typhoons). More importantly, the warm and humid climate indicated by the family name should alert planners to a probable high incidence of diseases.

ESTIMATED CROP PERFORMANCE AND SOIL MANAGEMENT PRACTICES

Although water supply is adequate, high night temperatures and short daylengths reduce the yield potential for maize in this soil family. With low inputs and low planting densities, 500–2000 kg grain/ha can be obtained with unimproved varieties. Without inputs, the land is incapable of producing maize on a sustained basis and is generally allowed to revert to weeds. The most common weed in abandoned fields is *Imperata cylindrica* (alang alang). With current technology and improved varieties, 4000–6000 kg maize grain/ha can be expected.

To achieve these yields, disease-resistant varieties adapted to warm and humid conditions need to be planted. Aluminum toxicity needs to be reduced to tolerable levels (less than 40 percent aluminum saturation). Lime is generally required to correct aluminum toxicity and frequently to correct calcium deficiency. An application of 1 ton $CaCO_3$/acre is generally applied to neutralize 1 meq of extractable aluminum. Complete fertilizers containing nitrogen, potassium, phosphorus, magnesium, and the micronutrients must be added.

Maize Yield Predictions for the Three Soil Families Based on Soil Taxonomic Criteria

The preceding discussion describes how information contained in the soil family name

can be used to estimate crop performance and management requirements based on land qualities for the three soil families under study in the Project. In this section, collective comparisons are made for the soil families. For easier comprehension, the comparisons are presented in tabular form.

In Table 5, the land qualities have been rated in a qualitative way. The column headed "Predicted maize grain yields" has been subdivided at two levels of management inputs, low and high. In this context, low inputs imply virtually no management inputs other than land preparation and mechanical weed control, consistent with subsistence farming. High inputs imply the application of advanced soil management and crop production technology, including controlled irrigation, fertilization, optimum plant density and time of planting, use of a well-adapted high-yielding variety, pest and disease control, and so on.

The estimated grain yields of maize listed in Table 5 are estimates derived from land qualities and general knowledge of maize production in the tropics. For the purpose of these predictions, the soil characteristics and qualities conforming to the central concept of the soil family were used, and it was assumed that the soils have not been intensely cultivated previously.

Precision of Predictions Based on the Soil Family

Not unexpectedly, the yield estimates presented in Table 5 vary considerably from the yields actually measured in field experiments reported in the next section. In rationalizing these discrepancies, it must be emphasized again that the predictions are largely based on the information that is by definition contained in the taxonomic name of the soil family. The predictions, therefore, can only be as accurate as this information. Although the soil family is quite narrowly defined, it still allows for a considerable range in some characteristics that may be important to plant growth and soil management. For example, the base saturation in the major part of the subsoil of the Eutrustox must, by definition, be 50 percent or more and thus may conceivably range from 50 to 100 percent. Similarly, the clayey particle-size class permits clay contents from 35 to 100 percent. It should further be remembered that in the case of the three kinds of soils investigated in the Project, the differentiating criteria for soil classification are applied in the so-called control section that starts below the plow layer. Although the general properties of the surface soil are covariant with the subsoil properties, they may differ from soil to soil despite the fact that

"Soil Taxonomy has the flexibility to indicate soil characteristics that are not considered in taxa definitions but are important for a specific land use."

they belong to the same soil family. Such surface soil conditions include organic matter content, soil reaction, nutrient availability, soil texture, horizon thickness, and others. Some of this variability reflects the past cropping and management history of the soil. Fertilization with ammonium sulfate, for example, may result in residual acidity in the surface soil. Furthermore, although the general climate of the area where a soil family occurs is indicated in the soil moisture and temperature regimes, the actual weather conditions during a given growing season, of course, cannot be inferred from the taxonomic unit with the degree of accuracy desirable for precise crop performance predictions.

Crop performance and soil management predictions could clearly be refined if they were based on information more specific than that contained in the soil family. In fact, Soil Taxonomy recognizes a categoric level below that of the soil family, the soil series. The differentiae used for series are mostly the same as those used for the classes in other categories to which the series belongs, but the range permitted is less than is permitted in the family or some other higher category. However, taken collectively, the number of possible distinctions is too large to be comprehended readily and to be incorporated in a key.

In addition, Soil Taxonomy has the flexibility to indicate soil characteristics that are not considered in taxa definitions but are important

for a specific land use. The phases provide for a utilitarian classification that can be superimposed on the taxonomy at any categoric level to permit more precise interpretations and predictions. Thus, one may recognize an "acid surface soil phase" of the clayey, kaolinitic, isohyperthermic family of Tropeptic Eutrustox.

The most precise predictions, therefore, can be made on the basis of phases of soil series. However, it would clearly be unrealistic to use this level in the process of international agrotechnology transfer. First, such detailed information rarely exists for LDCs. Second, soil series are not rigidly defined, and different rationales for establishing series are used in different countries. As a consequence, the lowest categoric level of Soil Taxonomy that can be universally applied in a uniform and consistent manner is the soil family. It is for this pragmatic reason that the soil family is used in the Project.

Coordinated efforts at all sites in all three soil families ensure that uniformity of crop yield data is obtained. Land clearing on Typic Paleudults in Indonesia (top), preparing water facilities on Tropeptic Eutrustox in Brazil (middle), and planting on Hydric Dystrandepts in the Philippines (bottom) are very labor-intensive in the absence of machinery and equipment.

Testing the Transfer Hypothesis

To date, the Project has verified through field experimentation and experience that accessory soil properties implied in the soil family taxonomic names are indeed inherent soil family characteristics, although the range of these characteristics varies from site to site within a family. In addition, the Project has successfully demonstrated that some of these soil family characteristics have specific inferences for management practices. In the second analysis of the transfer hypothesis, completed in January 1979, additional site variable information—minimum air temperature, modified Truog soil phosphorus, and soil nitrogen—is used along with applied nitrogen and applied phosphorus. Although a common response surface cannot be fitted to all sites, use of site variable information allows transfer of the phosphorus and nitrogen response relationships within practical limits. Thus, the operational model developed for the statistical test of the transfer hypothesis clearly indicates that soils of a given family respond alike to similar management inputs adjusted for soil nitrogen and phosphorus.

In every soil family there are certain limiting factors affecting good crop yields. These factors were confirmed by Project experimentation to be the same within the same family and different between soil families (Progress Report 1). An example is shown in Fig. 7 by the relationship of maize grain yield for the three soil families with each respective soil family environment. The cool and warm environments are related to the isothermic and isohyperthermic temperature regimes, respectively, while the wet and dry environments refer to the udic and ustic moisture regimes, respectively. These relative yields from each soil family were expected from our knowledge of the nomenclature in Soil Taxonomy. Management practices depend on the limiting factors and can therefore be predicted for specific soils.

Since fertilizer response is a land quality that can be measured quantitatively, the Project is testing soil family response to phosphorus (P) and nitrogen (N) in the transfer experiments in each soil family.

A feature of the treatment design being used in the transfer experiments (the 5^2 partial factorial modification of Escobar) is the distribution of the nitrogen and phosphorus levels over the factor space. Treatment combinations, therefore, are expressed as coded levels of N and P in order to maintain the desired pattern of treatments. The actual amounts of N applied are very similar throughout all three soil family networks, but the amount of P applied varies depending on the P-fixing capacity of the soil and past management

"The amount of phosphorus applied varies depending on the phosphorus-fixing capacity of the soil and past management of the site."

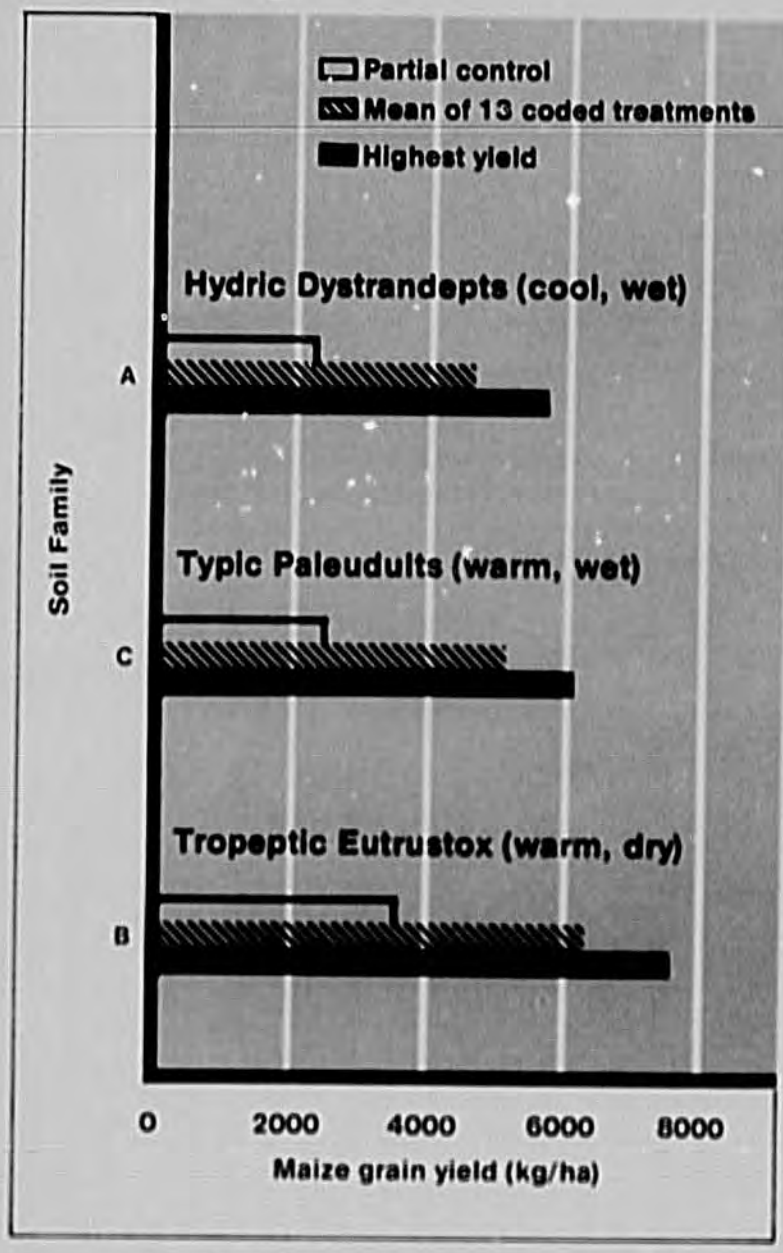


Fig. 7. Effect of agroenvironment on maize grain yield for the three soil families.

of the site. Table 6 shows the treatments used in the transfer experiment; Table 7 gives the actual levels of treatments in each country on each soil family.

Results of the Transfer Experiments

A total of 40 transfer experiments were conducted on the Hydric Dystrandept network, 26 on the Tropeptic Eutrustox network, and 12 on the Typic Paleudult network in 1978–1979 (Table 1, Appendix 1). The results confirm the findings of earlier transfer experiments, as reported in Progress Report 1, pages 29–39.

Thixotropic, Isothermic Family of Hydric Dystrandepts

In Hawaii, response to both N and P was generally obtained at most sites. Although these sites were former sugarcane fields and received P fertilizer in the past, the capacity of the soil to fix P is high so that additional amounts of P produced increased yields. Sites in Indonesia generally exhibited a response to N with a small response to P, if any. The low level of response to P is due to past management of the sites when they were used for vegetable culture and received additions of manure. Soil P levels are generally at or above the adequate level. A marked response to both N and P was generally observed at most sites in the Philippines. These soils did not receive much fertilizer in the past so that both N and P are needed for good crop growth. Table 2, Appendix 1, summarizes the yield data in 1978–1979 for the Hydric Dystrandept network.

Examples of the yield response surfaces predicted from the transfer equation reported in 1978 are shown for Hawaii (KUK-C), the Philippines (PUC-K), and Indonesia (LPH-E) (Fig. 8, *see* also Fig. 11). The general similarity of the response surfaces for these three Hydric Dystrandept sites is quite apparent, especially for the sites in Hawaii and Indonesia. The site in the Philippines exhibits some differences, primarily in the response to N at the low P levels. (*See* pages 36–39 for the statistical analysis of these sites.)

Thus, N and P rates can be predicted from one Hydric Dystrandept site to another, with proper adjustment for soil levels of N and P.

It is also apparent that the yield level in Hawaii is considerably higher than that in either Indonesia or the Philippines. One possible reason for the yield difference may be the difference in solar radiation: sites in Hawaii and the Philippines, for example, receive higher amounts of solar radiation than the sites in Indonesia (*see* Appendix 2 for weather data). Another possible reason may be the difference in maximum and minimum temperatures at the sites. Maximum and minimum temperatures are highest at the

Philippine sites, lowest at the Indonesia sites, and intermediate at the Hawaii sites. Although the high maximum temperature in the Philippines should allow greater carbohydrate production, the high minimum temperature probably caused greater use of carbohydrate in respiration, which resulted in lower net amounts of carbohydrate being produced. On the other hand, in Indonesia, temperatures were apparently too cool for high production of carbohydrate. Temperatures in Hawaii were apparently better suited for high carbohydrate production during the day and relatively low use of carbohydrate in respiration at night.

Clayey, kaolinitic, isohyperthermic Family of Tropeptic Eutrustox

There was a marked response to P and a relatively small response to N in some experiments in Brazil. Results in some other experiments were not as striking. The reasons for this are not known at present. Yield levels were comparable to those of Puerto Rico. There was generally a response to N in all experiments in Puerto Rico, while the response to P varied with the experiment but was generally small. Yields were generally lower in Puerto Rico than in Hawaii, although yields of 8000 to 9000 kg/ha were attained in some experiments. Soil pH was found to be lower than optimum in some experiments, a fact that may have prevented maximum yields from being achieved. In Hawaii, a yield response was obtained for both N and P in the two experiments harvested to date. Yield levels were high—9000 to 10,000 kg/ha.

Because of the higher amounts of solar radiation at the Eutrustox sites than at the Dystrandept sites, especially during the dry season, it is not surprising to find higher yields. Table 5, Appendix 1, provides a summary of yield data on the Tropeptic Eutrustox network.

Examples of the yield response to N and P in Brazil, Puerto Rico, and Hawaii are shown in Fig. 9. A marked difference in the yield response curves to P evident in the figures, with Brazil showing the largest response to P and Puerto Rico the smallest, while Hawaii was intermediate. These differences are due largely to

Table 6. Coded values of treatments used in transfer experiments

Treatment	Phosphorus	Nitrogen
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[a]	0
K	-0.85	0
L	+0.85	0
M	0	-0.85
N	0	+0.85
O	Complete control[b]	–
P	Partial control[c]	–
Q	0	–
R	–	0
S	0[d]	0

[a]0 = optimum treatment, includes micronutrients.
[b]O = no fertilizer applied.
[c]P = no treatment variables applied but given blanket application of macro- and micronutrients.
[d]Optimum treatments with no micronutrients applied.

Table 7. Actual rates of highest and lowest treatments in transfer experiments by soil family

	Nitrogen		Phosphorus	
Soil family	Coded level	Actual level (kg/ha)	Coded level	Actual level (kg/ha)
Hydric Dystrandepts				
Hawaii	-.85	30	-.85	20
	+.85	190	+.85	375
Indonesia	-.85	30	-.85	10
	+.85	190	+.85	110
Philippines	-.85	30	-.85	20
	+.85	190	+.85	250
Tropeptic Eutrustox				
Hawaii	-.85	30	-.85	10
	+.85	190	+.85	140
Puerto Rico	-.85	20	-.85	03
	+.85	170	+.85	40
Brazil	-.85	20	-.85	03
	+.85	170	+.85	40
Typic Paleudults				
Philippines	-.85	30	-.85	10
	+.85	190	+.85	150
Indonesia	-.85	30	-.85	10
	+.85	190	+.85	160

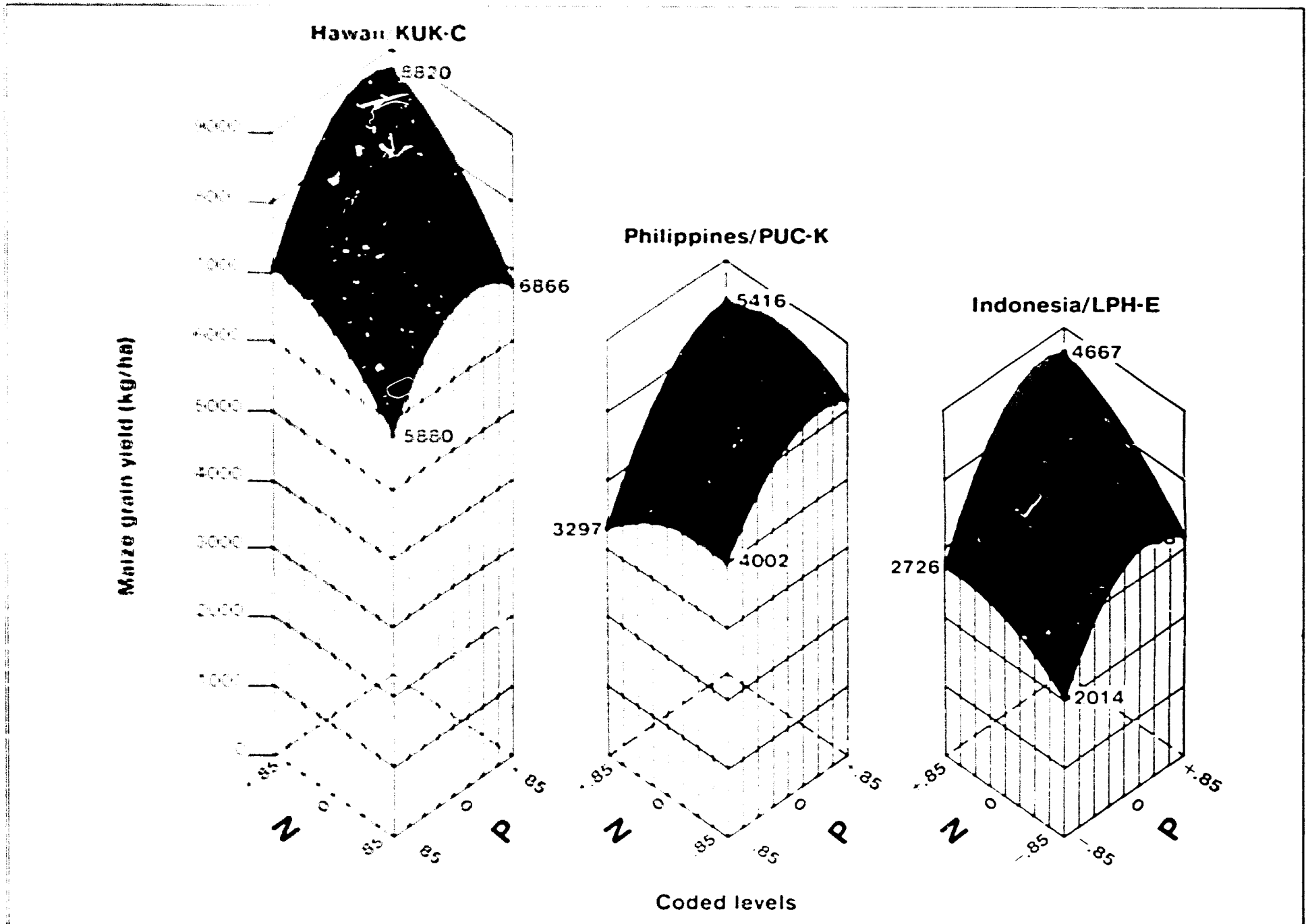


Fig. 4. Response surfaces of maize to coded levels of phosphorus and nitrogen in the Hydrix Dystrandepts network.

differences in the history of these sites. In the Brazil site, native vegetation had recently been cleared so levels of N and P varied depending on the nature of the vegetation. Apparently N levels were high, but P levels were low; therefore, a very marked response to P, but a relatively small response to N, is shown. Both the Hawaii and Puerto Rico sites were previously cropped, and so both received fertilizer applications in the past: the Hawaii site was a former pineapple field, and the Puerto Rico site is part of an experiment station. The larger response to P in the Hawaii site may be due to the greater fixation capacity of the soil, thus allowing additional P to increase yields. Both sites exhibited fairly good responses to N since they were cropped in the past and soil N levels were relatively low.

Clayey, kaolinitic, isohyperthermic Family of Typic Paleudults

The first yields from the Nakau and BPMD sites in Sumatra, Indonesia, indicated marked response to both N and P. At NAK-A, yields of up to 7000 kg/ha were achieved (Fig. 10). Yields of maize grown in NAK-A without application of P, and with reapplication of N and K, were 1000 to 2000 kg/ha lower than the first crops and there was still a response to P. Although the P-fixing capacity of the soil did not appear excessively high, the residual effects of P seem to be small with the relatively low amount of P applied. These sites were cleared from natural vegetation, and the fertility levels were low. Yields from the BPI site in Davao, the Philippines, indicated some response to P and N (Fig. 10), but the responses were not as large as in Sumatra. This site had been cultivated in the past, so residual P was present. The difference in the P response at the two sites may be explained largely by the modified-Truog soil-P values of 2 ppm for NAK-A and 19 ppm for BPI-D, which, respectively, are very low and moderately high figures.

Yield levels at Davao were not as high as those at Nakau possibly because of the higher solar radiation and temperature at the Nakau site than at the Davao site. A summary of yields in the Typic Paleudult network is shown in Table 4, Appendix 1.

The transfer of technology does not always mean introduction of heavy equipment. In the Philippines (left) with heavy alang alang growth, a water buffalo performs most efficiently; in Indonesia (right), several rototillers can be efficient since farming methods are labor-intensive.

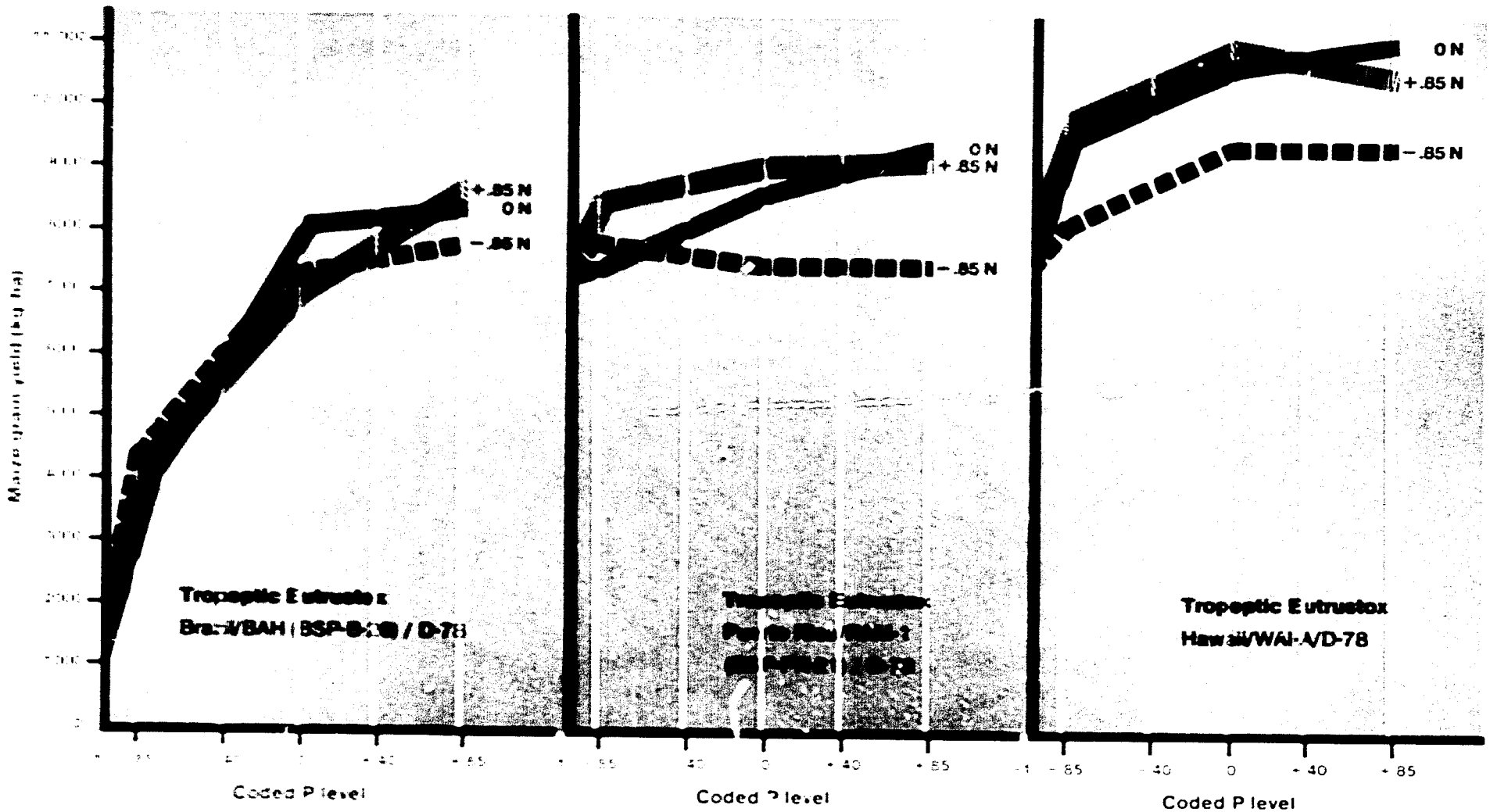


Fig. 9. Response of maize to coded levels of phosphorus and nitrogen in the Tropeptic Eutrustox network.

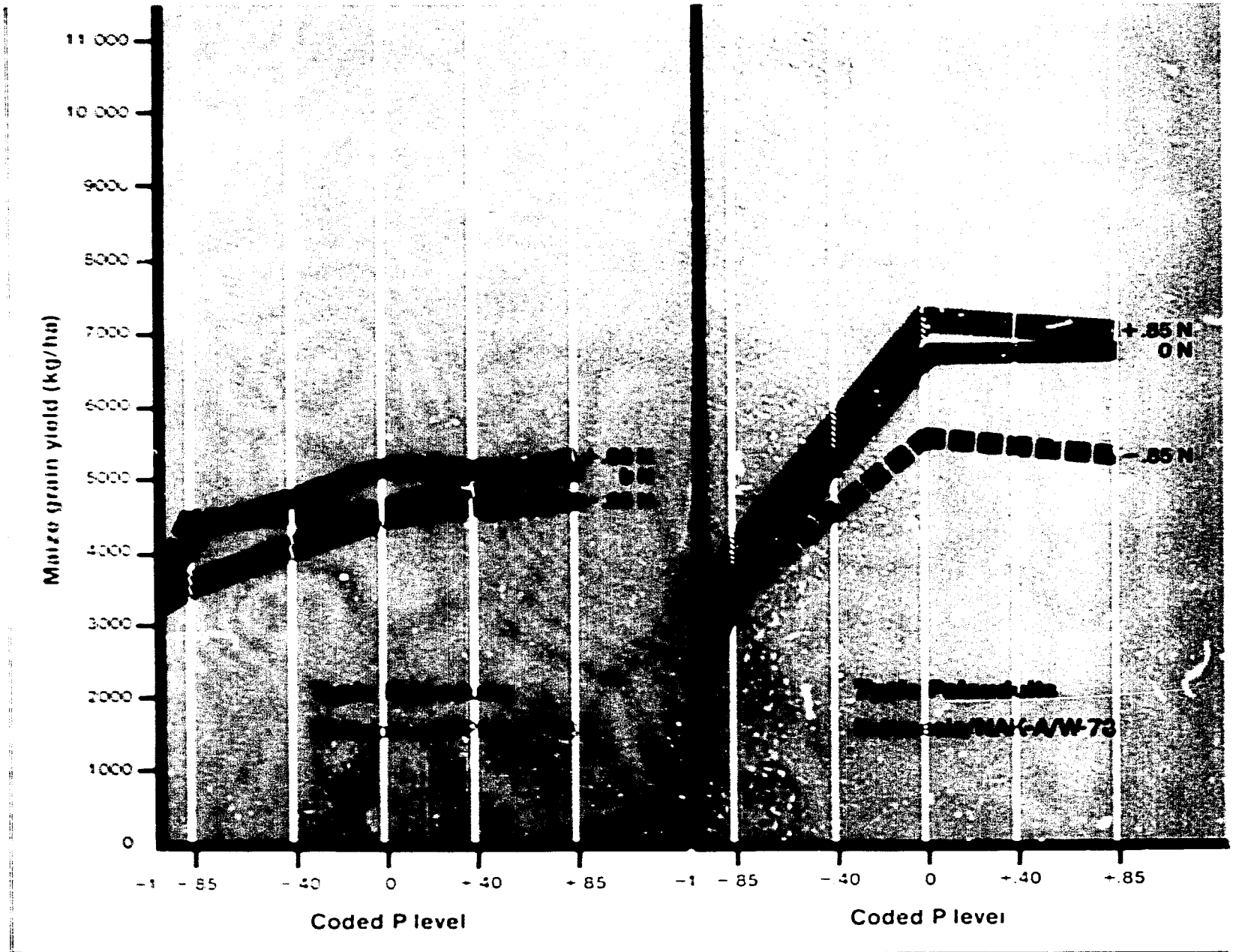


Fig. 10. Response of maize to coded levels of phosphorus and nitrogen in the Typic Paleudults network.

Development of the Transfer Model

The basic formulation of the transfer hypothesis and a numerical example of the methodology is given in the Benchmark Soils News (Vol. 2, No. 1, 1978) and in Progress Report 1 (1978).

As described in these early reports, a transfer model was developed to show the relationship between the response data and the design variables for each site. *See* Fig. 5 for the schematic drawing of the approach taken by the Benchmark Soils Project. Soil levels of the nitrogen and phosphorus treatment design factors are not constant across the experimental sites within a soil family, however, due to natural and earlier management variabilities. These and other variables, including weather factors such as temperature and solar radiation, cannot be controlled at a constant level, but they can be measured at each site and should be an integral part of the experimental design. Thus, the individual site response-input relationship can be affected by the specific biotic environment of the site, and only by including the uncontrolled site variables in the transfer model can the response to the controlled variables be clearly focused (Wood and Cady, 1979).

"The individual site response-input relationship can be affected by the specific biotic environment of the site."

In this second analysis, then, additional site variable information on solar radiation, modified Truog soil phosphorus, and soil nitrogen was incorporated into the formulations of the transfer model; in addition, the lime variable was replaced with an applied nitrogen variable.

For the second analysis, eight wet-season maize transfer experiments on the Hydric Dystrandepts were available for testing the transfer hypothesis. Three sites were eliminated from further analysis due to high coefficients of variation or no phosphorus response. The sites analyzed include two in the Philippines (PUC-K and BUR-B), two in Hawaii (KUK-C and KUK-D), and one in Indonesia (LPH-E).

Quadratic polynomial response surface models were estimated for each of the five sites and are illustrated in Fig. 11A. A common response surface model cannot be fitted to all sites as the individual surfaces are obviously different. So, it was necessary to introduce the site variables into the response equation to account for the variability among the individual site response surfaces. The site variable data for the five sites are given in Table 8. (*See* Appendix 2 for complete weather data throughout the Project network.)

Our approach is to predict the yields, denoted as $\hat{Y}_{(-i)}$, for one of k experimental sites, using a transfer function estimated from the other $(k-1)$ sites. This is then repeated for predicting the yields for each of the k sites based on a transfer function estimated from the other $(k-1)$ sites. The *transfer* residuals, $Y_i - \hat{Y}_{(-i)}$, can be compared with the *ordinary* residuals, $Y_i - \hat{Y}_i$, calculated by fitting a response function individually to each of the k sites.

A sum of squares criterion is used to compare the magnitude of the transfer residuals, $Y_i - \hat{Y}_{(-i)}$ with the ordinary within site residuals, $Y_i - \hat{Y}_i$. In particular, the ratio of the pooled sum of squared transfer residuals to the pooled sum of squared ordinary residuals is calculated. This ratio, called the transfer hypothesis test statistic and denoted as P, is expressed as

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

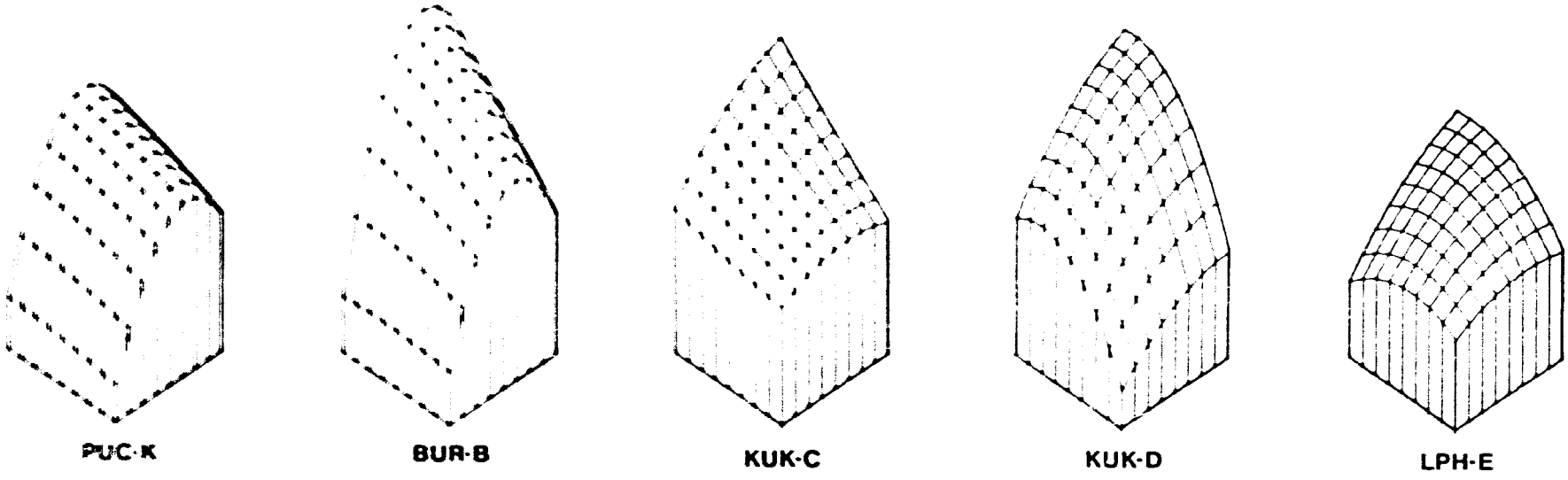
The P statistic using only the controlled PCODE (applied P) and NCODE (applied N) in a quadratic polynomial as the transfer function and predicting for an omitted site from the remaining four sites had a significance level less than 0.01. The transfer hypothesis had to be rejected, which substantiates the need for introducing site variable information into the transfer function.

Four important interactions between site variables and the controlled design variables were identified:

applied P × soil P
applied P × soil N
applied N × soil N
applied N × minimum temperature

After these four interactions were included with the controlled variables (quadratic polynomial)

A. Individual site model ($\hat{Y}$)



B. Transfer model ($\hat{Y}_{-i}$)

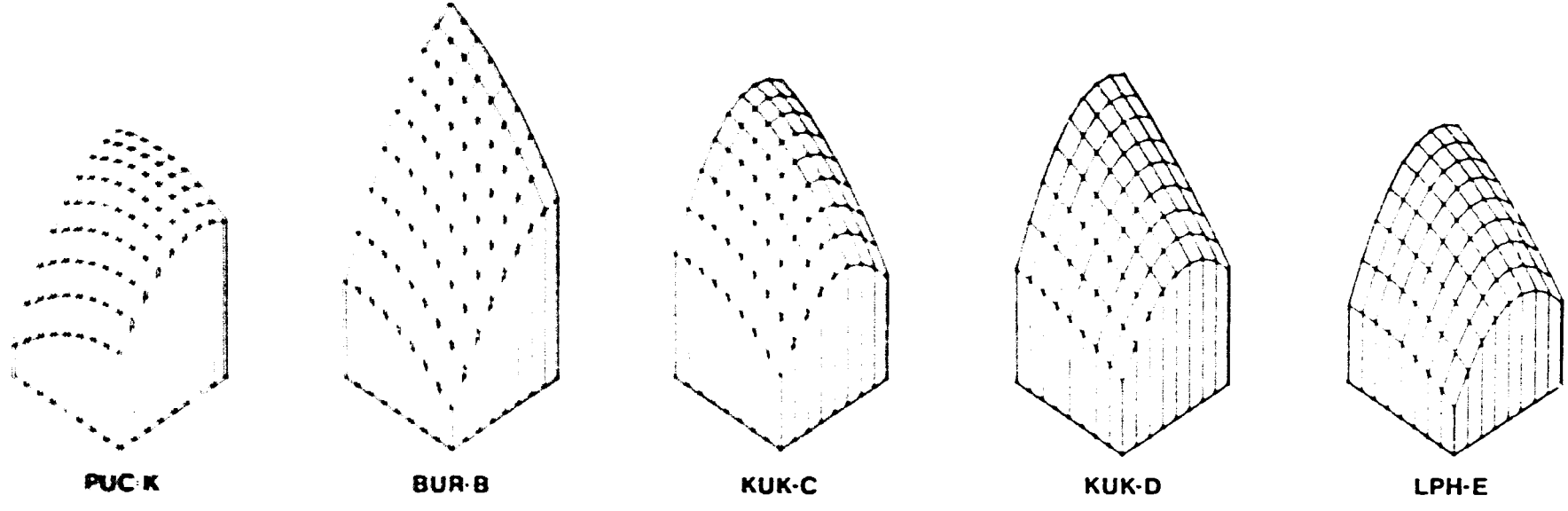


Fig. [illegible] Configurations of the multivariate response model (A) and the transfer response model (B) on the Hydric Dystrandepts [illegible]

Table 8. Site variable data[a] for five Hydric Dystrandept sites (wet season 1978)

Site	Mean yield (kg/ha)	Temperature (°C) Max.	Temperature (°C) Min.	Solar radiation (g cal/day)	Modified Truog P (ppm)	Extr. N (ppm)
PUC-K	4820	35.90	23.00	421	10	79
BUR-B	5418	30.05	21.50	352	5	29
KUK-C	7717	27.07	18.83	430	49	46
KUK-D	7188	25.84	17.90	405	62	29
LPH-E	3631	24.02	16.76	316	23	119

[a]The mean for each site variable is taken from 4 weeks before tasseling to 4 weeks after tasseling.

and a separate intercept for each site, the P statistic was calculated from the sum of squares in Table 9.

The prediction statistic, P, which is the ratio of the transfer residual sum of squares to the ordinary residual sum of squares, is 131,698,800/88,006,684 = 1.49. Thus, there is a 49 percent increase in unexplained variability when predicting one site from the remaining four sites. To attain the significance level of calculated P, we developed a distributional theory of the P statistic and associated computer programs. The probability of observing a P value of 1.49 or larger on chance alone is 0.19. A probability value of this magnitude is evidence that the response surface for applied nitrogen and phosphorus can be transferred with an estimated transfer function that includes interactions between the site variables and the linear effects of the controlled variables.

"With the uncontrolled variables taken into account, fairly accurate crop responses to the controlled variables can be predicted."

The estimated response surfaces showing the transfer prediction, $\hat{Y}_{i-j}$, for each site based on the other four sites are shown in Fig. 11B. There is a similarity of the responses in A with those in B. Since the transfer hypothesis was not rejected, it is of interest to compare the $\hat{Y}_i$, the predictions based on a response surface fitted from data at each of the five sites (A), with the $\hat{Y}_{i-j}$, the predictions based on response surfaces fitted from the other four sites (B). The difference between the two response surfaces for each site is approximated by calculating the absolute difference between $\hat{Y}_i$ and $\hat{Y}_{i-j}$ at (1) the 13 treatment-design points, (2) 81 points formed by a 9-×-9 equally spaced grid system as shown in Fig. 11, and (3) the central 49 points from the 81 grid points in (2). The mean absolute difference for the five sites is given in Table 10. Averaged over the five sites, the mean differences—365, 314, and 258 kg/ha—are so small that a preference for either the site-specific predictions, $\hat{Y}_i$, or the transfer predictions, $\hat{Y}_{i-j}$, could not be made for most practical purposes. These relatively small differences again indicate that the transfer of applied phosphorus and nitrogen technology is feasible.

Tentative Conclusions

The basic hypothesis of the Project is that soils of the same families as defined in Soil Taxonomy have a similar response to similar management

Table 9. Site variable and residual data for five Hydric Dystrandept sites

Site	Site variable: Modified Truog P (ppm)	Extr. N (ppm)	Min. temp. (°C)	Ordinary residuals	Transfer residuals
PUC-K	10	79	23.0	5,860,974	15,072,530
BUR-B	5	29	21.5	25,055,220	36,217,080
KUK-C	49	46	18.8	13,602,420	20,389,510
KUK-D	62	29	17.9	25,599,730	36,422,730
LPH-E	23	119	16.8	17,880,240	23,596,950
				88,006,684	131,698,800

The transfer of agrotechnology to lessdeveloped countries must take place predominantly in the tropics. Knowledge gained in the Philippines (top) and Indonesia (bottom) can be transferred to sites with similar soils anywhere in the tropical and subtropical belt.

Table 10. Mean absolute difference (kg/ha) between ordinary ($\hat{Y}_i$) and transfer ($\hat{Y}_{(-i)}$) residuals at five Hydric Dystrandept sites

	Model		
Site[a]	13 treatment design points (1)	81 grid points (2)	49 central grid points (3)
PUC-K	374	325	248
BUR-B	492	413	338
KUK-C	307	253	283
KUK-D	342	306	207
LPH-E	308	272	213
Average	365	314	258

[a] $\hat{Y}$ at the central grid point for each site, respectively, is 5534, 6313, 7827, 7726, and 3951.

practices. It is the prime purpose of the transfer experiments to generate the necessary data to scientifically test this assumption; the experience to date clearly indicates the general validity of the hypothesis.

"There are general trends predictable across all sites of each soil family network."

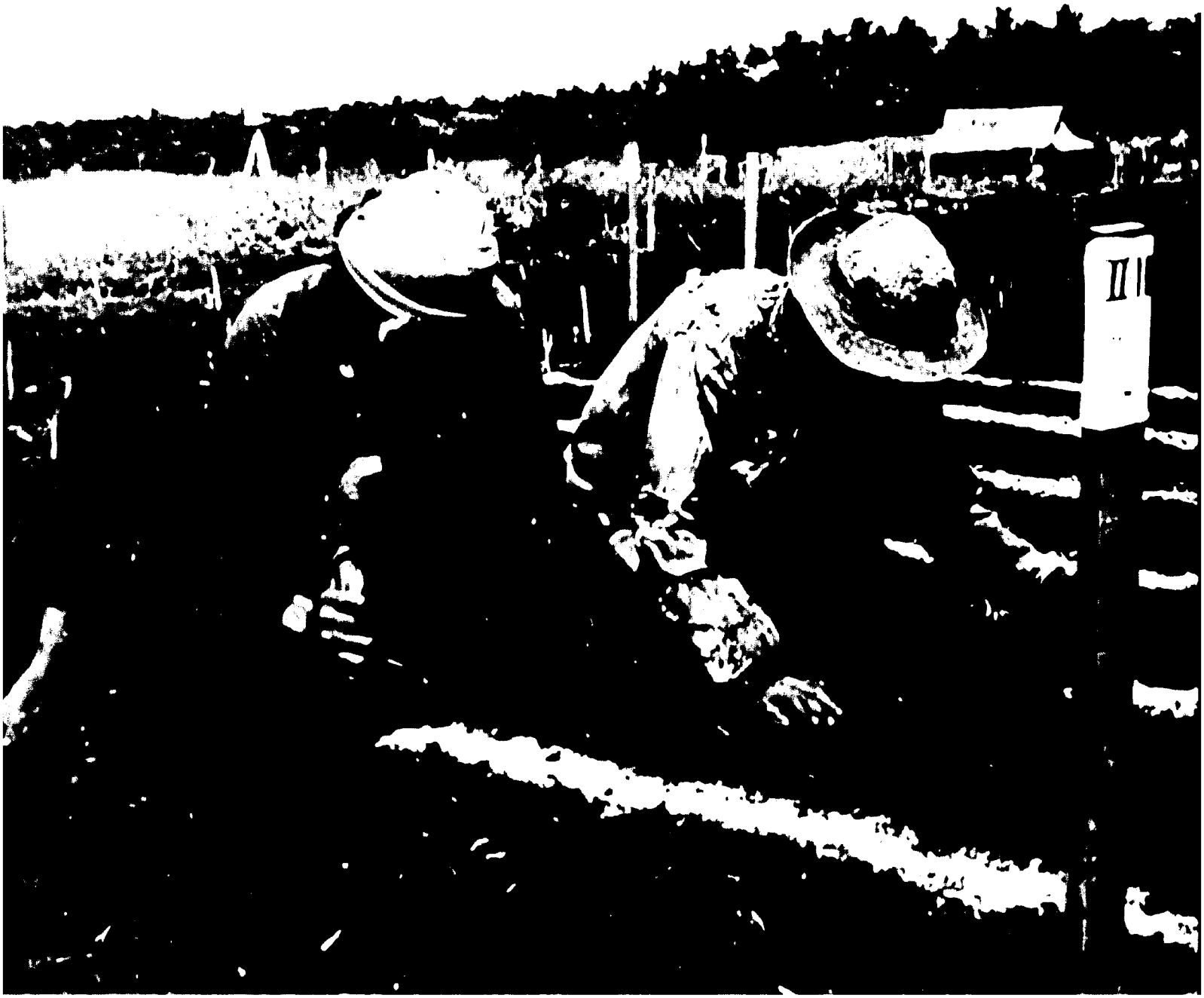
No matter how similar the soils are, yields obtained at different sites will always vary because of differences in weather conditions, diseases, insects, and previous management practices. Nevertheless, there are general trends predictable across all sites of each soil family network. With the uncontrolled variables taken into account, fairly accurate crop responses to the controlled variables can be predicted.

It is noteworthy that, although site differences do exist, on-site inspections of transfer experiments reveal that similarities are more striking than are dissimilarities. Visually observed as well as measured growth and yield response to treatments has been generally remarkably similar among sites. Where differences do occur, the causes are local variables, such as weather and previous site management. Natural variations of certain characteristics—for example, base saturation—even though within the family range, may also cause differential crop response among sites. Weather, as well as other uncontrolled variables, always influences crop response to treatments. These uncontrolled variables, therefore, have been monitored so that their effects on crop yields can be taken into account in the final analysis of data over all sites.

It must also be realized that the soil family still allows for variations in defined and undefined soil properties. In a clayey family of Eutrustox, for example, the base saturation in the subsoil may range from 50 to 100 percent, clay content may be from 35 to 100 percent, and surface soil reaction may be moderately acid to neutral. In practice, phases of soil families are therefore used to narrow the range of soil properties important to a specific purpose or land use. It follows that phases of soil families allow more precise predictions of crop performance than soil family taxa alone.

Thus, it is evident that the response of all soils of each soil family network and their production potential are quite similar. The responses to treatment variables have a similar trend, which suggests that all members of a soil family indeed have a common response to management practices that is characteristic of that family and distinct from others. Further experimentation and the final statistical analysis, therefore, are expected to corroborate the Project hypothesis.

Applied Research for Vertical Transfer



VARIETY TRIALS:

Analysis of Local Varieties

For proper assessment of the yield potential of a crop at different locations, common varieties must be planted at each site. In the transfer experiments in all three soil families, a variety of maize that is well adapted to its locale and agroenvironment is grown initially to minimize any catastrophe to an introduced variety. Another criterion used by the Project in selecting varieties for the transfer experiments is responsiveness to the variables being tested. Thus, varieties are screened in experiments that have N and P fertilizer differentials. Variety tests with maize confirmed the environmental adaptability of a given cultivar in a given network. Yield results to date indicate that a universal variety is not presently available for the Hydric Dystrandept network, but a single variety (Pioneer 'X304C') is performing well throughout the Tropeptic Eutrustox network.

A summary of varieties planted in the transfer experiments in all three soil families indicates the need to simultaneously plant both a variety experiment and a transfer experiment to identify a likely "best variety" for a given network. Fig. 12 shows the range of maize variety yields on the Hydric Dystrandept network. Table 11 summarizes the "best varieties" to date in each country in each soil family. Tables 5, 6, and 7, Appendix 1, present a summary of yields in variety experiments in the Hydric Dystrandept, Tropeptic Eutrustox, and Typic Paleudult soil family networks.

Thixotropic, Isothermic Family of Hydric Dystrandepts

Hawaii. One variety experiment with P × N variables was conducted in Hawaii during the wet season. Several Pioneer hybrids were included in the trial and generally outyielded the Hawaii variety 'H610'. Pioneer varieties 'X304C', '4816', '4817', and '5800' produced yields of 5 to 6 tons/ha during the less-than-optimum season. Another variety experiment was conducted during the dry season, and the Hawaii varieties 'H688' and 'H610' performed as well as Pioneer varieties 'X304C', '4816', and '4817' with yields of 8 to 8.5 tons. It is interesting to note that Pioneer 'X304C' has also performed well on the Tropeptic Eutrustox sites in Hawaii and in Puerto Rico.

Indonesia. One variety experiment with P × lime variables and two with P × N variables were installed in the dry and wet seasons, respectively. Indonesia varieties 'H6', 'Bastar Kuning', and 'Harapan' gave the highest yields of about 6 tons/ha and about 3 tons/ha in the dry and wet seasons, respectively. 'H610' from Hawaii and the Philippine varieties 'DMR Comp. 1' and 'UPCA Var. 1' produced less grain, but they still gave acceptable yields.

Philippines. One variety experiment with P × N variables for maize was conducted at the primary site during the dry season. The Hawaii

varieties 'H610' and 'H788' gave the highest yields, which were not different from those of 'UPCA Var. 1' (Philippine variety) or 'Bima' and 'H6' (Indonesia varieties). 'UPCA Var. 1' has been used in transfer experiments in the Philippines in the Hydric Dystrandept family.

Clayey, kaolinitic, isohyperthermic Family of Tropeptic Eutrustox

Variety trials conducted on the clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox demonstrated that a number of maize varieties are suitable for this family of soils on the sites tested. One variety, Pioneer 'X304C', has been consistently high yielding in both Hawaii and Puerto Rico. This hybrid has been observed to have a scarcity of brace roots, which suggests that it may be susceptible to lodging, but no such problem has occurred during the several seasons it has been used in variety trials and transfer experiments.

Other hybrids have also produced quite well in Brazil and Puerto Rico. 'IAC Phoenix 1110' was initially used in Brazil tests. This was followed by another hybrid, 'Cargill 111', which also yielded well in variety trails at Jaiba. In Puerto Rico the first transfer experiments were planted to Pioneer 'X306B'. But in 1978 all transfer experiments at all Eutrustox sites, including Hawaii, were planted to the hybrid, Pioneer 'X304C'.

Puerto Rico. Two maize-variety × phosphorus-level experiments were completed at Isabela during 1978, one in the wet season and one in the subsequent dry season. Varietal differences were large in both experiments; in neither case, however, was there a further response to the higher level of applied P, and there was no variety × phosphorus-treatment interaction.

Another variety trial planted in 1978 and completed in 1979 was established in a split-split-plot design with two phosphorus levels, two nitrogen levels, and eight maize varieties. Although these data have not been analyzed statistically, it appears that the hybrid Pioneer 'X304C' continued to rank high but was surpassed in yield by another Pioneer hybrid,

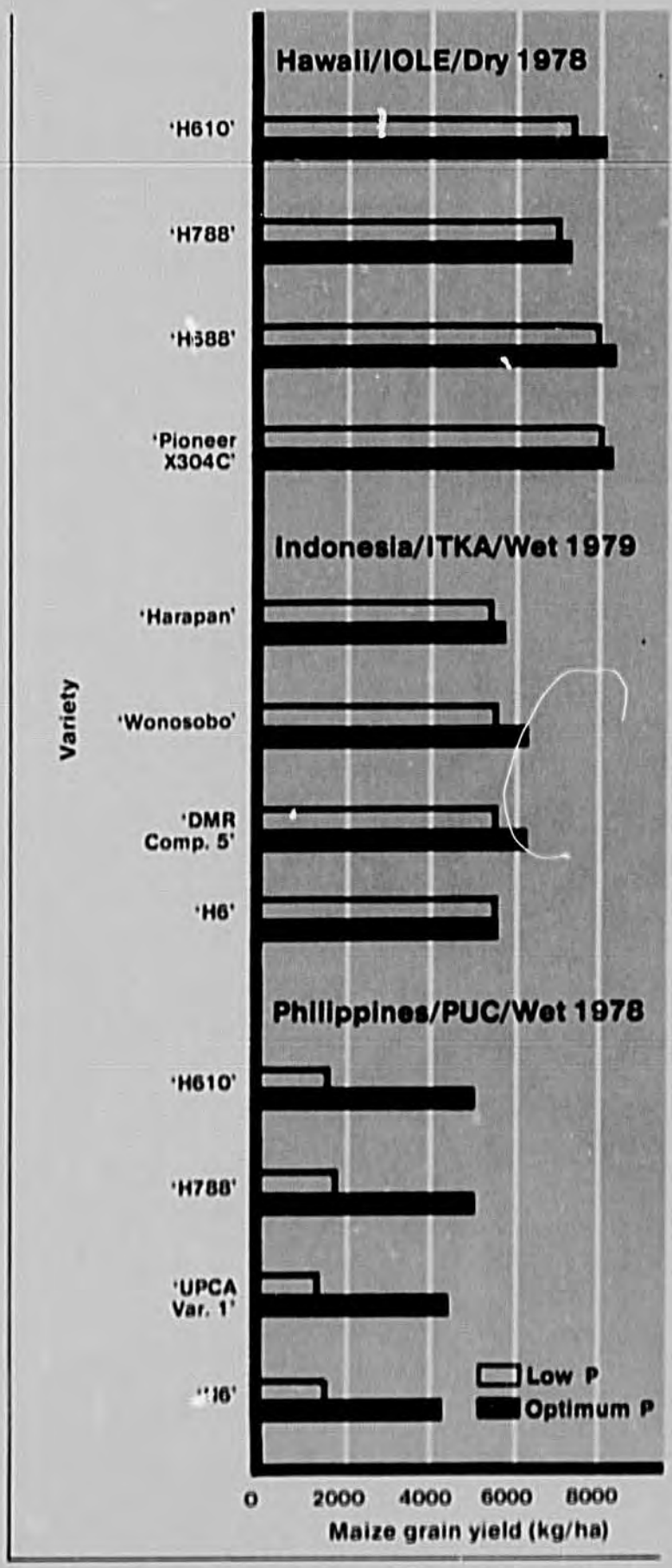


Fig. 12. Range of maize variety yields in three countries in the Hydric Dystrandepts network. Responsiveness of each variety to P added was most dramatic in the Philippines.

Table 11. Best adapted maize varieties for each soil family

Country	Cultivar
Hydric Dystrandepts	
Hawaii (USA)	H610
Indonesia	Harapan, H6
Philippines	UPCA Var. 1
Tropeptic Eutrustox	
Hawaii (USA)	Pioneer X304C
Puerto Rico (USA)	Pioneer X304C
Brazil	Pioneer X304C
Typic Paleudults	
Philippines	Tiniguib
Indonesia	H6

'5800'. This was a wet-season experiment, and most variety yields were relatively low.

Brazil. Brazil data have not been statistically analyzed; however, it would appear that Pioneer hybrids 'X304C' and 'X306B' and 'IAC Phoenix 1110' yielded best during the wet season, and 'Cargill 111' ranked highest by a narrow margin during the dry season.

The second INTSOY international soybean variety trial planted in Brazil was completed during 1978. Grain yields ranged from 1734 kg/ha for the variety 'Rillito' to 3367 kg/ha for the variety 'Davis'. 'Essex' and 'Columbus' yielded 2884 and 2845 kg/ha, just below, but not significantly less than, Davis. It is of interest that 'Bragg' and 'Bossier' are varieties that ranked low in this dry-season experiment but ranked near the top along with the variety 'Davis' in the INTSOY trial of the preceding wet season on the same site at Jaiba.

Hawaii. One variety trial was conducted on the Hawaii Tropeptic Eutrustox site. Pioneer 'X304C' gave the highest yield of 7 tons/ha and was followed by Hawaii varieties 'H788' and 'H610' with yields of 6.6 tons/ha. Other varieties had yields of 5.9 to 6.5 tons/ha. All varieties were responsive to N and P.

Clayey, kaolinitic, isohyperthermic Family of Typic Paleudults

Indonesia. The first N × P variety experiment was conducted at the Nakau site during the wet season, 1979. Varieties 'Kodok' and 'Metro' gave the highest yields of 5.9 and 5.4 tons/ha, respectively. Variety '116' gave the lowest yields of 4.5 tons/ha.

Philippines. The first N × P variety experiment at the Davao site was conducted during the dry season, 1979. Philippine variety 'DMR Comp. 1' and Indonesian variety 'H6' gave the highest yields of 5.3 and 5.1 tons/ha, respectively. Other Philippine varieties had yields of 3.8 and 4.6 tons.

There does not appear to be a generally adapted variety for the Typic Paleudults from these first two tests. We hope one may be found in the future.

MANAGEMENT EXPERIMENTS:

Utilizing Local Resources

Management experiments are conducted on all three soil families to study agronomic problems and to identify 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 for governments to provide 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 frequency of irrigation; and other important management practices.

A total of 32 management experiments were conducted on the three soil families, primarily at the request of cooperating countries of the Project.

Residual Effects of Phosphorus

Volcanic ash soils such as the Hydric Dystrandepts have the capacity to fix relatively large amounts of P fertilizers, so a farmer must apply large enough amounts of P fertilizer to partially satisfy the fixation capacity of the soil and still have some available P remaining for the crop. This can increase the farmer's fertilizer costs substantially. However, response to application of P fertilizer in these soils is obtained not only in the crop planted immediately after P application, but also in crops planted later. Persistence of P fertilizer is being assessed in some of the Benchmark Soils Project sites with successive plantings of maize or other crops in the same plots without further addition of P. Data for three crops planted over a 3-year period have been obtained in Hawaii, Indonesia, and the Philippines and indicate continued response to P even in the last crop planted. Irish potatoes, head cabbage, and soybeans, as well as maize, were planted in residual P experiments in Indonesia, and all indicated residual P supplied crop needs and increased yields.

"Persistence of phosphorus is being assessed in some of the sites with successive plantings of maize or other crops in the same plots without further addition of phosphorus."

A single P application was effective in supplying the P requirements of five consecutive

crops grown over a period of almost 18 months at the LPHS secondary site in Indonesia (Fig. 13). Yields are expressed as a percent of the yields of the middle treatment (coded zero P, zero lime levels) and plotted against coded P. Response to P varied markedly with the crop grown, but yields of all crops, except peanuts, increased over that of the control (zero P) with applied or residual P. Yields of the controls varied from 37 percent for head cabbage to 89 percent for maize. Yields of peanuts in the control treatment were 116 percent of yields of the middle treatment. Increased yields from fertilizer applied to the first crop were realized for all crops, except peanuts which appeared to be adversely affected by increasing amounts of residual P. N and K were reapplied as needed. The amount of P initially applied was 150 kg/ha for the −.85 P and 515 kg/ha for the +.85 P treatments.

Yields of the middle treatment (coded zero P, zero lime) for these crops, in order of planting, were 3821 kg/ha for maize; 17,173 kg/ha for potatoes; 19,300 kg/ha for head cabbage; 1400 kg/ha for peanuts; and 6385 kg/ha for the second crop of maize. The nearly twofold difference in maize yields was largely because (1) the first crop

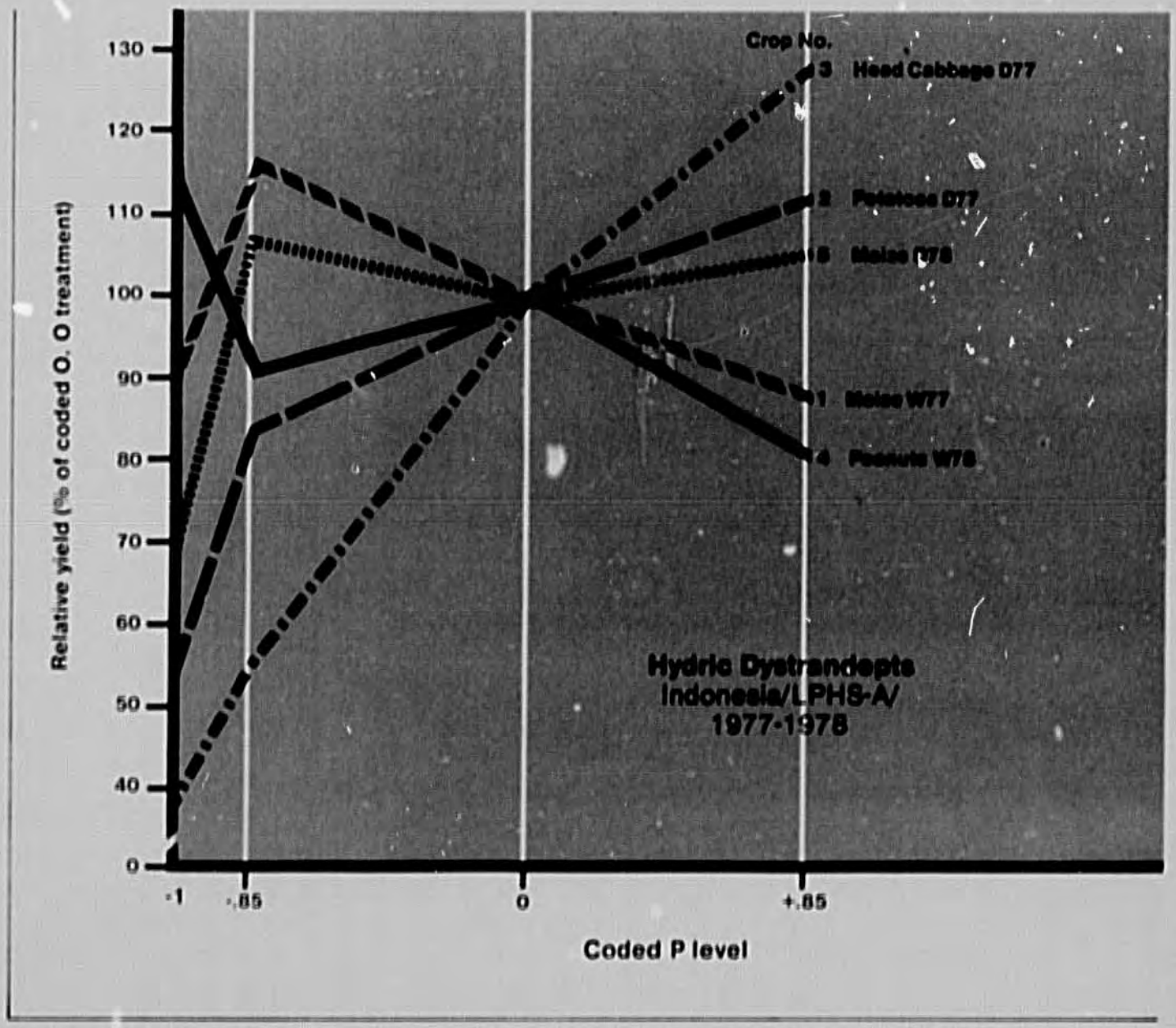


Fig. 13. Effect of a single phosphorus application on five consecutive crops on a Hydric Dystrandept in Indonesia.

Because small farmers often operate with limited capital, the residual effects of phosphorus fertilizer application on subsequent crops is being studied by the BSP. On Hydric Dystrandepts at ITKA, Indonesia, both maize and potatoes showed high yields in residual phosphorus experiments.

was grown in the wet season while the second crop was grown in the dry season and (2) an improved variety of maize was grown in the second crop. The −.85 P rate appeared to be adequate for the first crop of maize, while higher rates resulted in yield depressions. When the second crop of maize was planted over a year later, native soil P in the control plot had decreased, resulting in lower yields (89 percent vs 68 percent for the first and second maize crops, respectively). Yields with higher rates of P were similar to that with the −.85 P rate, which indicates that the residual P levels were on the yield response plateau. Therefore, application of 15.4 kg P/ha was more than adequate for the first maize crop and residual P from it was adequate for the second maize crop.

Continued availability of P fertilizer for several years after application implies that the cost of the fertilizer can be amortized over several years and thus P fertilizer can be considered a capital investment. An earlier study in Hawaii revealed that response to P application could be obtained in a legume-grass pasture for 9 years after application (Fox et al., 1968). Smaller amounts of P fertilizer persist for shorter times, but farmers may still realize responses to P for several crops, thus reducing their yearly P fertilizer costs.

Nutrient Requirements of Maize and Soybeans

An experiment was designed to determine the optimum N, P, and K application rates for maize by installing an NPK experiment at ITKA, Indonesia. Nitrogen rates ranged from 0 to 160 kg/ha; phosphorus rates ranged from 0 to 120 kg/ha; and potassium rates ranged from 0 to 100 kg/ha. Highest yields were obtained with 120 kg P, 40 kg N, and 100 kg K/ha; however, there was no significant yield difference between 0 and 100

kg K/ha. Response to N at this site was quite erratic and was not shown to be significantly different. Addition of the "blanket" fertilizer treatment only, which consisted of 100 ppm Mg, 15 ppm Zn, and 2 ppm B, increased yields significantly over the control treatment, which received no fertilizer.

Two experiments were installed to determine the P, K, and lime requirements of soybean variety 'Orba' on the Hydric Dystrandept sites in Indonesia. Adequate amounts of nutrients were 113 kg P/ha, 88 kg K/ha, and 4.3 to 6.5 tons lime/ha, depending on the site. At the ITKA site, (Fig. 14), the minus Mg

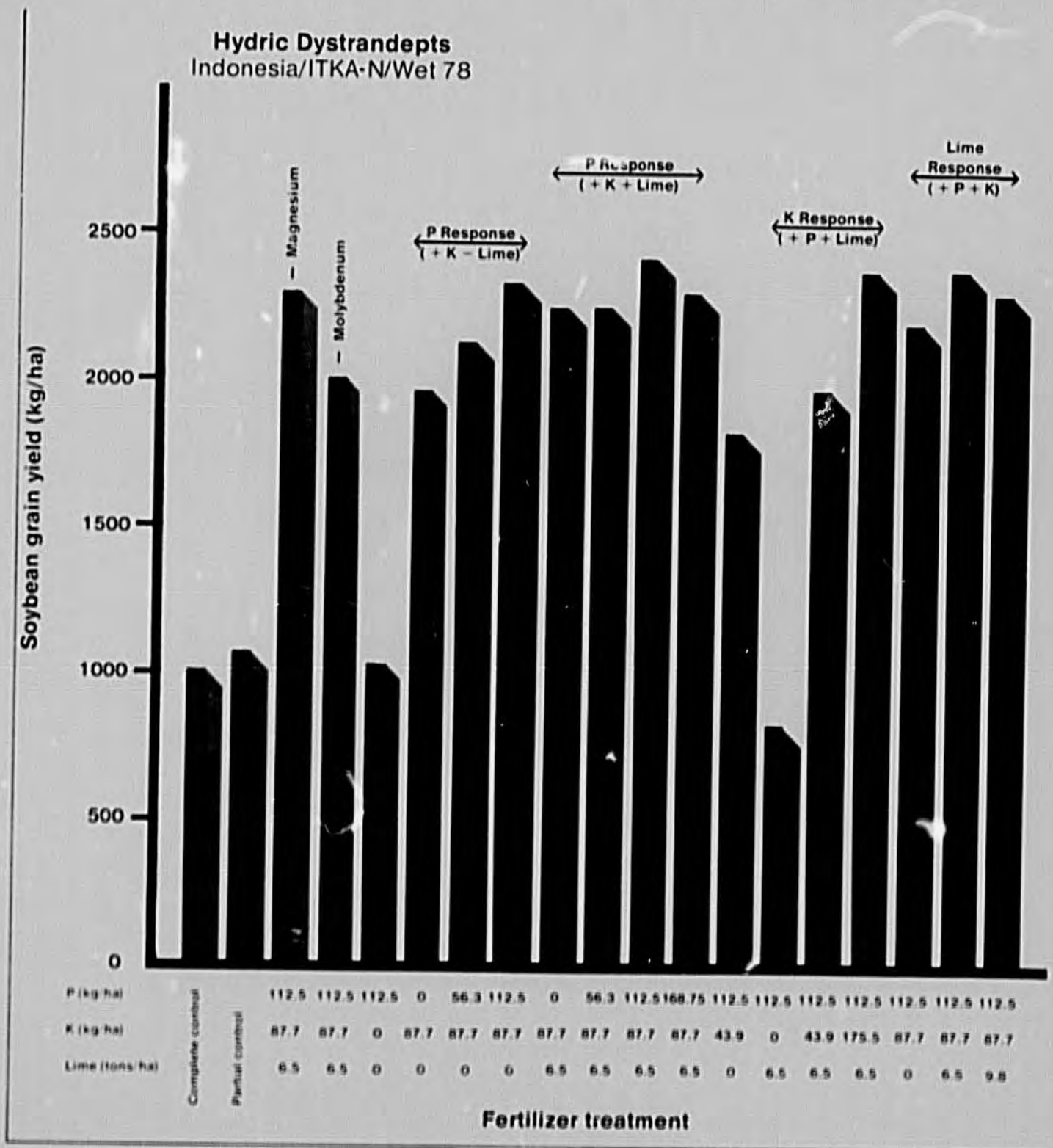


Fig. 14. Soybean ('Orba') response to phosphorus, potassium, lime, and micronutrients on a Hydric Dystrandept in Indonesia.

treatments reduced yields only slightly from the treatment with Mg, but leaving out Mo caused a yield decrease of about 400 kg/ha. Experiments of this type indicate the kind and level of nutrients required by a crop in a particular soil family.

P Placement × Organic Manure on Maize

This experiment was installed in 1977 and continued through 1978 at the primary site (ITKA) in Indonesia on the Hydric Dystrandept soil. There are four P-placement treatments: broadcast, 37.5-cm wide band, 25-cm band, and 12.5-cm band. The amount of P applied is to provide 0.05 ppm P in solution to the fertilized area. There is also a control plot that receives only the "blanket" application of fertilizer, consisting of Mg, Zn, and B, and a complete control plot that receives no fertilizer at all. The organic manure treatments are farmyard manure (FYM) and maize stover mulch. These treatments are applied in factorial combination. Four crops will be planted in this experiment, and additional P will be added in the banded P treatments so that the same total amount of P will have been added to all P plots by the time the fourth crop is planted. Maize variety 'Harapan' is being grown.

The broadcast P application with 30 tons/ha of FYM and mulch gave the highest yields (Fig. 15). Addition of both FYM and mulch gave consistently higher yields over all P treatments than either manure or mulch alone. Results of this experiment indicate that local farmers may realize yield increases at low cost by the addition of maize stover mulch or FYM, and will also indicate whether the same yields can be obtained from one large application of P, which requires considerable capital for the first crop, as from four small applications of P, which requires less capital per crop.

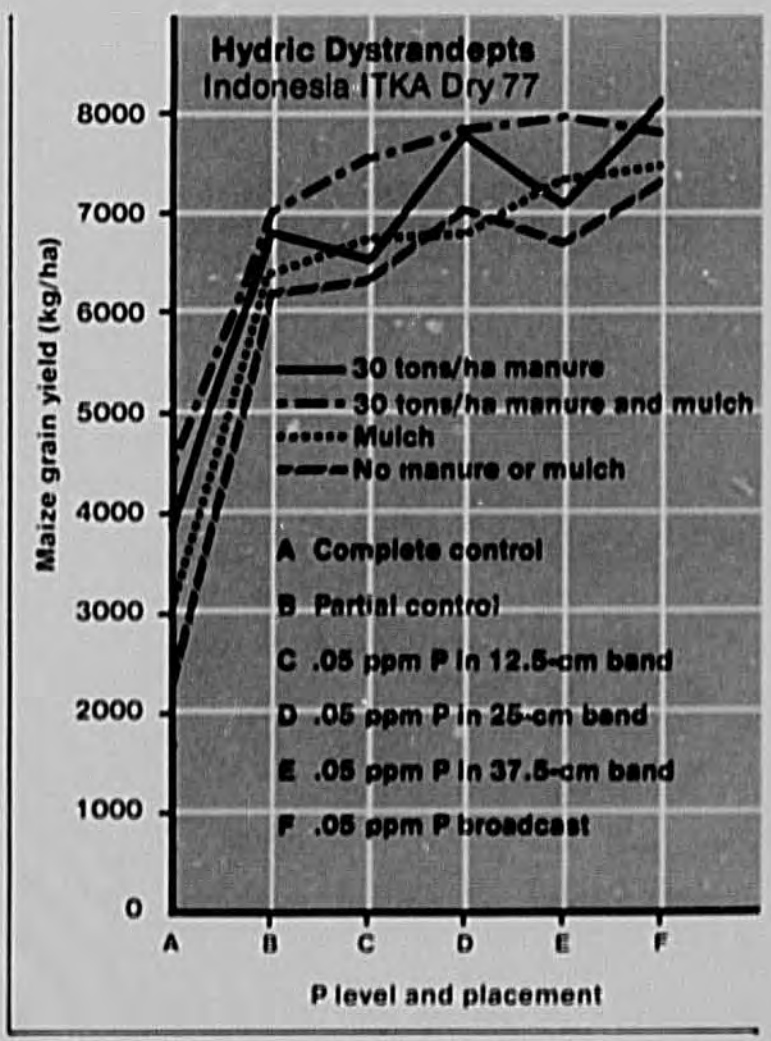


Fig. 15. Effect of manure and mulch, and phosphorus placement, on maize ('Harapan') grain yield on a Hydric Dystrandept in Indonesia.

Maximizing the Effect of Low P Inputs

Considering that Hydric Dystrandepts and similar soils require large amounts of P fertilizer, which is expensive for small farmers with limited

Narrow bands of superphosphate are applied by hand prior to planting at PUC, Naga City, the Philippines. Results from this experiment are shown graphically in Figure 16.

capital, a P rate × placement experiment was installed in March 1978 at the PUC site in the Philippines to determine the most efficient utilization of low rates of P fertilizer. Rate treatments ranged from 10 to 320 kg P/ha. Placements included broadcast application with incorporation (100 percent of tillage layer = 1) decreasing by steps to a band width of 9.8 cm (⅛ of the tillage layer fertilized), and finally a drill application in a small band to the side and below the seed row. Table 12 gives the complete list of treatments.

Yield results for the first maize crop (Fig. 16) indicate a negative effect from restricted placements at high rates of 80 kg/ha or above; however, at the low rates of 10 and 20 kg/hectare, yields 39 and 32 percent higher than the broadcast treatments, respectively, were obtained from the ⅛-band width placement. Thus, even for the first crop, placement increased the efficiency of the P fertilizer applied and the increased yield due to placement in these two cases was more than adequate to pay for the P fertilizer at these rates. Restricted placement is also expected to increase the residual effect of phosphorus and the experiment will be replanted in 1979 and 1980 to quantify this effect. These initial results show promise for developing fertilizer application methods that maximize returns from small P applications on soils with high P fertilizer requirements.

Table 12. Treatment combinations for rate x placement of phosphorus experiment, Hydric Dystrandepts, PUC, the Philippines, 1978

Placement of P		Rate of P (kg/ha)[b]									
Width relative to broadcast treatment[a]	Band width (cm)	0	10	20	40	80	113	160	226	320	Number of treatments
1	75		X	X	X	X		X	X	X	7
1/2	37.5			X	X	X	X	X			5
1/4	18.8			X	X	X		X			4
1/8	9.4		X	X	X			X			4
Drill	–		X	X				X			3
Control	–	X									1

[a] 1 = broadcast application; drill is estimated at 1/225.

[b] The lines connecting X's indicate treatments with equal concentration of phosphorus in the volume of soil fertilized.

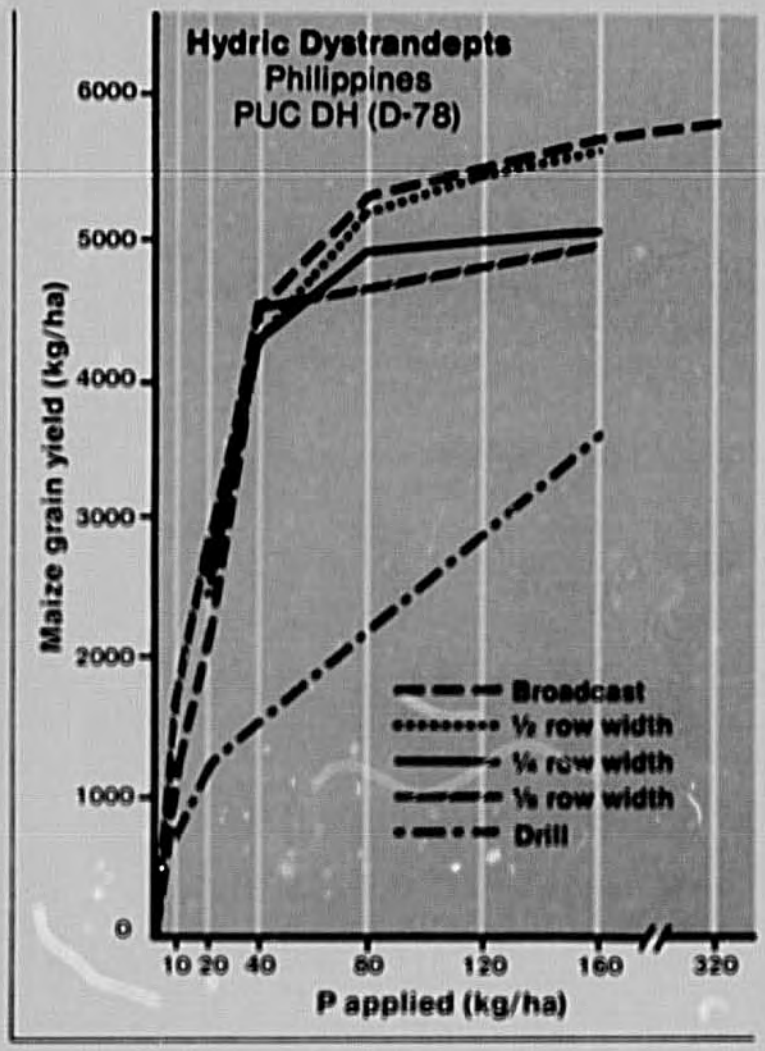


Fig. 16. Effect of phosphorus placement using drill, banding, and broadcast methods, on maize (UPCA var. 1) grain yields on a Hydric Dystrandept in the Philippines.

An NPK experiment provides a graphic picture of the effects of fertiliser application.

Maize Plant Density

At Jaiba, a maize plant population experiment was conducted at the primary site during the 1978 wet season. This was a follow-up of a previous plant population experiment conducted in 1977, but was laid out in the plant density "wheel" design rather than in a conventional design.

The objective of the experiment was to evaluate a very wide range of maize plant stand densities from hand-planted low populations common in small-farm operations in the tropics to relatively high plant densities using a modern hybrid maize well-adapted to the area.

Twenty-five concentric circles plus borders were planted each to 124 maize hills with three seeds in each hill and later thinned to one plant per hill. Space between concentric circles was adjusted to give plant populations from approximately 6,600 to 70,000 plants/ha from the inside to the outside circles, respectively.

A summary of the results of this experiment is presented in Fig. 17. Grain yield per unit area was reduced by over threefold as population density decreased from about 70,000 to 8,000 plants/ha. In addition, yield components such as number of ears per plant, grain weight per plant, and mean ear weight increased by up to nearly threefold as population density was reduced.

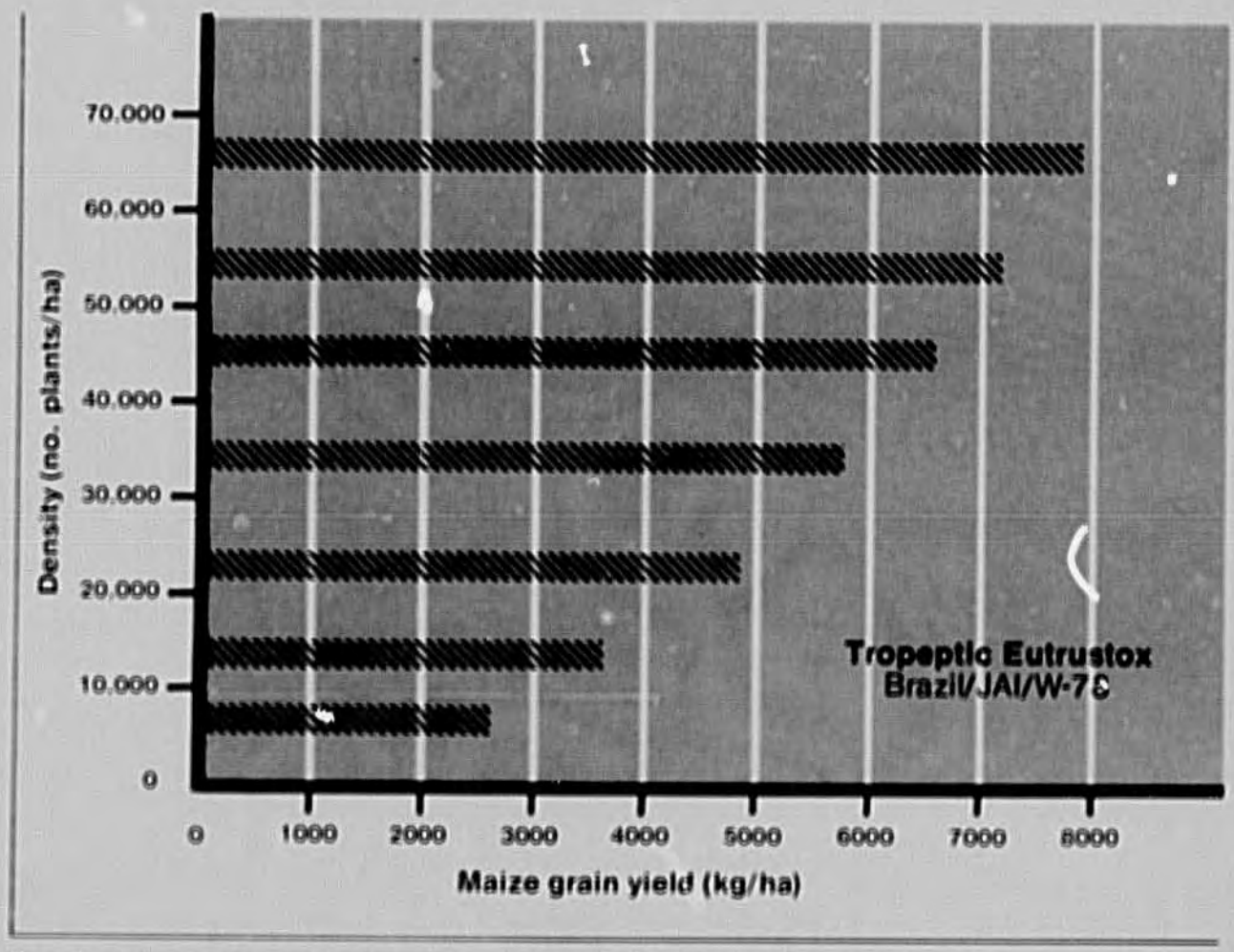


Fig. 17. Effect of planting density on maize grain yield on a Tropeptic Eutrustox in Brazil.

Impact and Utilization

National and International Networks

International coordination and cooperation is vital to the effective transfer of agroproduction technology, and the Benchmark Soils Project is assisting in gathering soils data and increasing information exchange within the tropical soils network. International linkages within the Project exist on two levels: by soil family and by cooperating country organizations and agencies. The objectives, concepts, and results of the Benchmark Soils Project are stimulating and facilitating host-country Benchmark activities, including classification of soils according to Soil Taxonomy, training activities on soil classification and agrotechnology transfer, and advisory councils on effective land-use planning utilizing Benchmark Soils Project concepts.

Linkages

The Benchmark Soils Project is a cooperative research program between the College of Tropical Agriculture and Human Resources at the University of Hawaii and the College of Agricultural Sciences at the University of Puerto Rico, with on-site experiments in the cooperating countries of Brazil, Indonesia, the Philippines, and soon Cameroon. Funding is by contract with AID.

"An agreement was signed between BSP and the IFDC for a collaborative research project on the evaluation of phosphorus fertilizer materials on a network of Benchmark soils of the tropics."

As of June 30, 1979, 21 experimental sites were operational on a network of three tropical soil families; the remaining sites are expected to be operating by the end of 1979.

The number of actively cooperating organizations in various countries is now 20. Official linkages exist between the Project and host-country cooperating agencies: EPAMIG (Empresa de Pesquisa Agropecuária de Minas Gerais), Brazil; ONAREST (Office National de la Recherche Scientifique et Technique), Cameroon; PCARR (Philippine Council for Agriculture and Resources Research), Philippines; SRI (Soil Research Institute), Indonesia; UH (University of Hawaii), USA; and UPR (University of Puerto Rico), Puerto Rico. Other agencies and institutions that are collaborating in comparing research results and requirements and thus are supporting BSP concepts and goals include EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária); IITA (International Institute of Tropical Agriculture); INTSOY (International Soybean Program); CST (Consortium on Soils of the Tropics); ORSTOM (Office de la Recherche Scientifique et Technique Outre-Mer); IFDC (International Fertilizer Development Center); ICRISAT (International Crops Research Institute for the Semi-Arid Tropics); SEARCA (Southeast Asian Regional Center for Graduate Study and Research in Agriculture); NifTAL (Nitrogen Fixation by Tropical Legumes); INPUTS (Increasing Productivity Under Tight Supplies),

East-West Center; the Soil Conservation Service (SCS) of the U.S. Department of Agriculture; the Food and Agriculture Organization of the United Nations (FAO); and various AID missions.

Agreement with ONAREST

An agreement was negotiated between Hawaii's Benchmark Soils Project and Cameroon's National Office for Scientific and Technical Research (ONAREST) in June 1979.

Under this agreement, Hawaii BSP will cooperate with Cameroon in the introduction of applied research directed toward linking soil survey and soil survey data interpretation with research on crop growth and the optimal use of soil resources. The BSP/ONAREST agreement complements the activities of the FAO/UNDP group in Cameroon who are concentrating their activities on soil surveys and land suitability studies for rural development projects and agroecological studies on plant and soil analyses. There is a need for crop production information to assist in soil interpretation, which makes the BSP activities very timely.

The Benchmark Soils Project is also being asked to assist in the preparation of a long-term research program in agropedology (plant and soil relations) for the humid tropical areas of Cameroon based on the results of its research.

Collaborative Research on BSP Soils Network

A new linkage between the Benchmark Soils Project and the IFDC (International Fertilizer Development Center) was established in November 1978, when an agreement was signed for a collaborative research project on the Evaluation of Phosphorus Fertilizer Materials and Placement Effects in a Network of Benchmark Soils of the Tropics.

David Harris, doctoral candidate at the University of Hawaii and graduate assistant with the BSP, will supervise plantings and harvests of maize at five BSP sites: Luzon, the Philippines; Mindanao, the Philippines; Java, Indonesia; Sumatra, Indonesia; and Hawaii. The experiments will compare phosphorus fertilizer materials at each site, including ground rock phosphates from two sources and minigranules made from these rocks by a process developed by the IFDC. Final harvests for the experiments are scheduled for mid-1980, and results will be compiled in Harris' doctoral dissertation.

Networking Assistance to NifTAL

At a January workshop on the Island of Maui, Hawaii, James A. Silva, Principal Investigator of the BSP, offered the use of Benchmark sites

Table 13. Summary classification of soils of the INPUTS experimental sites by the Benchmark Soils Project, 1979

Country	Soil series	Probable classification
Bangladesh	Sonatala	Haplic Hydraquents or Aeric Haplaquents, coarse-silty, mixed, hyperthermic
Guam	SND[a]	Lithic Dystropepts, fine, mixed, isohyperthermic
Iran	Amol	Typic Haplaquepts, fine, mixed, thermic
	Rasht	Aeric Haplaquepts, fine, mixed, thermic or mesic
	Dezful	Typic or Udic Ustrochrepts, fine, mixed, hyperthermic
Pakistan	Lalian	Typic Ustifluvents or Ustertic Torrifluvents, coarse-loamy or coarse-silty, siliceous
Philippines	SND[a]	Typic or Ustic Dystrocrepts, fine-loamy or fine-silty, mixed, isohyperthermic
Taiwan	Tali	Typic or Udic Ustifluvents, coarse-loamy or coarse-silty, hyperthermic
	Liuying	Same as Tali series
Thailand	Saraburi (1)	Aeric Tropaquepts, fine, mixed, isohyperthermic
	Saraburi (2)	Same as Saraburi (1) series

[a]SND = series not designated.

to NifTAL (Nitrogen Fixation by Tropical Legumes), a University of Hawaii project funded by AID contract ta-C-1207, as a beginning of a network of sites to test Rhizobium strains. Silva made a proviso, however, that prior approval be obtained by NifTAL from the host government in each country. NifTAL has already used the BSP Iole site on the Big Island of Hawaii.

Silva recommended that all experimental sites be classified according to Soil Taxonomy so that the crop and soil information gained can be added to the Benchmark Data Bank and be available for transfer throughout the tropical world. In addition, he offered BSP assistance in analysis for soil characterization and reminded the group that profile samples must be properly collected and described by a competent soil surveyor, as is required of the INPUTS (Increasing Productivity Under Tight Supplies) program of the East-West Center in Honolulu, another collaborative effort of the Benchmark Soils Project.

Cropping Systems Research

Jerry L. McIntosh, Cropping Systems Agronomist, Cooperative CRIA/IRRI Program (Central Research Institute for Agriculture/ International Rice Research Institute) in Indonesia, has been granted a year's study leave in 1980 with the Hawaii Benchmark Soils Project. He plans to study how BSP research relates to the cropping patterns and technology developed at CRIA in relation to relevant socioeconomic conditions affecting agricultural production. He is especially interested in how soil classification according to Soil Taxonomy might be used within CRIA in the development of cropping systems for different areas.

"Host-country networks of tropical soils are the first step in the development of an international network of Benchmark soils."

Host-Country Activities

To facilitate the transfer of agrotechnology to local farmers, several countries have established or have expressed interest in establishing national Benchmark soils networks.

These local networks are the first step in the development of a framework for an international network of Benchmark soils.

It is important to stress that it may not be possible to work at the soil family level on a national scale. Indeed, for some homogenous soil groups, it may be unnecessary.

Textural phases of subgroups may generally suffice for national Benchmark soil networks. Opportunities should continually be sought through research to determine the most effective level of the classification to be used for any part of the network. The most effective means is that level of the classification at which information transfer can be made accurately enough for regional or national planning purposes.

The experiments conducted on national Benchmark sites will need to be conducted in a systematic and cost-effective way, but they will not need to be as complicated as our transfer experiments. The purpose here is to obtain data to recommend farming practices for the average to better-than-average farmers. A good job of soil survey interpretation of mapping units and recommendations based on results of management experiments on a network of Benchmark sites will go a long way in increasing the value of soils information in agricultural development planning.

Brazil

EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária) expressed a keen interest in the concepts, strategy, and research of the Benchmark Soils Project. Of particular concern is the utilization of BSP-generated knowledge, in the areas of both required management practices and best-adapted varieties.

Brazilian officials of the Servico de Levantamento e Conservacao de Solos (SNLCS) of EMBRAPA have also expressed interest in national programs. During a recent visit to Brazil, F.H. Beinroth was asked to assist in conceiving a suitable strategy to utilize the Benchmark Soils concept in Brazil. In-country scientists and cooperators have been favorably impressed by Project operations in Jaiba and can

Agencies cooperating with the BSP in Indonesia (right) and the Philippines (left) facilitate the vertical transfer of agrotechnology to local farmers.

visualize the impact of linking a national network to one at an international level. Jorge Olmos, senior soil scientist with SNLCS, and Derli Prudente Santana, liaison between EPAMIG (Empresa de Pesquisa Agropecuária de Minas Gerais) and UPR, visited the BSP sites in Minas Gerais with Beinroth. Their trip reflected a growing interest on the part of SNLCS-EMBRAPA in the utilization of the Benchmark soils philosophy at a national level in Brazil.

EPAMIG continues to be an excellent and supportive cooperator of the BSP in Brazil. Helvecio Mattana Saturnino, President of EPAMIG, suggested that EPAMIG publicize BSP concepts and results in various existing EPAMIG publications and periodicals widely circulated in the State of Minas Gerais. He also proposed that field days be held on-site in Jaiba to provide researchers and farmers with an opportunity to learn about the Project.

CNPMS (Centro Nacional de Pesquisa de Milho e Sorgo) is cooperating with the BSP in conducting line-source sprinkler irrigation experiments with maize and sorghum in which the amount of applied water is a continuous variable.

Indonesia

OVER 200 IN COUNTRY CENTERS FORESEEN

Agricultural Development Centers (ADCs) have recently been established at Soropadon, Central Java, and Plumbon, West Java. According to D. Muljadi, Director of SRI (Soil Research Institute), these ADCs have integrated various agricultural disciplines to test different commodities, primarily food crops, for suitability for local farmers. Technical information from research institutes and universities on these commodities is provided to extension specialists at the ADCs for use by both field extension specialists and farmers.

A primary activity at each ADC is conducting applied field research for demonstration and pilot programs. Cropping systems at the center are determined by agronomists under the leadership of Ir. Wardojo, Director General of Food Crops. The information received and generated at these ADCs is then available for transfer to farmers and production centers on similar soils and environments.

Muljadi indicated that these centers are situated on Benchmark and extensive soils of

The first BSP experimental site was established in 1975 on a thixotropic, isothermic Hydric Dystrandept near Honokaa on the Island of Hawaii.

a particular area. The soils were identified by SRI, and each center is mapped at a scale of 1:2000. Two additional centers are nearing establishment in Bedali, East Java, and in Tegineneng, Lampung, Sumatra. Ultimately, 200 such centers are envisioned for all of Indonesia; hence, there is much emphasis on soil survey and soil classification to determine soil resources of Indonesia.

SRI has also initiated its in-country, or national, Benchmark Soils network with the establishment of an experimental farm in Lampung, South Sumatra. This site has been operational since early 1978. Also, in cooperation with the Central Research Institute for Agriculture (CRIA) and USIAD/Jakarta, SRI has been conducting soil surveys in Sumatra to identify soils on which nine agricultural research stations are to be situated. These stations may also become part of a national network of experiment stations on key or Benchmark soils.

SILVA, TSUJI PARTICIPATE IN AID REVIEW

J. A. Silva and G. Y. Tsuji participated in the annual review of Project 497-0189, Assistance to Agriculture, at the invitation of W.C. Tappan and M. Korin of the AID mission in Jakarta. Silva made a brief slide presentation of BSP activities with emphasis on work in Indonesia. D. Muljadi, Director of SRI (Soil Research Institute), I P.G. Widjaja-Adhi, SRI Coordinator for BSP-Indonesia, and R.G. Manuelpillai, UH Project Leader in Indonesia, were also present at the review. Project 0189 has served as an umbrella for the operation of the Benchmark Soils Project in Indonesia since 1976.

Silva, Tsuji, and Widjaja-Adhi also had a unique opportunity to meet and discuss Project goals and activities with U.S. Ambassador Eugene Masters in the company of Deputy Director Sara Jane Littlefield, Tappan, and Korin.

Philippines

PROPOSAL FOR NATIONAL PROGRAM

A national program is also being proposed in the Philippines. Recently, a draft of a proposal for a national research program on The Classification of Philippine Soils and Agrotechnology Transfer Using Soil Taxonomy was prepared jointly by G. N. Alcasid, Jr., and R. Santos of the Bureau of Soils; A. Maglinao of PCARR (Philippine Council for Agriculture and Resources Research); A.A. Briones of the University of the Philippines at Los Baños; and M.E. Raymundo, BSP Project Leader in the Philippines.

The proposal includes the general framework, the manpower and logistic requirements, and the timetable for operations. The areas proposed to be covered include the Ilocos region, the Cagayan Valley, the Bicol region, all in Luzon; Samar and Leyte in the Visayas; and the Agusan River Basin in Mindanao. Existing regional agricultural development programs in these areas would be greatly aided by the proposed workshops on Soil Taxonomy and agrotechnology transfer using BSP concepts.

The draft proposal is scheduled for presentation to financing agencies sometime in April. Final preparation of the program proposal and initial implementation of the program will require cooperation from outside consultants, including BSP personnel.

PHILIPPINE ADVISORY COMMITTEE RECOMMENDS CLASSIFICATION OF SOILS

Strong interest was exhibited by Philippine government agencies in utilizing the concept of agrotechnology transference based on soil classification according to Soil Taxonomy, which is the basis of the Benchmark Soils Project.

Present Philippine soil maps are mostly soil reconnaissance surveys conducted before the Soil Taxonomy existed. The Philippine advisory committee to the Benchmark Soils Project supported the concept of developing a more useful basic classification system but explained that they had neither the personnel nor the equipment to undertake such a classification. They suggested that classification of soils should be initiated in three areas: Cagayan Valley, Isabela; Ilocos Norte; and the Bicol River Basin.

The University of the Philippines at Los Baños (UPLB) indicated that research efforts at the University could be tied into the classification effort; the CIADP (Cagayan Integrated Area Development Program), also offered both financial and research assistance.

PCARR EVALUATION AT DAVAO

A soil research evaluation team of the Soils and Water Research Division of the Philippine Council for Agriculture and Resources Research (PCARR) made a two-day review evaluation of ongoing soil research in Davao on April 6–7, 1978. They visited the Benchmark Soils Project site in the BPI-Davao Experiment Station and the projects of the Bureau of Soils and the Philippine Coconut Authority.

Other Expressions of Interest

Expressions of interest in the prerequisites for the utilization of BSP concepts have been received recently from A. Derenoncourt, President of AGROTECNIQUE of Haiti, and F. Iyamureye of ISAR-Rubona, Butare, Rwanda.

Brazil cooperation includes line-source sprinkler irrigation experiments with maize and sorghum, in which the Centro Nacional de Pesquisa de Milho e Sorgo worked with EPAMIG and the BSP. Soybean trials using varieties contributed by INTSOY were also run in Brazil and Puerto Rico.

Communications Network

The communication of research results and the establishment of a response capability to assist developing countries in transferring agrotechnology in tropical and subtropical areas is the main thrust of the dissemination and utilization program. One of the major means of dissemination of information is the Benchmark Data Bank, which has the capability of establishing a worldwide agrotechnology transfer network. Conferences and workshops combine theory and practical application among members of the national and international community of agencies and institutions and individuals. The Benchmark Training Program is being developed with workshops in host countries on Soil Taxonomy and agrotechnology transfer. Publications are an effective means of promoting world awareness of BSP concepts and utilization of Soil Taxonomy as a means to agrotechnology transfer.

Awareness of Project goals at the international level has been created through training programs, workshops, conferences, and publications. Communication linkages with international agricultural research centers and cooperating national research institutions are maintained through regular mailing of various publications and through correspondence and visitors.

"Data generated by the Project under precise quality control will form the core of the BSP data bank system, which will be gradually developed and modified."

Host-country cooperators in Indonesia and the Philippines have convened advisory committees to create an awareness of Project concepts and activities at the national level. These committees are composed of scientists, program planners, and administrators who can provide the necessary guidelines and inputs to cooperate with the Project in developing a framework for the vertical transfer of information for country-use. For example, representatives of the Philippine Council for Agriculture and Resources Research (PCARR), the Bureau of Soils, the College of Agriculture at the University of the Philippines at Los Baños (UNLB), the Bureau of Plant Industry, the National Economic Development Authority (NEDA), USAID/Manila, and BSP form the advisory committee to BSP in the Philippines, while the Soil Research Institute (SRI), the Central Research Institute for Agriculture (CRIA), and BSP form a technical committee to BSP in Indonesia. In addition, in Indonesia, both the former group and the Bureau of Planning and USAID/Jakarta form the advisory committee to BSP. Advisory committees established by the host country lend further support to the acceptance of Project concepts and goals.

National research networks are the basic foundation for an international network linking, for the first time, agricultural research stations in the tropics.

Dissemination of results of research and the theories and implications of the Benchmark Soils Project has stimulated interest in the Project and catalyzed activities in various areas. These activities effectively link the growing network of communicating and cooperating research institutions.

Benchmark Data Bank

Early progress in the development of a data bank system was primarily focused on the storage and retrieval of soil characterization data, including site and profile descriptions and chemical and physical analyses. Much of the impetus of the soil data file was initiated through a cooperative effort between BSP and an SCS-funded (Soil Conservation Service) contract with the Department of Agronomy and Soil Science, University of Hawaii.

Recent progress has been in designing a framework for the development of a functional data bank system that would permit interpretation of soil survey data for agricultural development and land evaluation. A consultant systems analyst provided technical assistance in planning this expanded program.

Thus, a soil interpretation data bank system is being developed to serve both scientists and agricultural planners. The framework of the bank is shown diagrammatically in Fig. 18.

The Project has collected and is continuing to collect all three types of data: soil, crop, and weather. In essence, the soil and crop performance information and environmental data are to be matched to produce an output that can be translated for a specific user. Hence, data generated by the Project under precise quality control will form the core of continued development modification and updating of the BSP data bank system.

Fig. 18. The three kinds of data now included in the Benchmark Data Bank will be incorporated into an expanded soil interpretation file that will be available to various users.

Conferences and Workshops

Discussion of Impact of Agrotechnology Transfer at International Workshop

The Benchmark Soils Project concepts formed the core of the discussion at a workshop entitled Operational Implications of Agrotechnology Transference Research, held at ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), Hyderabad, India, October 23–26, 1978. Working sessions were devoted to the transfer of BSP-related data, techniques, training, and other technology.

The results of the workshop were that the SCS/USDA agreed to "internationalize" Soil Taxonomy and workshop participants agreed to create an international body to oversee soil resource inventory quality control and to mobilize talents and resources to begin collecting soil and crop data for soil interpretation, soil correlation, and agrotechnology transfer.

Participants supported by the Benchmark Soils Project came from Indonesia, the Philippines, Sri

BSP personnel participate in workshops and conferences throughout the tropical world. In September 1978, the Second International Soil Classification Workshop was held in Malaysia and Thailand and was organized by the University of Puerto Rico.

Lanka, Brazil, the Netherlands, Hawaii, and Puerto Rico. Other representatives were from USAID, ICRISAT, IRRI, SCS, FAO, and the World Bank.

Soils with Variable Charge Conference in New Zealand

The Benchmark Soils Project has been extended an invitation by Commissions IV, V, and VI of the International Society of Soil Science through Mike Leamy of the New Zealand Soil Bureau to participate in an international conference entitled Soils with Variable Charge to be held in Palmerston North, New Zealand, on February 11–18, 1981. A full day has been set aside for a symposium on the Benchmark Soils Project, for which Project personnel have been asked to prepare a program. The conference will be held under the auspices of both the New Zealand Society of Soil Science and The Royal Society of New Zealand.

Workshop on Soil Research Inventory and Evaluation

The Philippine Council for Agriculture and Resources Research (PCARR), the Philippine Bureau of Soils, and the Soil Science Society of the Philippines sponsored a three-day national conference-workshop on Soil Resources Inventory and Evaluation for Countryside Development on January 18–21, 1978 in Manila. A major component of the workshop was the use of Soil Taxonomy in development planning. Group sessions identified the need for soil resources inventory by farmers, researchers, and planners and resulted in proposals for soil resources

inventory programs to support development planning. M.E. Raymundo and A.A. Briones were participants from Benchmark at this workshop.

Asian Food Conference

Goro Uehara, Soil Scientist with the Benchmark Soils Project, attended the 14th Asian Food Conference in Singapore October 29–November 2, 1978. Held annually in Latin America and Asia, these meetings are sponsored by the International Minerals and Chemical Corporation of Libertyville, Illinois. Uehara was asked to present a talk on the Benchmark Soils Project at the 1979 conference, tentatively scheduled for Taipei, Taiwan. Members at the 14th conference were provided copies of the BSP Progress Report 1, Research on Agrotechnology Transfer in the Tropics.

PCARR Sponsors Workshop-Seminars

Philippine Project Leader, Martin Raymundo, participated in three seminar-workshops sponsored by PCARR (Philippine Council for Agriculture and Resources Research) in 1978.

Raymundo discussed a paper on soil conservation and the Regional Development Project at the National Seminar-Workshop on Soil Conservation, July 28–30. He presented a paper on Soil Management at the FAO—Philippines National Workshop on Development and Management of Rainfed Crop Production, July 31–August 1, and he spoke on Minimum Pedological Data for Field Experiments at the National Workshop on Minimum Sets of Data for Field Experiments on Crops, September 29–30.

All the workshops were held at PCARR headquarters in Los Baños, Laguna, the Philippines.

Workshop on Soil Taxonomy in Malaysia and Thailand

Under a special grant from the U.S. Agency for International Development (AID), the University of Puerto Rico organized the Second International Soil Classification Workshop in Malaysia and Thailand, August 28–September 9, 1978. The Department of Agriculture of Malaysia, the Land Development Department of Thailand, the Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA), Cornell University, the University of Hawaii, the University of Ghent, Belgium, and the Soil Conservation Service of the USDA collaborated to stage the event.

The overall purpose of the workshop was to improve Soil Taxonomy with regard to tropical soils and to further the application of Soil Taxonomy as a uniform system of soil classification in Southeast Asia in order to facilitate agrotechnology transfer to and within that region. More specifically, the workshop focused on Oxisols, Alfisols, and Ultisols with low-activity clays. Participants critically examined the taxonomy of certain classes of tropical soils and formulated a series of recommendations for Soil Taxonomy and associated subjects that may well serve as the framework for future international activities in soil classification. The proceedings of the workshop will be published by the Land Development Department of Thailand. The soil descriptions and analytical data generated from the workshop are important contributions to the Benchmark Data Bank.

"The overall purpose of the workshop was to improve Soil Taxonomy with regard to tropical soils."

Training Program Development

An expanded training program is an essential component of the Benchmark Soils Project. To assist in utilization of Project concepts, workshops and training sessions are being planned and conducted in soil classification and identification, soil survey interpretation, and soil-based agrotechnology transfer. In addition, graduate students from three countries are being trained at the University of Hawaii to provide

professional personnel for continuing utilization of the Benchmark Soils Project concept and its adaptation to future national needs.

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

In 1977, the BSP worked with Cornell University in organizing and conducting a Workshop on Soil Resources Inventory and Agrotechnology Transfer which was held in the Philippines (Progress Report 1). The first workshop on Soil Taxonomy sponsored by the Benchmark Soils Project was held June 4–29, 1979 in Los Baños, the Philippines.

"The workshops will catalyze a closer working relationship between agricultural scientists and planning agencies at both the national and international levels to facilitate the transfer of agrotechnology for increasing food production."

Four key in-country achivements were noted:

- Participants were encouraged to complete their own classification projects as a follow up.
- An inventory of resources for the Philippines will be compiled from these projects.
- The University of the Philippines at Los Banos received its first soil survey map with all its land classified according to Soil Taxonomy.
- 170 soils in the Philippines were classified into soil families according to Soil Taxonomy.

In addition, participants were enthusiastic about conducting their own workshops in the future and about training colleagues and co-workers in soil classification according to Soil Taxonomy.

The four-week workshop was sponsored by the Benchmark Soils Project; co-sponsors were the Philippine Council for Agriculture and Resources Research (PCARR) and the U.S. Agency for International Development (USAID). The 13 workshop participants came from the Bureau of Soils, the Philippine Coconut Authority, Central Luzon State University, the National Irrigation Authority, and the Philippine Ministry of Agrarian Reform. Sessions included classroom and field activities and a concluding seminar report by the participants.

Participants learned to recognize the criteria used in soil classification; to use the Soil Taxonomy key; to recall properties and behavior of soils from the classification names in Soil Taxonomy; and to relate Soil Taxonomy to soil survey interpretations.

Throughout the workshop, the instructors suggested ways that the participants could apply Soil Taxonomy to their local areas and jobs and advised them on how to create their own visual aids using local soils. Copies of Soil Taxonomy; the Benchmark Soils Project Technical Report 1, Laboratory Data and Descriptions of Soils of the Benchmark Soils Project (Ikawa); and several other reports were distributed.

A similar workshop for Indonesia is planned for January 1980. At the conclusion of these workshops, materials for a package of training materials on the fundamentals of Soil Taxonomy will be compiled and published.

A total of seven graduate students are now under the sponsorship of the Project: two from the Soil Research Institute in Bogor, Indonesia; two from the Philippine Council for Agriculture and Resources Research, and one from the Bureau of Soils, the Philippines; and two from the United States. The curriculum of each of the students involves courses in soil classification and Soil Taxonomy and an introduction to concepts of agrotechnology transfer. Their thesis topics will be related, in part, to the objectives of the Project.

Publications

The publications program was expanded in 1978, and dissemination of results of research through publications and visuals has stimulated and

A major constraint to the transfer of agrotechnology in many tropical countries is a lack of personnel trained in soil classification according to Soil Taxonomy. Training workshops on soil classification and the concepts of agrotechnology transfer are sponsored by the BSP with the cooperation of various institutions and agencies.

catalyzed interest in and utilization of Project concepts. A bibliography of Project publications and papers is printed in Appendix 3.

The Project mailing list has increased from 900 to over 1400, due to individual and organization requests for copies of publications. The BSP mailing list includes recipients in over 50 countries. Thus, there is already a network of interested agencies, organizations, and individuals that can be tapped in the future as the Project progresses.

Copies of the hardcover book, Soil-Resource Data for Agricultural Development, edited by L.D. Swindale, now Director of ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), have been mailed to over 1000 libraries, institutions and agencies, planners, and agronomy and soil specialists throughout the world. "I think it is the first global review of agricultural and pedological data related to subtropical and tropical belts," says V. Kovda, Institute of Agrochemistry and Soil Science, Moscow Region, Russia, in correspondence received in Hawaii.

The basic areas of dissemination include the quarterly Benchmark Soils News; annual reports; Progress Reports; Technical Reports of research; and utilization materials, including the instructional/training packages, programs, and proceedings. The Project also prepared exhibits for display at the Hawaii State Farm Fair as a contribution for the Department of Agronomy and Soil Science, College of Tropical Agriculture and Human Resources, University of Hawaii. In 1978 the display was on soils research in international agriculture. In 1979 the presentation was a 5-minute slide show on possibilities for careers in agriculture using BSP staffing as an example of various levels, skills, and talents that must be employed.

"The book is the first global review of agricultural and pedological data related to subtropical and tropical belts."

The major purposes of the publication program are to (1) report the results of research and (2) catalyze utilization activities. Effective communication throughout the worldwide network of cooperating countries, agencies, and individuals is also important to link the international corps of Project personnel.

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Appendix 1.
Crop and Soil Performance Data

Table 1. Experiments completed, January 1978-June 1979

Soil	Crop	Transfer experiments	Variety experiments	Management experiments	
Hydric Dystrandepts					
Hawaii	Maize	7	2	1	
Indonesia	Maize	20	3	6	
	Soybean	0	0	2	
	Potato	0	0	2	
	Peanut	0	0	1	
Philippines	Maize	13	1	6	
Subtotals		40	6	18	
Tropeptic Eutrustox					
Brazil	Maize	9	3	5	
Hawaii	Maize	4	1	1	
Puerto Rico	Maize	13	2	2	
Subtotals		26	6	8	
Typic Paleudults					
Indonesia	Maize	7	1	4	
Philippines	Maize	5	1	2	
Subtotals		12	2	6	
TOTALS		78	14	32	= 124

Table 2. Podric Dystrandepts transfer experiments on maize, yield data (Kg/ha)[a], January 1978-June 1979

Treatment							
Coded P	Coded N	Location/site					
Hawaii		DOLE-A D 78	DOLE-F W 78	KUK-A D 78	KUK-C W 78	KUK-D W 78	HAL-B D 78
+0.95	+0.95	7982	5555	7852	8768	8471	8169
+0.95	0	7309	3137	7113	8269	8254	7059
+0.95	-0.95	3966	1759	6982	7358	6293	4971
+0.40	+0.40	6939	4848	7107	8161	8291	7616
+0.40	-0.40	6697	3141	6599	7257	7663	6441
0	+0.95	7095	4322	6993	8917	8606	8191
0	0[b]	6827	3371	7041	7852	7362	6324
0	-0.95	3612	3130	6532	7132	5753	4517
-0.40	+0.40	6874	3905	7240	7775	7249	7009
-0.40	-0.40	6919	2851	6119	7511	6757	5499
-0.95	+0.95	6749	6483	6040	7723	6547	7419
-0.95	0	6255	4143	5528	7181	7014	7016
-0.95	-0.95	5178	2961	5982	7021	5164	5510
Complete control		4247	2428	3184	4005	3715	2317
Partial control		4835	3580	4049	4836	3963	2993
0	No N	****	1449	****	****	****	****
No P	0	****	****	****	****	****	****
0	0[c]	****	****	****	****	****	****
Mean/P treatment		6614	3676	6702	7717	7188	6546
Mean/control		4541	3089	3614	4421	3839	2655
P treatment over partial control (%)		37	2	66	60	81	119

Philippines		PUC-A W 78	PUC-A D 78	PUC-K D 78	PUC-Q D 79	PUC-R D 79	PAL-A W 78	PAL-C D 79	PAL-G D 79	PAL-E D 79	BUR-B W 78	BUR-D D 79
+0.95	+0.95	6858	5086	5462	5253	7473	4559	6005	4342	6772	6931	4918
+0.95	0	5440	4239	5245	4883	6636	4598	5657	4231	6241	6177	4675
+0.95	-0.95	2738	2442	4887	3144	4327	4693	5227	4322	6242	4862	2632
+0.40	+0.40	5707	3340	5875	4509	6492	5933	4970	4553	6238	6071	4631
+0.40	-0.40	4041	3173	5300	3727	5395	5016	4749	4044	6184	6275	3530
0	+0.95	4942	2953	5634	3736	6384	3966	4201	3954	5738	6848	4804
0	0[b]	3360	3858	5288	4080	6550	5105	4103	4246	5669	6122	3892
0	-0.95	1231	2569	5063	2817	5081	4567	4461	4074	5369	5352	2648
-0.40	+0.40	4309	2740	5395	2884	5619	4084	4644	3378	5156	6557	4280
-0.40	-0.40	3451	1963	5048	1871	5385	4049	3875	3543	5082	5492	3247
-0.95	+0.95	827	240	3137	151	2985	2988	3228	730	1965	3276	2428
-0.95	0	1414	639	2934	352	3135	2960	3595	610	1832	2877	2058
-0.95	-0.95	1051	833	3187	139	2577	3893	2955	1183	2250	3590	1354
Complete control		0	0	0	0	0	1428	964	223	0	0	0
Partial control		146	0	0	****	****	1888	1723	****	****	0	****
0	No N	****	****	****	1977	3732	****	****	3565	5456	****	2004
No P	0	****	****	****	280	0	****	****	1424	0	****	336
0	0[c]	****	****	****	****	****	****	****	****	****	****	****
Mean/P treatment		3832	2629	4820	2890	5232	4332	4436	3324	4980	5418	3469
Mean/control		88	0	0	0	0	1658	1344	223	0	0	0
P treatment over partial control (%)		2204	****	****	****	****	129	157	****	****	****	****

Indonesia		ITKA-C W 78	ITKA-C D 78	ITKA-D D 78	ITKA-D W 79	ITKA-K D 78	PLP-F W 78	PLP-F D 78	PLP-G D 78	LPH-D W 79	LPH-E W 78	LPH-E D 78	LPH-E W 79	LPH-G D 78
+0.85	+0.85	3343	4917	5466	6206	3833	2547	4591	8344	7052	4586	4851	5208	5201
+0.85	0	3231	4566	5262	6342	4136	2641	4743	6310	6858	4223	4375	4892	4699
+0.85	-0.85	2999	4702	4911	5635	2985	1095	2496	5335	6195	3126	3768	4003	3351
+0.40	+0.40	3301	4283	5398	6363	2425	2712	5422	6791	6979	4260	5338	5286	4534
+0.40	-0.40	3066	4849	5028	6098	4253	1323	2550	5367	6773	3734	4134	4360	5030
0	+0.85	4047	4785	4608	5452	3652	2474	3584	6500	6672	3223	3460	3445	4504
0	0[b]	3308	4825	4991	5368	4317	2150	3650	6407	6108	3747	4130	4931	4827
0	-0.85	2611	5689	4517	6224	2911	778	1850	4582	6071	3760	4308	4429	4529
-0.40	+0.40	3535	4305	5085	6290	4019	214	3711	7098	6393	3905	3286	5032	4727
-0.40	-0.40	3615	4251	5024	5524	3153	280	4662	5470	6797	3818	3519	3816	4918
-0.85	+0.85	2985	4345	5191	6510	3982	161	2546	6415	5035	2954	3891	4202	4526
-0.85	0	3356	4875	5795	6098	3038	242	3829	6354	5327	3098	3208	3537	4233
-0.85	-0.85	2052	3990	4585	5366	2860	53	1347	4322	5055	2770	2989	4066	3994
Complete control		2613	3554	3309	3945	3037	1458	3574	****	2567	2632	2592	****	2598
Partial control		2744	4441	3392	5199	2834	1465	2424	1814	3801	2898	2346	3595	3598
0	No N	2212	4227	3013	3348	****	970	1372	3627	****	****	****	3477	3334
No P	0	3263	4057	4398	5519	****	1464	1979	****	****	****	****	****	3680
0	0[c]	2642	4387	4203	4784	****	996	1973	****	****	****	****	****	3114
Mean/P treatment		3181	4662	5066	5960	3506	1942	3460	6100	6255	3631	3943	4401	4544
Mean/control		2679	3997	3350	4572	2936	1462	3099	1814	3184	2765	2469	3595	3098
P treatment over partial control (%)		16	5	49	15	24	33	32	236	65	25	68	22	26

Treatment		Location/site									
Coded N	Coded lime	Hawaii	Philippines		Indonesia						
		HAL-A D 78	PAL-C D 78	BUR-A D 78	ITKA-E W 78	ITKA-K W 78	LPH-A D 78	LPH-A W 79	LPH-D W 78	PLP-D W 78	PLP-D D 78
+0.85	+0.85	7956	9265	7764	6078	2289	6684	6596	6266	4558	5097
+0.85	0	7825	8195	6989	5784	2494	5999	6807	5430	5218	5479
+0.85	-0.85	8622	7967	6596	5748	1904	6685	7056	5473	5344	5199
+0.40	+0.40	8120	7552	5829	6324	2880	6212	6340	5235	4780	5652
+0.40	-0.40	7946	8421	6978	6109	1598	6847	6651	5647	5697	5090
0	+0.85	6322	8038	6780	6098	2444	6385	5871	5798	4991	4636
0	0[b]	7856	7451	5112	6632	2117	5778	6721	5748	4785	5715
0	-0.85	8629	8422	5131	5657	2144	6441	6068	5603	4679	4981
-0.40	+0.40	7851	8324	4435	5418	1952	5672	5744	5986	5799	6112
-0.40	-0.40	8187	7435	4881	6009	2014	5934	6150	4997	5110	5983
-0.85	+0.85	5793	6582	858	6137	1656	6493	6678	5271	4248	4937
-0.85	0	7792	7286	684	6020	2082	6844	5893	4787	4849	3797
-0.85	-0.85	7972	7504	448	4869	1997	5702	5872	5153	4348	5311
Complete control		707	1916	159	4655	1438	4056	4778	1781	1413	2362
Partial control		3636	1239	258	4753	1692	4414	4111	3316	3965	3835
0	No N	****	****	****	5563	****	****	****	****	****	****
No P	0	****	****	****	6028	****	****	****	****	****	****
0	0[c]	****	****	****	5184	****	****	****	****	****	****
Mean/P treatment		7759	7880	4806	5914	2121	6283	6342	5492	4954	5230
Mean/control		2172	1577	209	4704	1565	4235	4444	2549	2689	3098
P treatment over partial control (%)		113	536	1761	24	25	42	54	66	25	36

[a] Zero means no yields; asterisks indicate no data obtained.
[b] Optimum treatment with micronutrients.
[c] Optimum treatment with no micronutrients.

Table 3. Tropegytic Entrusion transfer experiments on maize, yield data (kg/ha)[a], January 1978-June 1979

Treatment		Location/site			
Coded P	Coded N				
Hawaii		MUL-A D 78	MUL-B W 79	WAI-A D 78	WAI-B W 79
+0.85	+0.85	10462	8773	10513	11530
+0.85	0	9928	6985	11035	9827
+0.85	-0.85	7957	4983	9456	8654
+0.40	+0.40	9576	8546	10875	10953
+0.40	-0.40	9266	6087	9751	9365
0	+0.85	9887	8185	10920	10843
0	0[b]	9368	6973	10782	10483
0	-0.85	7970	4677	9465	7924
-0.40	+0.40	9994	6940	9744	10899
-0.40	-0.40	8837	5696	9995	9427
-0.85	+0.85	8451	7592	9685	11015
-0.85	0	9136	6977	9633	10258
-0.85	-0.85	7301	4106	8177	8992
Complete control		6628	2551	****	7382
Partial control		7092	2528	7696	****
0	No N	****	****	9865	6793
No P	0	****	****	7949	9299
0	0[c]	****	****	****	****
Mean/P treatment		9079	6676	10002	10013
Mean/control		6860	2539	7696	7382
P treatment over partial control (%)		28	164	30	****

Treatment		Location/site												
Coded P	Coded N													
Puerto Rico		PR-20	PR-21	PR-23	PR-27	PR-30	PR-31	PR-33	PR-34	PR-35	PR-36	PR-37	PR-38	PR-39
+0.85	+0.85	7536	9122	5158	5550	7905	6827	4586	6598	6662	2214	7462	7556	3077
+0.85	0	6958	9391	4735	5497	7167	5181	5089	6408	6506	1732	7678	7647	2379
+0.85	-0.85	6252	7499	4129	3637	6925	2303	4667	6045	7274	2607	6984	7577	3268
+0.40	+0.40	7205	8611	3344	6141	7590	5544	4405	5439	6588	1959	6629	7383	4084
+0.40	-0.40	6456	7982	3888	4445	6492	4806	5177	6717	6134	2016	7222	7946	3687
0	+0.85	6790	9005	3934	5488	8503	6910	3981	4430	5348	1155	6450	7640	2900
0	0	7055	8596	2839	6261	6976	5322	5437	4919	5766	2557	6923	8115	2181
0	-0.85	6465	7547	2377	3852	6379	2366	3523	4790	5634	2754	6794	7110	3577
-0.40	+0.40	6398	8471	3063	5427	7746	5768	4993	3933	4302	2139	4977	6329	2724
-0.40	-0.40	6360	8290	3539	4352	7025	4431	4405	4288	5603	2113	6694	7489	3035
-0.85	+0.85	6043	8409	4572	4327	7874	6198	4885	2481	4247	1735	4841	7387	3599
-0.85	0	5902	7392	3311	5396	7394	5791	4526	1133	2632	1152	5062	7429	4248
-0.85	-0.85	4033	7976	2753	4055	6793	2215	3701	972	4424	1244	4436	7617	3250
Complete control														
Partial control		5646	7369	1571	3559	6240	1599	3515	813	3040	2074	4931	6989	4286
0	No N	5694	7285	1860	3731	5810	1850	3148	1401	1659	1264	4916	6265	3217
No P	0	6153	7677	4237	4813	7707	4837	4546	5152	6351	2008	5876	8342	3815
0	0													
Mean/P treatment		6309	8164	3519	4783	6759	4497	4418	4473	5471	1952	6315	7479	3231
Mean/ control		5646	7369	1571	3559	6240	1599	3515	813	3040	2074	4931	6989	4286
P treatment over partial control (%)		12	11	124	34	8	181	26	450	80	-6	28	7	-25

Brazil		B-19	B-20	B-21	B-22	B-23	B-24	B-25	B-26	B-27
+0.85	+0.85	5328	6522	5134	7786	4507	8595	8809	8453	6725
+0.85	0	5510	6095	5082	5024	3480	7747	7410	7155	5407
+0.85	-0.85	5478	6760	4965	1895	1959	7659	7005	4144	3176
+0.40	+0.40	4352	6517	4402	7247	3730	8319	7655	7713	5898
+0.40	-0.40	4516	6067	4548	3373	2220	7424	7434	6827	3691
0	+0.85	4559	5938	4638	7718	4692	8194	7139	8436	6429
0	0	4653	5518	4777	5007	3428	7449	7037	8072	5701
0	-0.85	3677	6072	4616	1292	2039	7125	7073	3952	2221
-0.40	+0.40	3043	5837	3684	7034	3869	7932	6807	7543	5876
-0.40	-0.40	3131	6142	3275	3746	2487	6239	6644	6467	4832
-0.85	+0.85	2591	5352	2261	7551	5361	7949	7321	7849	6734
-0.85	0	2140	5467	2082	5485	3681	8117	6477	7233	4622
-0.85	-0.85	2439	5165	2938	1741	1871	7348	6417	4337	3799
Complete control										
Partial control		1304	5810	1725	655	1533	7097	7656	1396	2819
0	No N				7267		8331		8805	
No P	0				853		6523		1396	
0	0									
+0.85	No N					5061		7683		6641
No P	+0.85					1968		5871		3141
Mean/P treatment		3766	5947	3866	4992	3360	7700	7171	6783	5009
Mean/control		1304	5810	1725	655	1533	7097	7656	1396	2819
P treatment over partial control (%)		189	2	124	662	119	8	-6	386	78

[a]Zero means no yields; asterisks indicate no data obtained.
[b]Optimum treatment with micronutrients.
[c]Optimum treatment with no micronutrients.

Table 4. Typic Paleudults transfer experiments on maize, yield data (kg/ha)[a], January 1978-June 1979

Treatment		Location/site											
Coded P	Coded N	Philippines					Indonesia						
		DAV-A W 78	DAV-A D 78	DAV-C W 79	DAV-D D 78	DAV-F D 79	NAK-A W 79	NAK-A D 79	NAK-D D 79	BPMD-A W 79	BPMD-A D 79	BPMD-C D 79	BUK-A D 79
+0.85	+0.85	7507	5116	5703	5153	5358	6989	5079	6344	6889	3530	4639	6771
+0.85	0	7106	5300	5957	5191	4918	6843	4787	6539	5986	3351	4269	6256
+0.85	-0.85	6845	3183	4882	4800	2913	5342	3076	4032	4438	3491	2443	3968
+0.40	+0.40	7244	5417	6336	5047	5369	6735	4982	5262	5550	3385	4071	7160
+0.40	-0.40	6947	4602	5602	4452	4671	6157	4440	4934	5547	3272	4202	5072
0	+0.85	6619	4650	6219	5103	5535	7078	4656	6556	6578	3616	4237	7234
0	0[b]	7133	5582	6380	4569	5038	6750	5122	5822	5624	3844	3549	6649
0	-0.85	6436	3577	5438	4618	3370	5519	3726	5246	3604	2750	2679	4381
-0.40	+0.40	7164	4912	6114	4846	5699	6369	3735	6239	5097	2888	3626	6521
-0.40	-0.40	6873	4631	5484	4749	4419	5669	3779	5073	4701	4573	3095	5538
-0.85	+0.85	5843	4980	6516	3828	5587	3976	1109	4074	2538	218	2737	3956
-0.85	0	6682	5284	5648	3770	5166	3657	1058	3578	3388	695	1563	5806
-0.85	-0.85	5788	3981	5193	4503	3182	3582	1154	3138	3048	884	1995	3763
Complete control		5785	3633	5784	2656	4679	1800	549	1664	668	118	493	78
Partial control		6231	2771	4211	3429	2096	2263	912	1662	543	66	625	87
0	No N	5629	2624	4514	4172	2090	5487	3344	3824	3634	2609	2079	3528
No P	0	****	****	****	****	****	1285	615	1390	451	128	437	117
0	0[c]	****	****	****	****	****	5911	5063	5893	4442	2484	1825	6662
Mean/P treatment		6784	4758	5806	4664	4710	5743	3592	5141	4845	2807	3316	5621
Mean/control		6008	3202	4998	3042	3387	2032	730	1663	606	92	559	82
P treatment over partial control (%)		9	72	38	36	125	154	294	209	792	4154	430	6361

[a] Zero means no yields; asterisks indicate no data obtained.
[b] Optimum treatment with micronutrients.
[c] Optimum treatment with no micronutrients.

Table 5. Hydric Dystrandepts variety experiments on maize, yield data (kg/ha), January 1978-June 1979

Treatment									
Coded P	Coded N	Variety							
Hawaii/IOLE-G	W 78	H610	H788	X304A	X304B	X304C	X4816	X4817	X5800
-0.85	-0.85	4718	4038	5104	4145	5035	4420	4858	4297
-0.85	0	4852	4950	5469	5682	6400	6250	5968	6382
0	-0.85	5022	3885	4288	4690	5724	5734	5535	4335
0	0	4886	4463	4702	5014	6907	6658	5649	5308
Mean		4870	4334	4891	4883	6017	5766	5503	5081
Hawaii/IOLE-H	D 78	H610	X306B	H788	X304B	X304C	X4816	X4817	H688
-0.85	-0.85	7537	7496	7119	6602	8138	7979	7957	8084
-0.85	0	8846	8330	8806	7729	8782	8772	9234	8916
0	-0.85	7127	6617	6798	6950	8200	7814	6970	8327
0	0	8542	8619	7610	8196	8688	9113	8918	8843
Mean		8013	7765	7583	7369	8452	8420	8270	8542
Indonesia/ITKA-L	W 78	H610	Bastar Kuning	UPCA	Harapan	H6	Bima		
-0.85	-0.85	2055	2384	1994	2514	3653	2270		
-0.85	+0.40	1941	3203	1785	2672	3491	1878		
+0.40	-0.85	2561	2099	2795	3106	2307	2263		
+0.40	+0.40	2596	4053	2392	3295	4283	3172		
Mean		2288	2935	2242	2897	3434	2396		
Indonesia/ITKA-O	W 78	H610	Bastar Kuning	Harapan	H6	Bima	DMR Phil		
-0.85	-0.85	2300	2570	2760	2497	2637	2473		
-0.85	0	2533	2353	2423	2297	2647	2270		
0	-0.85	2760	2840	1853	3087	3220	2897		
0	0	2080	2460	2617	2890	3493	2597		
Mean		2418	2556	2413	2693	2999	2559		
Indonesia/ITKA-N	W 79	Bastar Kuning	Harapan	H6	DMR-5	Wonosobo			
-0.85	-0.85	5203	5505	5541	5708	5665			
-0.85	+0.85	5252	4815	5470	5755	5512			
+0.85	-0.85	6141	6183	5968	5832	6724			
+0.85	+0.85	5796	5689	5520	6606	6660			
Mean		5598	5548	5625	5975	6140			
Philippines/PUC-M	W 78	H610	UPCA 1	H788	H6	Bima			
-0.85	-0.85	1656	1501	1845	1592	1607			
-0.85	0	2583	2349	2654	2475	2569			
0	-0.85	2756	3161	3248	2969	2673			
0	0	5052	4704	5031	4467	4435			
Mean		3012	2929	3194	2876	2821			

Table 6. Tropeptic Eutrustox variety experiments on maize, yield data (kg/ha), January 1978-June 1979

Treatment									
Coded P	Coded N	Variety							
Hawaii/MOL-C	D 78	H610	X306B	H788	X304B	X304C	H688	Phoenix 1110	Cargill 111
-0.85	-0.85	5474	5810	5833	5631	6386	5420	5351	5698
-0.85	0	7028	6709	7352	6318	6955	6106	5421	6390
0	-0.85	6625	6493	6203	6927	7658	6214	6037	6417
0	0	7253	7128	7098	7070	7395	7137	6658	6733
Mean		6595	6535	6622	6486	7099	6219	5867	6310
Puerto Rico/PR-18	W 77	H610	H638	Phoenix 1110	X306B	X304B	X304C	H507	UPCA-1
-0.85	0	1067	2601	2100	3358	3764	4284	2733	3111
0	0	857	3338	2795	3418	3530	3639	2223	3251
Mean		962	2970	2447	3388	3647	3962	2478	3181
Puerto Rico/PR-18	W 77	Ag 504	Ag 259	Maya X	S1973	Cargill 111	QK 487	QK 231	QK 217
-0.85	0	2120	1042	2966	3675	2128	1183	3660	2935
0	0	2216	1416	1742	2792	2182	1251	2869	2483
Mean		2168	1229	2354	3234	2155	1217	3264	2709
Puerto Rico/PR-22	D 78	X304C	X306B	H610	X304B	X304A	Cargill 111	Diente de Caballo	
-0.85	0	8457	7072	4467	7571	9174	7253	7031	
0	0	9538	8520	5604	8797	8462	7786	7132	
Mean		8998	7796	5036	8184	8818	7520	7081	
Puerto Rico/PR-28	W 78	X304A	X306B	X304C	X4816	X4817	X5800	Cargill 111	Diente de Caballo
-0.85	0	5089	5808	6221	4996	4827	6759	4112	4903
-0.85	+0.85	6247	5973	5874	4315	5233	7063	3576	5038
+0.85	0	4047	5015	5600	4671	5332	5354	3617	3538
+0.85	+0.85	5816	5820	5726	5526	5443	7060	3422	4230
Mean		5300	5654	5855	4877	5209	6559	3682	4434
Brazil/B-14	D 78	Cargill 111	Phoenix 1110	H610	X306B	Maya X			
Control		2271	2041	2547	2110	1021			
		5411	4461	4944	4422	4005			
		5014	4236	3944	4532	4094			
		5121	4554	4666	4467	4267			
Mean		4454	3823	4025	3883	3347			
Brazil/B-18	W 78	X306B	X304A	X304B	X304C	Phoenix 1110	Cargill 111	H610	
Mean		7524	4903	4045	7738	7193	4908	5351	

Table 7. Typic Paleudults variety experiments on maize, yield data (kg/ha), January 1978-June 1979

Treatment						
Coded P	Coded N	Variety				
Indonesia/NAK-B D 79		H6	H159	Metro	Kodok	
-0.85	-0.85	2983	3598	5457	4749	
-0.85	+0.40	3230	3858	4855	6178	
+0.40	-0.85	4984	4229	5033	6157	
+0.40	+0.40	6800	7347	6385	6686	
Mean		4499	4758	5432	5943	
Philippines/BPI-B W 79		DMR-1	UPCA 1	DMR-2	Tiniguib	H6
-0.85	-0.85	4031	4237	5234	3997	4820
-0.85	0	4797	5074	5667	3906	5689
0	-0.85	4237	4357	4671	3711	4661
0	0	4646	5025	5599	3660	5343
Mean		4428	4673	5293	3819	5128

Appendix 2.
Weather Data

Weather Data Gathered at All Sites, Benchmark Soils Project

Site/season	Variety	Planting date	Harvest date	Solar radiation (g cal/day)	Cumulative rainfall (mm)	Temperature (°C) Max.	Temperature (°C) Min.	Relative humidity (%) Max.	Relative humidity (%) Min.	Wind run (km/hr)	Yield (kg/ha) Partial control	Yield (kg/ha) Mean	Yield (kg/ha) High
Thermic, Isothermic Ustic Dystrandepts													
Hawaii													
HUK-A Dry	HA110	6/29/78	11/29/78	320	441	27.3	20.1	92	69	10.01	4049	6318	7852
HUK-C Wet	HA110	2/06/78	6/01/78	404	585	26.5	18.8	92	65	9.66	4578	7718	9623
HUK-D Wet	HA110	5/06/78	7/03/78	405	586	25.8	17.5	92	63	9.33	3963	7188	8606
HULE-E Dry	HA110	6/05/78	11/21/78	437	392	24.8	18.7	97	67	16.38	4835	6630	7768
HULE-F Wet	HA110	1/18/78	7/18/78	454	394	23.8	16.8	95	62	15.42	2428	3805	5555
HWL-A Dry	HA110	6/30/78	12/06/78	415	623	24.6	17.4	99	77	10.72	3636	8046	8629
HWL-B Dry	HA110	7/13/78	12/20/78	414	531	24.6	17.4	99	76	10.39	2993	6547	8191
Philippines													
PUC-A Wet	UPCA 1	4/25/78	8/22/78	347	745	33.6	24.2	95	72	7.35	499	3832	6858
PUC-A Dry	UPCA 1	12/22/78	3/02/79	382	498	31.1	19.6	92	47	8.03		2629	5086
PUC-B Dry	UPCA 1	2/22/78	6/23/78	410	437	35.2	23.2	97	56	6.53		4820	5875
PUC-D Dry	UPCA 1	1/05/79	3/06/79	394	397	31.6	19.5	91	44	7.89		2890	5255
PUC-E Dry	UPCA 1	1/11/79	3/07/79	394	397	31.7	19.6	90	43	7.90		5232	7473
PUL-A Wet	UPCA 1	4/14/78	8/06/78		819	32.3	21.9	83	56	5.13	264	4332	5933
PUL-C Dry	UPCA 1	12/29/77	4/28/78	408	229	31.9	29.9	83	46	4.89	1239	7880	9265
PUL-C Dry	UPCA 1	12/29/78	3/05/79	374	490	30.7	18.4	96	46	6.71		4436	6005
PUL-D Dry	UPCA 1	2/10/79	6/09/79	383	645	31.9	19.4	97	47	5.96		3324	4553
PUL-E Dry	UPCA 1	1/13/79	5/11/79	373	497	31.2	18.6	97	45	6.05		4980	6772
PUR-A Dry	UPCA 1	12/21/77	5/08/78	229	397	29.0	20.4	95	58	10.26	258	4762	7764
PUR-B Wet	UPCA 1	5/02/78	7/06/78	331	822	30.9	21.8	95	56	7.48	577	5418	6931
PUR-D Dry	UPCA 1	1/20/79	6/03/79	327	834	30.1	21.1	93	57	8.98		3449	4918
Indonesia													
IUKA-C Wet	Ratapan	1/22/78	6/21/78	359	539	25.9	16.4	98	60	5.21	2744	3338	4047
IUKA-C Dry	HA	7/18/78	1/02/79	361	397	26.0	15.6	96	54	5.16	4441	4662	5689
IUKA-C Dry	HA	2/25/79	7/19/79	299	497	26.1	16.1	93	55	5.04	4482	6207	6940
IUKA-D Dry	HA	7/05/78	12/14/78	362	349	26.1	15.5	97	53	5.00	3392	5066	5798
IUKA-D Wet	HA	1/26/79	6/20/79	308	557	26.0	16.3	95	57	5.10	5199	5960	6510
IUKA-E Wet	HA	12/21/78	5/21/79	317	531	25.7	16.2	95	57	5.42	4753	5914	6137
IUKA-E Wet	Ratapan	12/27/77	5/29/78	363	591	25.8	16.4	98	60	5.29	1692	2121	2880
IULP-D Wet	Ratapan	12/22/77	5/26/78	378	1107	28.7	17.4	99	59	3.33	3965	4954	5799
IULP-D Dry	HA	6/28/78	11/27/78	360	300	29.2	16.5	99	54	3.16	3835	5230	6112
IULP-F Wet	Ratapan	1/23/78	6/14/78	373	1190	28.6	17.2	99	59	3.29	1465	2017	2809
IULP-F Dry	HA	7/09/78	12/22/28	354	381	29.1	16.5	99	54	3.11	2624	3460	5422
IULP-G Dry	HA	7/07/78	12/08/78	365	332	29.2	16.5	99	54	3.11	1814	6099	8344
LPH-A Dry	HA	7/05/78	1/01/79	330	553	23.9	15.5	99	56	3.44	4414	6283	6847
LPH-A Wet	HA	1/25/79	6/14/79	293	744	27.8	17.4	99	73	3.40	4111	6342	7056
LPH-D Wet	Ratapan	12/26/77	5/22/78	314	578	23.5	14.9	98	69	4.37	3316	5492	6266
LPH-D Wet	HA	1/23/79	6/09/79	292	763	27.8	17.4	99	73	3.40	3801	6255	7052
LPH-E Wet	Ratapan	1/22/78	6/19/78	307	444	21.8	13.8	97	68	4.29	2632	3862	4586
LPH-E Dry	HA	7/13/78	12/19/78	340	447	24.0	15.6	99	54	3.45	2346	4084	5352
LPH-E Wet	HA	2/02/79	6/25/79	293	735	27.7	17.3	99	73	3.40	3595	4401	5286
LPH-G Dry	HA	7/10/78	12/06/78	340	425	23.6	15.2	99	53	3.44	3598	4544	5201

Clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox

Hawaii

MOL-A Dry	X304C	7/06/78	12/07/78	568	335	29.8	21.9	97	73	22.55	7092	9589	10462
MOL-B Wet	X304C	1/09/79	7/17/79	509	565	26.4	18.5	91	69	19.13	2528	6676	8773
WAI-A Dry	X304C	7/20/78	11/29/78	433	372	30.8	22.0	98	41	8.75	7696	9868	11035
WAI-B Wet	X304C	1/01/79	6/21/79	391	454	27.0	19.7	91	52	8.04		10013	11530

Puerto Rico

PR-20	X304C	11/15/77	3/27/78	373	443	27.9	18.3	79	54	4.97	5646	6309	7536
PR-21	X304C	12/12/77	4/20/78	362	474	27.9	18.3	79	54	5.34	7369	8164	9391
PR-23	X304B	1/12/78	5/22/78	314	673	28.1	18.7	79	53	5.35	1571	3519	5158
PR-27	X304C	4/25/78	8/08/78	485	673	29.6	20.7	76	62	5.01	3559	4783	6261
PR-30	X304C	5/08/78	8/30/78	478	736	29.5	20.8	74	61	4.99	6240	6759	8503
PR-31	X304C	5/20/78	8/28/78	482	717	29.8	21.0	75	61	5.05	1599	4497	6910
PR-33	X304C	6/06/78	9/26/78	463	710	30.0	21.2	75	59	4.61	3515	4418	5437

Brazil

B-19	Cargill hybrid III	11/10/77	3/30/78	355	448	28.0	18.39	79	54	4.90	1304	3766	5510
B-20	Cargill hybrid III	11/20/77	4/26/78	367	522	28.0	18.5	79	55	5.21	5810	5947	6760
B-22	Cargill hybrid III	11/21/77	5/05/78	373	460	28.1	18.6	79	55	5.24	1725	3866	5134
B-22	X304C	6/20/78	12/15/78	404	331	31.2	15.0	97	40	2.11	655	4992	7786
B-23	X304C	6/16/78	12/14/78	408	325	31.2	14.9	97	40	2.10	1533	3360	5361
B-24	X304C	6/20/78	11/29/78	406	233	32.3	14.5	--	--	--	7097	7700	8595
B-25	X304C	6/17/78	11/22/78	404	135	32.3	14.3	--	--	--	7656	7171	8809
B-26	X304C	6/19/78	12/05/78	421	216	33.3	14.5	--	--	3.07	1396	6783	8453
B-27	X304C	6/19/78	12/2/78	415	215	33.3	14.5	--	--	3.09	2819	5009	6725

Clayey, kaolinitic, isohyperthermic Typic Paleudults

Philippines

BPI-A Wet	Tinigaib	4/15/78	7/26/78	449	885	32.8	21.1	59	56	5.10	5231	6784	7507
BPI-D Dry	Tinigaib	8/17/78	11/23/78	417	631	31.1	24.7	99	57	4.48	3429	4664	5191
BPI-A Dry	IRCA I	8/20/78	12/04/78	414	719	31.5	23.1	98	57	4.72	3014	4490	5094
BPI-F Dry	Tinibaib	12/07/78	3/20/78	433	207	32.4	21.9	98	46	7.02	2096	4710	5699
BPI-C Wet	Tinigaib	2/12/79	5/25/79	478	739	36.2	24.5	99	45	6.08	4211	5806	6516

Indonesia

NAS-A Wet	Ho	10/03/78	1/30/79	414	472	34.2	24.4	91	37	4.58	2263	5743	7078
NAS-A Dry	Ho	2/21/79	6/02/79	401	628	36.1	23.4	97	32	3.25	912	3592	5122
NAS-D Dry	Ho	2/06/79	5/29/79	409	907	36.0	23.7	97	33	3.36	1662	5141	6556
BPMD-A Wet	Ho	10/05/78	2/01/79	426	337	35.0	24.2	99	40	2.28	543	4845	6889
BPMD-A Dry	Ho	2/27/79	6/19/79	419	707	33.8	20.5	99	33	1.78	66	2807	4573
BPMD-C Dry	Ho	2/13/79	5/20/79	436	812	33.2	20.0	99	33	1.77	625	3316	4639
BUK-A Dry	Ho	2/15/79	5/21/79	451	732	34.3	22.0	79	41	3.66	87	5621	7234

Appendix 3.
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Title page, p. 3: The experimental design of the Benchmark Soils Project is standardized throughout the six-country network of sites. Because water availability is often a constraint to good crop yields in the tropics, drip irrigation, such as that shown at a BSP site on Tropeptic Eutrustox in Jaiba, Brazil, is installed at all sites.

Part I Title page, p. 7: Random development and urbanization of prime agricultural land can permanently reduce the agricultural potential of an area for food production. Thoughtful land-use planning and a thorough knowledge of soil qualities will be necessary to protect the inherent agricultural potential of tropical soils.

Part II Title page, p. 17: Monitoring the long-term climatic environment and studying its effects on crop yields is an essential part of the Benchmark Soils Project approach to the transfer of agrotechnology. Weather data, such as those from BPI, Davao, the Philippines, are now included in the statistical model that is being used to test the hypothesis.

Part III Title page, p. 41: On the Hydric Dystrandepts in the Philippines, management experiments have been installed to demonstrate to local farmers that the economic benefits of band are longer lasting than broadcast application of limited amounts of fertilizer. Management experiments are designed to intercept horizontally available information from another area or region and to render it useful for local consumption.

Part IV Title page, p. 53: The Benchmark Soils Project concepts on agroproduction technology transfer, when utilized by agricultural planners, can have immeasurable impact on the agricultural economy of the country and its local farmers.

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- Office National du Recherche Scientifique et Technique (ONAREST), Cameroon
- Philippine Council for Agriculture and Resources Research (PCARR), Philippines
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