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# SOIL-BASED AGROTECHNOLOGY TRANSFER

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# Foreword

This is the age of communication. People everywhere are working to improve the quality and speed of information exchange. Science contributes to and benefits from these developments. Scientists in many fields can conduct cooperative, inter-related theoretical and empirical studies simultaneously in different parts of the world with great precision and effectiveness. Ease of communications allows them to share their experimental results quickly. The future is bright and exciting.

This is also the age of desertification. The deserts are advancing inexorably upon the settled land. In an extended sense, the term "desertification" is used by the international community to mean a slow and long-term decline in agricultural productivity and a concurrent loss of forests. The evidence for these changes is widespread and alarming. Their long-term effects upon the ability of the world to support its burgeoning population will be just as disastrous as the advance of the Sahara.

Better communication about soils will limit productivity decline and desertification. The Benchmark Soils Project of the Universities of Hawaii and Puerto Rico and the Soils Research Organizations of Brazil, Cameroon, Indonesia, and the Philippines has been an attempt to improve communications about soils, their environment, and their wise use and management in agriculture.

The germ of the idea of these projects lies in the common observation that masses of important and valuable information about soils and their management lie locked up in dusty reports and filing cabinets for want of an effective means of bringing them to the attention of those who could use them. The objective of the Benchmark Soils Project was to bring this information to the attention of those who could use it. The theoretical basis of the project is beguilingly simple. A "benchmark soil," as defined by soil surveyors and classifiers, is a soil that occupies a key interpretative position in the soil classification framework and/or covers a large area. It is considered to be a representative reference site from which research results can be transferred or extrapolated to other sites with similar properties. These other, similar sites can be identified by the use of "Soil Taxonomy," a general system of soil classification

developed by the U.S. Department of Agriculture with the help of many collaborators throughout the world. The fifth level of classification in Soil Taxonomy is called the soil family and is designed to group all soils within a subgroup—the fourth level of classification—having similar physical and chemical properties that affect their responses to use and management. From a well-researched benchmark soil site classified at the soil family level, results should be transferable for use—perhaps with some modifications—on other soils in the same family wherever they occur in the world. A data bank of soil families provides a data base for widespread transfer of soils, land use, and agricultural information throughout the world. Communities of soil scientists can communicate through families of soils.

The Benchmark Soils Project is now complete. This is the final report of the University of Hawaii Project. The primary result of the project has been improved communication among the participants, institutes, and scientists about the characteristics and performance of common soils. There have also been added benefits: a technology transfer model in agriculture was tested successfully; two follow-up projects, the Soil Management Support Services (SMSS) and the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) were begun; and soil scientists have benefited from the stimulation of working together on common and often simultaneous experiments at 24 different benchmark sites around the world.

Most of the efforts over the nine years of the project's existence have been devoted to testing the basic hypothesis that the soil family does indeed provide a basis for technology transfer. While the soil family is used frequently within the United States for this purpose, the concept had never before been scientifically tested. An advisor to the Benchmark Soils Project pointed out early on that this could best be done in the United States where precise control could be exercised over the required experimental work. Project researchers, rejecting this good advice, proceeded to test the concept under much more difficult conditions in the tropics where experimental sites on exactly the right soils had at times to be carved out of the bush. In so doing they greatly increased the difficulties of conducting the experiments. Nevertheless, this research effort greatly speeded up the possibilities of technology transfer, increased the value of the projects, and contributed significantly to strengthening soils research in participating countries in the tropics.

The Benchmark Soils Project has helped create research infrastructures in several countries, trained scientists and technicians to do quality agronomic experiments, devised new statistical tests of significance in agricultural research, and created a substantial body of information

on three soil families in different orders of the Soil Taxonomy. The project has conducted and contributed to several scientific meetings and published a newsletter, "Benchmark Soils News," so that information about the Benchmark Soils Project and its results could be widely disseminated. Several other countries also adopted project concepts. In particular, India, with its great need to increase the use intensity of its soils, published "Benchmark Soils of India," a major compilation of information about 64 selected soils, at the time of the 12th International Congress of Soil Science held in New Delhi in February 1982.

And what of the transfer hypothesis? In the end it was found that results of soil management experiments could be better predicted *within* each of the three soil families than *among* them. The soil family assists in the transfer of soil management information and the prediction of soil performance.

In addition, the project carried out other experiments on soil management using many crops and soil management methods. These results should be useful to all Benchmark Soils Project participants and to all with similarly classified soils. Furthermore, it is not difficult to extrapolate the results to other soil families, particularly those that differ only in texture or soil temperature or soil moisture regimes. Extrapolation to other families may require experiments designed for that purpose but it is possible and desirable because the soil family is limited in range and area. Fortunately, the results of experimental work within a single soil family can be extended to other soils in a systematic and rational way.

The Benchmark Soils Project has demonstrated how soil management research should change for the future and how soil science can participate in the communications revolution. All soils used for research can become benchmark soils if all soil management experiments collect a certain minimum set of essential data that will allow proper characterization of the soil, the crop used, and the environment. Future books and articles about the properties of soils of a country or region should not include statements like "the soils are generally low in phosphorus," or "the soils have a tendency to crust." Instead, they should give specific results about properly classified and characterized soils and their performance under well-specified conditions. Readers will then be able to make effective use of these data from their understanding of soil management and the benchmark soils concept. Adaptive research will certainly still be needed, to a greater or lesser extent depending on the similarities and differences of the soils being compared, but efficient communication of research results and principles can be achieved resulting in a reduction in wasted research time and resources.

The Benchmark Soils Project has done much for soil science. It has

contributed to reducing the dangers of desertification. But its benefits will be realized most fully in the future when soil science responds more completely to the communications revolution of today.

L. D. Swindale
Director General
International Crops Research Institute for
the Semi-Arid Tropics (ICRISAT)

# Preface

The food and population problems of the Third World were brought into sharper focus and new prominence following the World Population Conference held in Bucharest in 1973 and the World Food Conference held in Rome in 1974. Efforts to confront the steadily worsening food situation, especially in the tropical world, must consider the fact that marked increases in crop production will be restricted in many areas by the high cost of chemical inputs and by environmental limitations. In order for food production to keep pace with population growth rates in the developing world, the productive capacity in the developing countries must be expanded by increases in both yield per unit area and in acreage of cultivated land.

Time has shown that the extrapolation of agricultural experience from developed countries in the temperate zone to developing countries in the tropics 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 developing countries must take place predominantly within the tropics.

The ideas and concepts that eventually evolved into the Benchmark Soils Project originated with Dr. L. D. Swindale in the early seventies when he was Director of the Agricultural Experiment Station of the University of Hawaii. These ideas were incorporated into two research proposals prepared by the University of Hawaii (UH) and the University of Puerto Rico (UPR) and submitted to the U.S. Agency for International Development (USAID).

In May 1974, a contract (AID/Contract No. ta-C-1108) was signed between USAID and the University of Hawaii to initiate a project entitled "Crop Production and Land Capabilities of a Network of Tropical Soil Families." The contract (AID/Contract No. ta-C-1158) for the companion project, "Crop Production and Land Potential of Benchmark Soils of Latin America," was signed with the University of Puerto Rico in January 1975. The projects are popularly known as the Benchmark Soils Project (BSP).

The purpose of the Benchmark Soils Project was to test an innovative

approach to agrotechnology transfer designed to assist developing countries in appropriately utilizing their land resources for increased and better quality food production. This approach to agrotechnology transfer bypasses three major constraints: scarcity of qualified research personnel, insufficient capital, and, above all, time needed to close the widening gap between agroproduction and food requirements. The traditional approach to agricultural research is extremely time-consuming. Yet farmers urgently need the basic information conducive to higher yields, and they cannot wait f . local research to regenerate information that is already available to them via transfer.

The concept—transfer of agrotechnology from one tropical region to another tropical region on the basis of Soil Taxonomy at the soil family level of classification—will have a far greater effect on food production and its tempo than may seem possible at first glance. Its effect may well be profound. First, millions of dollars worth of research information produced by thousands of man-years will be available for immediate tapping. Second, costs of site-specific trials all over the world, which reach millions of dollars, will be alleviated. Third, a worldwide network of experts and a soil and crop data bank will be available to expedite and provide information and facilitate communication for development. Fourth, the concept of agrotechnology transfer is all-encompassing: it allows the transfer of information on soil management practices and all that goes with it—information on crops and cropping systems, water management practices, erosion control measures, the suitability of soils to new crops, and the economics of crop production.

The focus of the Benchmark Soils Project was the acceleration and reduction of cost of agricultural planning and development in developing countries through the process of agrotechnology transfer. This relates to USAID's objective of expanding the information available on the management of tropical soils to increase food production in the tropics. The objectives of the project were

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, and
3. to demonstrate the value of soil and land classification in formulating agricultural development plans in selected areas.

The Benchmark Soils Project of the University of Hawaii was initially funded for three years—1974–77—during which time sites were sought in cooperating countries to build the soil family network. Sites were established on the thixotropic, isothermic family of Hydric Dystrandepts in Indonesia, Hawaii, and the Philippines. A three-year extension of the project (1977–80) was granted by USAID with the rec-

ommendation that a third soil family, a family of the Ultisols, be included in the scope of activities as requested by Indonesia and the Philippines. Sites on the clayey, kaolinitic, isohyperthermic family of Tropeptic Eutrustox were established in Hawaii. Sites for the third soil family, clayey, kaolinitic, isohyperthermic Typic Paleudult, were established in Cameroon, Indonesia, and the Philippines during this period. Field experiments with maize were carried out at all sites of the three soil family network to generate data for evaluating the concept of agrotechnology transfer. Because of the late establishment of the Typic Paleudult network and the need to continue data collection on this and the other soil families, the project was granted a second extension—from 1980–83—to allow for the completion of data collection. All overseas activities were completed in 1983. The project was granted a one-year, non-funded extension to allow for the completion of data analysis and preparation of the Final Report. A more detailed history of the Benchmark Soils Project may be found in Appendix A.

The objectives of the Benchmark Soils Project of the University of Puerto Rico were similar to those of the UH project; experimental sites were established in Brazil and Puerto Rico on the clayey, kaolinitic, isohyperthermic family of Tropeptic Eutrustox. The experimental and data recording techniques were also similar to those of the University of Hawaii project. The University of Puerto Rico Benchmark Soils Project was initially funded for three years—1975–78. After this, it was extended for a three-year period to January 1981. The project received a further one-year extension without additional funding to allow for the orderly conclusion of project activities by December 1981. The "Final Report of the Puerto Rico Benchmark Soils Project 1975–1981" was published in February 1982. The Executive Summary of this report is presented in Appendix B.

This final report of the University of Hawaii Benchmark Soils Project is divided into three parts. The first is the major report of project activities in fulfilling its objectives and includes four sections—Principles and Concepts, Research Methodology, Quantitative Evaluation of the Transfer Hypothesis, and Matching Maize Requirements to the Agroenvironment. The second—Additional Agrotechnology Transfer Studies—includes four sections—Phosphorus Management in Benchmark Soils, Crop Performance in Benchmark Environments, Utilization of the Benchmark Soils Network, and Matching Crops and Environments by Soil Taxonomy. The results of investigations undertaken to clarify observations and questions raised during project activities are presented in this part. These studies, conducted by graduate students supported by the project, provided information on the effects of the characteristics of the three soil families on crop performance, fertilizer availability, and

susceptibility to erosion. The third part—Executive Summary—highlights the accomplishments of the Benchmark Soils Project and summarizes major results of the other sections.

The information presented in this final report should be of value to soil and crop scientists, planners, government agencies, and extension personnel. It is hoped that the efforts of the Benchmark Soils Project have helped in some small way to accelerate food production and agricultural planning and development with reduced cost through the process of agrotechnology transfer.

J. A. Silva
Principal Investigator
Benchmark Soils Project

# Acknowledgments

The Benchmark Soils Project gratefully acknowledges the cooperative efforts of many individuals, especially in Cameroon, Indonesia, the Philippines, and Hawaii who have contributed to the success of the project. Without their support the project could not have achieved its objectives.

The conceptualization of the Benchmark Soils Project by L. D. Swindale is gratefully acknowledged. He initiated the project and his visionary leadership in the first three years set the tone for its successful completion. He then moved on to become Director General of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). He maintained his interest and support of the project through the years.

USAID is duly recognized for providing funds for the project for the life of the contract. The steadfast support and guidance of T. S. Gill, Program Manager, for USAID/Agriculture is gratefully acknowledged.

Implementation of the project overseas would not have been possible without the assistance and support of dedicated individuals in each country. These are listed below with their titles at the time of their association with the project. Many of them have moved on to different positions, but this will not be reflected in the titles presented.

Cameroon: Staff of the Institut de Recherches Agricoles et Forestières (IRAF), now Institut de la Recherche Agronomique (IRA), who assisted in developing an agreement and provided support for implementation of the project in Cameroon include N. Ngatchou, Director of IRAF; J. P. Eckebil, Director of IRA; J. Menyonga, Director, Ekona Station; S. N. Lyonga, Chief of Center, Ekona Research Center; and J. N. Awemo, Chief of Center, Barombi Kang. Valuable support and assistance were received from G. W. van Barneveld, Pedologist/manager; J. P. Greisbach, Manager; and B. Delvaux, Associate Expert, of the Food and Agriculture Organization/United Nations Development Project (FAO/UNDP) Soil Resources Project, Ekona. G. W. van Barneveld, Pedologist, FAO/UNDP and G. R. Moormann, Pedologist, International Institute of Tropical Agriculture (IITA), Nigeria, were most helpful in site selection and establishment. The project received assistance from the USAID Regional Develop-

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The Philippines: Staff of the Philippine Council for Agriculture and Resources Research and Development (PCARRD) who provided valuable assistance in site establishment, project planning and implementation included J. Madamba, the late J. D. Drilon, Jr., and R. V. Valmayor, successive Heads of PCARRD during the Project; S. M. Miranda, Director, Soil and Water Research Division; E. G. Panasiico, Director, Crops Research Division; A. R. Maglinao, Director, Farming Systems Research Division; and C. R. Escano, Assistant Director, Crops Research Division. G. N. Alcasid, Jr., Director, Bureau of Soils (BOS), and his staff provided assistance to the project in soil survey and site selection. The late J. D. Drilon, Jr., Director, South East Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA), assisted the Project in implementation of training courses in the Philippines. A. A. Briones, Department of Soil Science, University of the Philippines at Los Baños (UPLB) and C. Alcalde, BOS, co-project leaders at various periods, were most helpful in facilitating project operations. Assistance was also provided to the project by staff of the USAID/Manila Mission including F. W. Shephard and L. E. Holdcroft, Assistant Directors for Agricultural Development; W. S. McCluskey, Agricultural Research Advisor; R. J. Edwards, Food and Agricultural Officer; and E. J. Rice, Agricultural Research Advisor.

Hawaii: The support of the Department of Agronomy and Soil Science, the College of Tropical Agriculture and Human Resources (CTAHR), the University of Hawaii and the Research Cooperation of the University of Hawaii are acknowledged. The efforts of J. R. Thompson, Superintendent, Beaumont Research Center, in providing

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PART I

# ASSESSMENT OF AGROTECHNOLOGY TRANSFER

Principles and Concepts

Research Methodology

Quantitative Evaluation of the Transfer Hypothesis

Matching Maize Requirements to the Agroenvironment

## *Principles and Concepts*

# 1 Transfer of Agrotechnology

*J. A. Silva* and *G. Uehara*

Rapidly increasing populations and limited time and resources for research have created an urgent need in tropical countries for agrotechnology transfer. While few countries have the time to either conduct original scientific research or to experiment with trial-and-error agricultural transfers, scientists at national and international research centers have already developed sound agrotechnologies that are applicable to the tropics. Mechanisms for transferring these technologies to appropriate areas can accelerate the increase in food production in tropical countries and decrease the possibility of widespread famine.

## Transfer by Diffusion

A common method of agrotechnology transfer is by "diffusion" of information from one country to another or from one area of a country to other areas where the technology may be needed. This "diffusion model" was adopted as the foundation for technical assistance after World War II and led to an "extension bias" in aid programs in the 1950s (Hayami and Ruttan, 1971). Much of the technology available at that time originated, however, in temperate areas of developed countries and was therefore not generally applicable to the tropics. According to Moseman (1970), the scarcity of modern indigenous technology and the general unsuitability of U.S. temperate zone materials and practices to tropical agricultural conditions contributed to the limited success of the "extension bias" approach of this period. Still, international diffusion of agricultural technology has taken place for many years—in, for example, the transfer of new crops such as potatoes, maize, and tobacco to Europe after the discovery of the Americas—and has had a profound effect on European agriculture (Hayami and Ruttan, 1971). This diffusion resulted from travel and information exchanges undertaken for other purposes. The transfer of new varieties of crops and improved strains of animals also occurred by this diffusion process.

According to Hayami and Ruttan (1971), the three stages of international technology transfer by diffusion are (1) the material transfer stage, which is the simple transfer of new materials such as seeds,

plants, animals, machines, and techniques associated with these materials, (2) the design transfer stage, in which technology is transferred mainly as blueprints, formulas, or materials for the purpose of copying its design rather than using the technology itself, and (3) the capacity transfer stage in which scientific knowledge is transferred to allow the local production of a technology that exists elsewhere. An important element in capacity transfer is the migration of agricultural scientists. A country wishing to improve its productivity has three options by which to accomplish capacity transfer (Evenson and Binswanger, 1978): (1) through direct transfer, in which technologies from other countries are screened and the best adapted one(s) used without modification in another setting, (2) through adaptive research to modify or redesign technologies borrowed from other countries and adapt them to local conditions, or (3) through comprehensive research programs undertaken to use the knowledge gained from other countries to produce a local technology. Whichever method a country uses, its ultimate objective is to increase its productivity in the shortest time and with the least expense.

## Requirements for Successful Agrotechnology Transfer

The three requirements for the successful transfer of agrotechnology are (1) a basis for transfer, (2) a common language for communicating information for transfer, and (3) a source of innovations for transfer.

*A basis for transfer.* In the past, agrotechnology was often transferred on the basis of personal experience, e.g., a technology that was successful in a person's home country was applied to a country in which he was visiting. If the environments (climate, soil, etc.) in the donor and recipient countries were similar, then there was some hope that the new technology would succeed. Often, however, the environments were different and the transferred technology resulted in disaster in the new environment.

It is now generally understood, however, that agrotechnology can be transferred more easily *within* than *across* agroclimatic regions. To facilitate such transfer, countries have been classified into agroclimatic zones based on their climate and soil. This approach has been used extensively by the Food and Agriculture Organization (FAO) of the United Nations for planning future agricultural development. Information on climate and length of growing period was used along with that from a soil inventory based on the 1:5,000,000 FAO/UNESCO Soil Map of the World to match the climatic and soil requirements of crops and identify those areas best suited for the production of particular crops (FAO, 1978).

About 1950, the U.S. Department of Agriculture embarked upon a plan to develop a soil classification system for making and interpreting

soil surveys that would accommodate all soils of the world. After many revisions and many years of testing in the United States and elsewhere around the world, the Soil Conservation Service of the U.S. Department of Agriculture issued in 1975 a handbook titled *Soil Taxonomy: A system of soil classification for making and interpreting soil surveys* (Soil Survey Staff, 1975). This handbook made available for the first time a comprehensive system of soil classification that could accommodate all soils and that provided a basis for the transfer of agrotechnology between similar environments.

*Common language.* Soil Taxonomy also provided a common language for communicating soil and climatic information to scientists in widely separated countries. Many countries have developed their own soil classification systems as the basis for calibration of other measurements. However, scientists from countries with different soil classification systems cannot communicate effectively about soils and therefore are not able to determine a common basis for the transfer of technology. The use of Soil Taxonomy as an international language makes it possible for scientists to communicate about agricultural technologies and implement appropriate transfers.

*A source of innovations for transfer.* Many experiments have been conducted at national and international research centers throughout the world. Not all of these provide information that is suitable for transfer because the soil, climatic, and experimental conditions have not been carefully determined and monitored. Thus, because the results are site-specific, it is not possible to identify similar conditions (environments) in other areas to which results may be transferred. However, experiments that have been carefully conducted on well-characterized and monitored sites provide technologies that are transferable to other areas with similar environments. The development of a network of research centers covering a range of properly characterized soil and climatic conditions will generate innovations that are widely applicable. The Benchmark Soils Project developed a network of three soil families in the tropics in which it conducted its experiments. Soil at these sites was characterized and classified to the family level according to Soil Taxonomy and weather was continuously monitored. This allowed results of research conducted at these sites to be transferred to other areas with similar agroenvironments.

## Conditions for the Transfer of Agrotechnology

A basis for transfer and the availability of innovations makes it possible to transfer technology, but the conditions required for transfer must be met to increase the likelihood of successful adoption of the technology. One of the conditions for transfer is that the innovation must be *technically possible*—that is, the required resources must be available to imple-

ment the technology. For example, if the technology transferred is the application of phosphorus fertilizer to maize, a supply of phosphorus must be available.

In addition, the available phosphorus must be of reasonable cost and/or the increased yield resulting from the use of phosphorus must be sufficiently valuable to make the innovation *economically feasible* in the new area. This also implies that the required market for the additional product is present and the required infrastructure to transport the product to market is or will be available.

The successful adoption of a new technology also requires that it be *socially acceptable* to the population of the region. If, for example, a new technology to increase a country's food supply, particularly after severe storms that destroy local conventional crops, is the introduction of high-yielding varieties of sweet potato and it so happens that the local population considers this crop to be suited only as food for animals, it is not likely that this technology will be widely adopted.

The new technology must also be *environmentally sound*—that is, it must be compatible with the environment and not a contributing factor to conditions such as increasing soil erosion that will result in its destruction.

The coordination of resources required for an innovation and the development of an infrastructure for the marketing, transportation, and regulation of the product involve development of an administrative framework as well. This requires that the process be *administratively manageable* so that the consequences of the transferred innovation are positive. The new technology should also meet the perceived needs of the country or area as formulated by the national or local government and therefore be *politically acceptable*. The priorities of the government have a profound effect on the successful adoption of a new technology in that the necessary credit, regulations, and quotas will be more readily developed if the technology addresses a national or local priority.

If any of the first three conditions is not met, it is highly unlikely that the transferred technology will be adopted in the area. If any of the last three conditions is not met, the technology may be adopted to some extent initially, but it is unlikely that it will be adopted permanently.

## Agrotechnology Transfer Based on Soil Family Name

The criteria set forth in Soil Taxonomy enable specific, named kinds of environments to be identified. This book contains research results conducted on three kinds of benchmark agroenvironments characterized by soil family names. Soil family names play an important role in technology transfer because they stratify 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 charac-

teristics that affect response to management. Thus, the soil family name constitutes a condensed scientific statement that integrates the knowledge about a soil with its environment.

A great deal of information is stored in the soil family name. It not only provides information on environmental constraints such as rainfall, temperature, and solar radiation that are outside the province of human control, but it also makes it possible to anticipate constraints that can be altered or removed by man. The soil family name carries information about the kinds of insects, weeds, and diseases to be anticipated in an area; the soil's suitability for use as foundations for small dwellings, septic tank absorption fields, local roads and streets, and playgrounds; and the soil's susceptibility to compaction by traffic, erosion by wind or water, and acidification by acid rains.

The soil family classification also provides information related to crop adaptability, the need for irrigation, and appropriate management practices. Direct measurements of soil properties are required to assess the effects of past management or site variations and to determine specific management inputs required for a given crop. Soils belonging to the same family, therefore, should have essentially the same management requirements and responses and should have similar potentials for crop production. Consequently, the inherent qualities of a soil family should make the transfer of agrotechnology possible. Transfer of agrotechnology based on the soil family, allows the transfer of appropriate management practices developed for a particular soil family to other members of that family elsewhere thereby saving the expenditure of additional time, money, and manpower to develop these practices at the other locations (Figure 1).

## Alternative Methods for Agrotechnology Transfer

The unique agroecological niches identified by a soil family name throughout the world are considered analogues and crops or management practices adapted to this niche may be transferred among these analogues with a high likelihood of success. Various approaches have been developed to transfer agrotechnology among analogues or to match crop/management requirements with the appropriate agroecological conditions.

Matching transfer is a method used to identify the environmental niche in which a particular crop (or other management practice) is likely to succeed. This technique involves identification of crop requirements for growth and the soil and climatic characteristics that are important for that particular crop. These crop requirements are compared with the soil and climatic characteristics of the proposed site and a site which provides most or all of the crop's requirements—where there is a good match—is considered well suited for production of that crop. Where

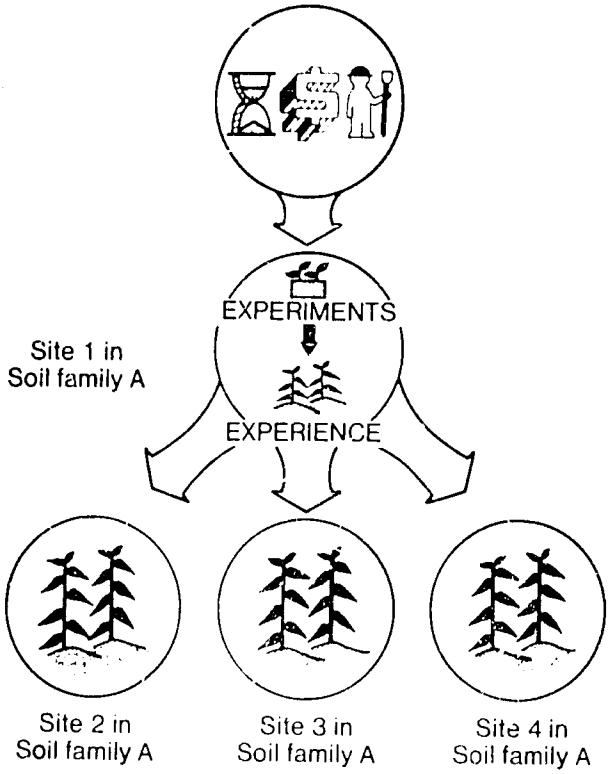


**Fig. 1.** Project research results and transfer hypothesis verification will minimize time, money, and manpower spent as planners use soil and crop data gathered elsewhere.

there is a mismatch, the crop will not grow well unless the deficiency is corrected by management.

Mathematical models of various kinds are used to describe the relationship between soil, climate and management variables, and crop yield. Such models may be used to transfer agrotechnology. These mathematical models vary greatly in complexity, i.e. in the variables and subrelationships included, and can range from the simple linear equation with one variable to the complex equation with many variables and subrelationships. One approach is to develop a mathematical model for a particular soil family to transfer agrotechnology (an innovation) to other sites of that family. In so doing, the agroclimatic variables of importance to crop growth are held relatively constant (these sites are analogues) and the transfer is likely to succeed. This is the approach used by the Benchmark Soils Project.

Another approach is to include important agroclimatic variables and

relationships in the mathematical model which increases its complexity but also increases its flexibility. These models allow the simulation (prediction) of crop yields over a wide range of conditions since selected values may be assigned to the variables and the agroclimatic conditions of the proposed site described. Chemical transformations in soil and physiological processes in the plant can also be included in these models which allows simulation of plant growth throughout the growing period. Transfer with these models is not limited to analogue transfer since soil and climatic conditions unique to the site may be specified in the model and the simulation performed specifically for that site.

Transfer of agrotechnology may be accomplished by any of the described methods, but the degree of success varies with the accuracy of identifying the important soil and climatic conditions and with the correctness of the mathematical model.

## Sphere of Transferability

Many management and agronomic relationships may be transferred on the basis of the soil family name. While the transferability of the phosphorus response of maize grown on soils of a soil family has been rigorously tested by the Benchmark Soils Project, that in itself represents only one of a host of other potentially transferable relationships. For example, even before the first field experiment was installed in 1974, the Benchmark Soils Project staff was warned by consultants that the devastating fungal disease, downy mildew (*Peronosclerospora* spp.), would render maize unsuitable as a test crop in certain countries. However, it turned out that the first soil family network occurred in environments that do not permit the downy mildew organism to flourish. It was learned that downy mildew is not a problem in regions with isothermic (15–22 °C) or cooler soil temperature regimes. This information applies not only to the thixotropic, isothermic family of Hydric Dystrandepts but also to all soil families with isothermic or cooler soil temperature regimes. Thus, certain environmental relationships established on one soil family often apply to all soil families having the same causal factor —e.g. the sphere of transferability can under certain conditions be extended to soils outside a given soil family.

Since soil families are stratified not only on the basis of composition and organization of the soil material but according to soil climate as well, it is frequently possible to generalize about soil use on the basis of a single soil factor. One example that is frequently cited is the historical expansion of wine production outside of Europe. Notable grape-growing areas are California, Chile, South Africa, and South Australia. All of these regions have one soil factor in common—they all occur in regions with xeric soil moisture regimes. There is a high degree of corre-

spondence between xeric soils and Mediterranean climates, e.g., soils in Mediterranean climates are xeric. Not all soils in Mediterranean climates, however, are suitable for growing grapes. Some are too shallow, others too steep or salty, and still others too poorly drained or droughty. The soil family must stratify soils within large agroecological zones into classes that behave and perform alike.

It is interesting in this regard that there are two international agricultural research centers operating in the dry regions of the tropics and subtropics. These are the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) in India and the International Center for Agricultural Research in Dry Areas in Syria (ICARDA). These centers operate, however, in two distinct dry environments. In Soil Taxonomy, ICRISAT's dry agroenvironment is named ustic, whereas the agroenvironment of ICARDA is xeric. The ustic soil moisture regime corresponds to those regions where rains fall in the summer, whereas the xeric or Mediterranean climate corresponds to areas with winter rains. Thus, although many soil families occur in the mandated areas of each of these two centers, they all possess a unifying characteristic, the soil moisture regime, which allows transfer of certain management practices over all soil families within the same soil moisture regime. It is this capacity of Soil Taxonomy to stratify soils according to agroclimatic zones as well as to stratify soils according to soil composition and organization that enables the soil name to be used not only to predict soil behavior but to evaluate land for crop suitability and performance.

## References

Evenson, R. E., and H. P. Binswanger. 1978. Technology transfer and research resource allocation. *In* Induced innovation. H. P. Binswanger and V. W. Ruttan, eds. The Johns Hopkins University Press. Baltimore, Maryland.

FAO. 1978. Report on the Agro-ecological Zones Project: Vol. I. Methodology and results for Africa. Food and Agriculture Organization of the United Nations, Rome.

Hayami, Y., and V. W. Ruttan. 1971. Agricultural development: An international perspective. The Johns Hopkins University Press. Baltimore, Maryland.

Moseman, A. H. 1979. Building agricultural research systems in the developing nations. Agricultural Development Council, Inc., Washington, D.C.

Soil Survey Staff. 1975. Soil Taxonomy. A basic system of soil classification for making and interpreting soil surveys. Soil Conservation Service. U.S. Dept. Agr. Handbook 436. U.S. Govt. Printing Office, Washington, D.C.

## *Principles and Concepts*

# 2 Soil Taxonomy and Agrotechnology Transfer

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Seed for a new high performance food crop cultivar is a common product of modern agricultural research. The plant that emerges from the seed, however, is sensitive to the environment in which it is planted. When the seed of the cultivar is transferred to distant locations, the cultivar does well in certain places and poorly in others. In order for the new cultivar to perform well in a new location, the person responsible for making the transfer must make sure that the environmental characteristics of the transfer site match the environmental requirements of the new cultivar. Most transfers are made, however, without complete knowledge of the environmental requirements of the transfer object and the environmental characteristics of the site. The success of such transfers therefore often depends on chance. Since faulty technology transfers are as costly to the recipient as successful transfers are profitable, one aim of agricultural research is to maximize successful transfers and to minimize failures.

## Soil Taxonomy

Two things are needed to properly evaluate a country's soil resources for agrotechnology transfer: a soil classification system that serves as a guide for making and interpreting soil surveys, and a soil survey of the area itself. To be effective, the classification system must be based on the best available knowledge and should be designed to accommodate all soils occurring in the world. Classification systems for a specific country or region often do not meet this important requirement. International transfer of agrotechnology requires the use of a comprehensive classification system that has sufficient depth to enable the user to predict soil responses to management and manipulation.

The Benchmark Soils Project uses the principles and concepts of Soil Taxonomy to increase the success rate of technology transfer. Soil Taxonomy (Soil Survey Staff, 1975) provides a comprehensive classification system that groups soils with similar physical and chemical properties that affect their behavior and use.

Six categories are recognized in Soil Taxonomy. They are order, suborder, great group, subgroup, family, and series (Figure 1). As in any

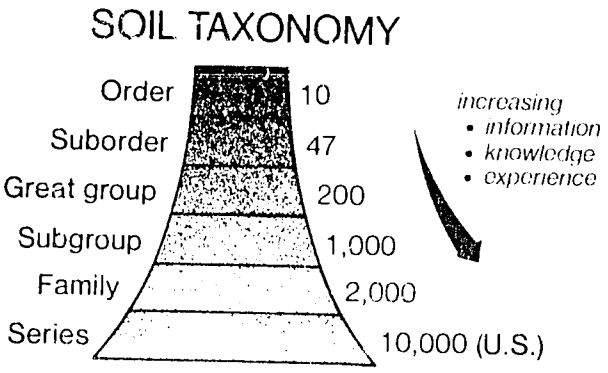


**Fig. 1.** The number of statements that can be made about a soil increases as one moves down the taxonomic ladder.

hierarchical system of soil classification, the specificity of information provided about the object being classified increases from the highest to the lowest category. Thus, the soil series would theoretically be the best category to use as analogues. That is, since elements of soil climate, such as soil temperature and soil moisture regimes, are incorporated into Soil Taxonomy, one would expect soils of the same series not only to look and behave alike but also to have analogous crop production potential, limitations, and management requirements.

As it turns out, however, Soil Taxonomy does not provide rules to define the soil series. The lowest category for which differentiating criteria are specified is the soil family. It is thus possible for a pedologist to place any soil in the world in one of the soil families of Soil Taxonomy.

Just as there are no two identical human beings, though, soils within a family are not identical but similar. They differ in characteristics that separate soil into series, but more important, they can differ in slope, stoniness, degree of erosion, and other features known as soil phases. The benchmark analogue for agrotechnology transfer is, therefore, a phase of a soil family.

The soil family was selected because it stratifies the soils of the world into relatively narrow groups, integrating the environmental (climatic) information in the form of soil moisture and soil temperature regimes that are important for crop growth with the physical and chemical characteristics that affect soil response to management. Thus, soils belonging to the same family should have essentially the same management requirements and responses and similar potentials for crop production. Consequently, the inherent qualities of a soil family are expected to make the transfer of agrotechnology possible.

The aim of the Benchmark Soils Project was to test the hypothesis that agrotechnology can be transferred among locations that are agro-

ecologically similar. This hypothesis is based on the premise that the soil family as defined in Soil Taxonomy stratifies the agroenvironment into narrow agroproduction niches sufficient to enable transfer of agrotechnology among soils that are members of the same family. The soil family stratifies such agronomic factors as plant nutrient deficiency, soil acidity, nutrient immobilization, and such soil climatic factors as soil temperature and soil moisture regimes, soil suitability for various crops, soil suitability for engineering uses, and the likelihood of the occurrence of specific insects, weeds, and plant pathogens.

Although Soil Taxonomy is a scientific system of classification, as opposed to a technical classification system designed to group soils for specific uses, it includes important technical descriptions to distinguish families of soils within a subgroup. For example, in mineral soils, the most frequently used family distinctions are particle-size, mineralogy, and soil temperature classes. In organic soils, reaction and soil temperature classes are most commonly used. The number of combinations of particle-size, mineralogy, and soil temperature classes is not large, but when the combinations are further subdivided according to subgroups, the number of soil families increases.

Soils with identical particle size, mineralogy, and soil temperature designations can and generally do have very different management requirements if they belong to different taxa in higher categories. Thus, the technical information used to differentiate families within subgroups is useful only if it is used in conjunction with the higher categories. The higher categories are separated on the basis of properties that characterize soil behavior. These characteristics used in combination with the added technical description of the soil family enable the user to make estimates of soil responses to management and manipulation.

If a soil classification system is to serve as a basis for agrotechnology transfer, the system must stratify climate, as well as other crop production parameters, along a gradient. In Soil Taxonomy, cloud cover and rainfall are related to the soil moisture regime that appears at the suborder category; soil temperature, which is related to air temperature, appears at the family category. The slope of a volcano is an example of climatic gradients encountered in the tropics. Warm temperatures, even temperatures at sea level, turn to freezing conditions at high elevations over a distance of several miles. Although cloud cover, rainfall, and temperature vary over short distances, temperature at any point on the landscape remains relatively constant and rainfall and cloudiness vary predictably for a given time of year.

Figure 2 illustrates the relationship between lettuce yield and soil solution phosphorus for several temperatures. Increasing levels of soil solution phosphorus were obtained by increasing the application of phosphorus fertilizer. The results show that more phosphorus is needed

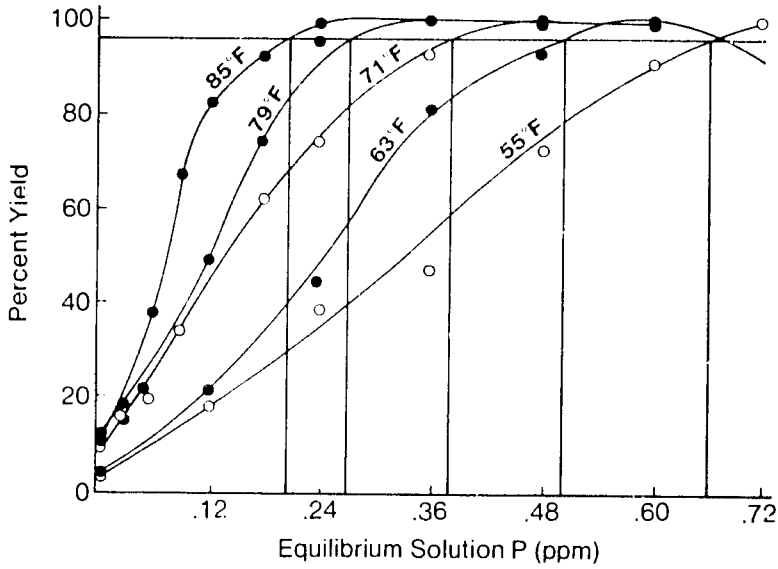


**Fig. 2.** Relative lettuce yield as a function of soil-solution phosphorus and temperature. (Courtesy of J. P. Jones, University of Idaho, Moscow, Idaho.)

to obtain 95 percent of maximum yields as temperature decreases. The soil temperatures are stratified into warm (hyperthermic), moderately cool (thermic), cool (mesic), and cold (frigid) for temperate climates; and isohyperthermic, isothermic, isomesic, and isofrigid for the tropics. This stratification enables the crop-production technology dependent on temperature to be transferred to widely separated parts of the world that have soils belonging to a common soil family. Thus, it is more reasonable to transfer the crop-production technology from the slopes of Mt. Kilimanjaro to the slopes of Mauna Kea (halfway around the world but in the same soil family) than to assume similar crop-production requirements on widely different soil families in either region.

## Using Soil Surveys and Soil Classification Systems

Conducting soil surveys based on a comprehensive classification system is a necessary first step, but it does not guarantee their proper use. Taxonomists design surveys and classification systems, but the agronomists, engineers, and planners use the systems and many of these users cannot interpret soil surveys. Thus, a major second role of taxonomists is to explain to users and potential users how to use soil surveys. The users in turn must seek the help of the taxonomists to ensure that soil surveys are used in the best possible way to achieve desired goals. The

use of soil surveys, in short, should be a joint effort between taxonomists and users.

## Agrotechnology Transfer in the Tropics

Soil classification helps us forecast soil behavior and estimate soil potential for many uses. Soil Taxonomy is a system of soil classification that offers the developing countries a technical package based on the best current knowledge to plan and implement agricultural development. This system enables planners to import technology that is tailored to their country's needs.

Many experimental stations in the tropics are involved in research to increase efficiency in food production. The research output from a single station may not be large, but the combined output from all stations is considerable. It is also very likely that a station's research results are relevant not only to neighboring areas but also to widely dispersed regions in the tropics. Research discoveries are most applicable in those places, however widely separated, where the physical environment is similar. The identification of similar environments is made possible through soil surveys and soil classification.

It is also quite likely that many on-going research projects have already been completed on a similar soil, for the same crop, at another station. A soil correlation among experimental stations in the tropics should serve to open channels of communication for information exchange. Soil correlations do not eliminate the need to repeat experiments, but they do enable one research effort to profit from the successes and failures of others.

There is a great need for exchange of agricultural innovations in the tropics. Although exchange and transfer of technology can occur longitudinally as well as latitudinally, exchanges are most successful in the east-west direction. Similar soil families do not occur over long distances in a north-south direction, technology transfer from the high-latitude countries of the north and south to the tropical belt will predictably fail in some aspects unless appropriate modifications are made in the technology package. These modifications must be tailored for a particular environment, with the soil family serving as the mark of this environment. The need to modify technology packages is greatly reduced, however, when the transfer occurs in an east-west direction within the tropics because the probability of locating similar or closely related families in an east-west direction within the tropical belt is high.

A survey and classification of experimental station soils in the tropics based on Soil Taxonomy could serve as the logical basis for information exchange. A document containing, in addition to the soils inventory, a brief description of each station's research emphasis and crop studies

would be desirable; such a document would streamline the total research effort in the tropics by helping stations and scientists locate others that have common interests and goals. While the transfer of technology from outside the tropics must continue, it is the exchange of technology packages within the tropics that offers the greatest promise for achieving ends that suit the lifestyle of people firmly fixed in the tropical environment.

## Reference

Soil Survey Staff. 1975. Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. Soil Conservation Service, U.S. Dept. Agr. Handbook 436. U.S. Govt. Printing Office, Washington, D.C.

## *Research Methodology*

# 3 Soil Family Network

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Three soil families, classified according to Soil Taxonomy (Soil Survey Staff, 1975), were selected to fulfill the general objectives of the Benchmark Soils Project. The soil family was selected as the basis for the transference of agrotechnology because it stratifies the soils of the world into relatively narrow groups, integrating the environmental (climatic) information that is important to plant growth with the physical and chemical characteristics that affect soil response to management. Thus, the soil family name constitutes a condensed scientific statement that integrates the knowledge about a soil with its environment.

## The Three Soil Families of the Project

Soil families selected for the project included (1) the thixotropic, isothermic family of Hydric Dystrandepts, (2) the clayey, kaolinitic, isohyperthermic family of Tropeptic Eutrustox, and (3) the clayey, kaolinitic, isohyperthermic family of Typic Paleudults. These are upland soils of the tropics with "moist and cool," "dry and warm," and "moist and warm" agroenvironments, respectively, and with potential to be productive under appropriate management practices.

The thixotropic, isothermic family of Hydric Dystrandepts was selected because this soil was easy to locate and Benchmark Soils Project personnel had long experience with its management. The second family —clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox—occurs in Puerto Rico and Hawaii and was selected to foster closer linkage between the Puerto Rico and Hawaii projects. The third family—clayey, kaolinitic, isohyperthermic Typic Paleudults—was included at the request of the host countries because it is an important, under-utilized soil of the tropics.

## Selection of Soil Family Sites

The selection of the Benchmark Soils Project sites was preceded by a search of existing soil survey data (soil survey reports including laboratory data and maps). Individuals were also contacted to obtain information before actual field work was implemented. In Hawaii, for example,

project staff reviewed published soil surveys (Foote et al., 1972; Sato et al., 1973) to determine the areas of interest, and then conducted field investigations of potential sites. Auger-sampling and laboratory characterization of the soil samples preceded profile description, pit-sampling, and further laboratory characterization. Soil-geomorphic relationships were also used to predict the occurrence of a particular soil in a landscape.

Soil-geomorphic relationships were used extensively in locating sites in the Philippines, Indonesia, and Cameroon where soil survey data were unavailable or, if available, of limited nature. For sites outside Hawaii, arrangements were made with appropriate government and research institutions to obtain the help of in-country soil scientists. Working with these soil scientists, project personnel evaluated several sites by examining the necessary experimental requisites, including availability of water, adequate space, and nearness to other experimental facilities. In nearly every situation, soil pits were dug and soils described and sampled for laboratory characterization and classification according to Soil Taxonomy (Soil Survey Staff, 1951, 1975). Figure 1 shows the network of the three soil families and Table 1 locates the 24 experimental sites. Additional details on each site are given in Appendix C.

## Characteristics of the Soil Families

Profile descriptions and laboratory data for the soils at each site (14 soil profiles representing 24 sites) were collected and compiled (Ikawa, 1979; Reinroth, 1979). The three soil families belong to three soil orders: Inceptisols, Oxisols, and Ultisols. The hierarchy of each order is outlined in Table 2 along with the soil characteristics or properties associated with the taxonomic nomenclature at the soil family level. Table 3 summarizes the general characteristics of the three soil families.

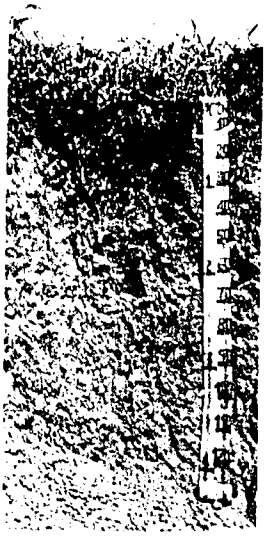
Soil Taxonomy recognizes that soils have many properties that have causal relationships to soil behavior. Those properties with the greatest number of covariant or accessory characteristics define and separate the various classes and categories. Classes of the system are defined in terms of soil properties, but there is a tendency to place more weight on soil properties of agricultural relevance, particularly at the lower levels. Because soil properties control soil behavior, the taxa of Soil Taxonomy should reflect behavioral patterns. Soil families are differentiated within a given subgroup primarily on the basis of soil characteristics, such as texture, mineralogy, and soil temperature, and they provide classes having relative homogeneity in properties important to plant growth and indicative of soil-water-root relationships. Soils classified in the same family should, therefore, have nearly the same management

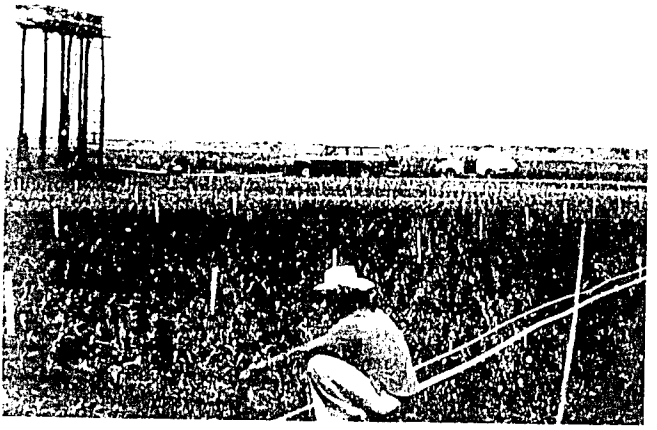
The Philippine Union College (PUC) experimental site with Mt. Isarog in the background near Panicuason, Camarines Sur, Luzon, the Philippines. Profile of a Hydric Dystrandept with a dark surface horizon.

Landscape shows transfer experiment being conducted at the Institute Theologia Keguruan Advent (ITKA) site near Bandung, Java, Indonesia. Volcanic cone, such as in the background, is a source of volcanic ash parent material. Profile of a Hydric Dystrandept, showing a dark subsurface horizon, at the experimental site.

Landscape of the Hydric Dystrandept, with one of the many cinder cones associated with the Kohala Mountains of Hawaii. Profile of a Hydric Dystrandept at the IOLE site in the Kohala region with a dark brown surface and a dark reddish brown subsurface horizon visible.

Pineapples, shown in landscape, occupy much of the nearly level landscape of Tropeptic Eutrustox in Hawaii. Profile shows Tropeptic Eutrustox at Waipio (WAI) site with dark reddish brown surface and dusky red and reddish brown subsurface horizons with moderate expression of subangular blocky structure.





The sloping landscape of the Typic Paleudult in Cameroon was previously in forest and tree crops, such as cocoa and coffee, before being cleared for the project experiment. Profile of this soil from the Barombi-Kang Experiment Station (CAM) near Kumba shows the yellowish brown argillic horizon.

An example of the kind of sloping landscape associated with Palehumults and Paleudults is found in South Sumatra, Indonesia. Profile shows a rhoxic Palehumult, previously classified as Typic Paleudult, at the Nakau (NAK) site. The photograph also shows a volcanic ash cover over the argillic horizon.

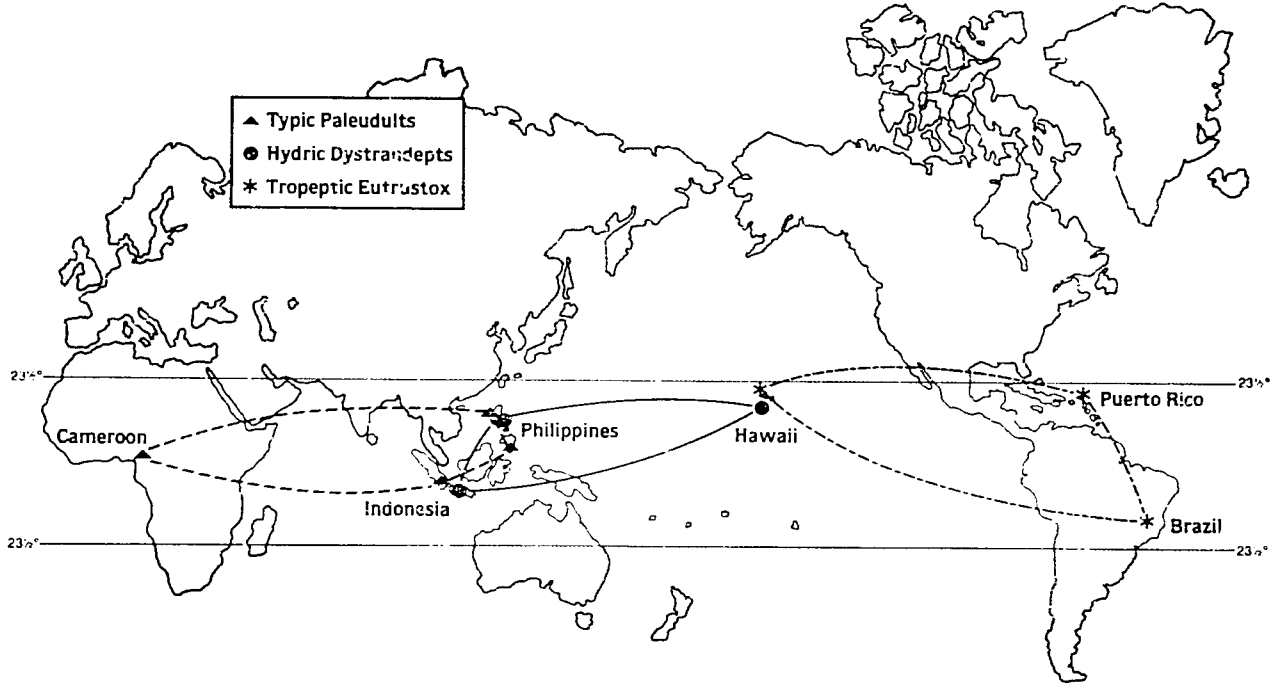



**Fig. 1.** The network of three soil families of the Benchmark Soils Project.

**Table 1. Soil family network of experimental sites.**

| Location | Area (nearest city) | Site |
|---|---|---|
| | **Thixotropic, Isothermic Hydric Dystrandepts** | |
| Hawaii | Hawi, Hawaii | IOLE |
| | Honokaa, Hawaii | KUK |
| | Hawi, Hawaii | HAL |
| Philippines | Panicuason, Camarines Sur, Luzon | PUC |
| | Pili, Camarines Sur, Luzon | PAL |
| | Calabanga, Camarines Sur, Luzon | BUR |
| Indonesia | Cisarua, Bandung, Java | ITKA |
| | Lembang, Bandung, Java | PLP |
| | Cipanas, West Java, Java | LPH |
| | **Clayey, Kaolinitic, Isohyperthermic Tropeptic Eutrustox** | |
| Puerto Rico | Isabela | ISA |
| | Isabela | ISA-2 |
| | Isabela | ISA-3 |
| Brazil | Jaiba, Minas Gerais | PAR |
| | Jaiba, Minas Gerais | BAH |
| | Jaiba, Minas Gerais | CEA |
| Hawaii | Maunaloa, Molokai | MOL |
| | Waipio, Oahu | WAI |
| | **Clayey, Kaolinitic, Isohyperthermic Typic Paleudults** | |
| Philippines | Davao City, Davao, Mindanao | DAV |
| | Sorsogon, Camarines Sur, Luzon | SOR |
| Indonesia | Kotabumi, Lampung, Sumatra | NAK |
| | Sukanegeri, Lampung, Sumatra | BUK |
| | Kotabumi, Lampung, Sumatra | BPMD |
| Cameroon | Kumba, Southwest | CAM |
| | Kumba, Southwest | BAK |

requirements, a common response to cultural practices, and a similar potential for crop production.

Within the same soil family, as in any sample population, there is, however, a range in general characteristics. Although efforts were made by Benchmark Soils Project staff to select sites having the similar phase of the same soil family, this was not always possible. The range in characteristics was acceptable, though, within a given family, and the outcome of the experiments was expected to vary only within a similarly narrow range. Tables in Appendix D summarize the ranges in characteristics of the three soil families.

**Table 2. Benchmark Soils Project soil families and associated soil properties as they relate to the taxa in Soil Taxonomy.**

| | |
|---|---|
| Order: | Inceptisols |
| Suborder: | Andepts |
| Great group: | Dystrandepts |
| Subgroup: | Hydric Dystrandepts |
| Family: | Hydric Dystrandepts, thixotropic, isothermic |
| Thixotropic | High surface activity of colloids |
| Isothermic | Cool soil temperatures (15–22 °C); small difference between summer and winter temperatures (<5 °C) |
| Hydric | Moist humid soils |
| Dystr- | Low base saturation (<50%) |
| -andept | Low bulk density (<0.85 g/cm³) |
| Order: | Oxisols |
| Suborder: | Ustox |
| Great group: | Eutrustox |
| Subgroup: | Tropeptic Eutrustox |
| Family: | Tropeptic Eutrustox, clayey, kaolinitic, isohyperthermic |
| Clayey | More than 35% clay in the subsoil |
| Kaolinitic | Dominated by low activity 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 |
| Order: | Ultisols |
| Suborder: | Udults |
| Great group: | Paleudults |
| Subgroup: | Typic Paleudults |
| Family: | Typic Paleudults, clayey, kaolinitic, isohyperthermic |
| Clayey | More than 35% clay in subsoil |
| Kaolinitic | Dominated by low activity 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%) |

**Table 3. General characteristics of the Benchmark Soils Project soils.**

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

## Reclassification of Some Soils

In the site selection process, the general landscape of the area of interest was examined and efforts were made to sample a representative soil pedon for laboratory characterization and classification. Some of the sites were later reexamined by the Soil Management Support Services (a program of U.S. Agency for International Development implemented by the Soil Conservation Service, U.S. Department of Agriculture) during which time another pedon was collected for further verification. These evaluations resulted in the reclassification of four of the Paleudults selected for study. The Paleudult at the DAV site (Mindanao, the Philippines) was reclassified as a Tropudalf because the cation

**Table 4. The original and new classifications of three Dystrandepts and four Paleudults of the Benchmark Soils Project.**

| Soil and Location | Original | New |
|---|---|---|
| PUC, PAL, and BUR sites, Philippines | Hydric Dystrandepts thixotropic, isothermic | Hydric Dystrandepts thixotropic, isohyperthermic |
| DAV site, Philippines | Typic Paleudults clayey, kaolinitic, isohyperthermic | Ultic Tropudalfs very fine, kaolinitic, isohyperthermic |
| SOR site, Philippines | Typic Paleudults clayey, kaolinitic, isohyperthermic | Orthoxic Palehumults clayey, kaolinitic, isohyperthermic |
| NAK site, Indonesia | Typic Paleudults clayey, kaolinitic, isohyperthermic | Orthoxic Palehumults clayey, kaolinitic, isohyperthermic |
| BUK site, Indonesia | Typic Paleudults clayey, kaolinitic, isohyperthermic | Orthoxic Palehumults clayey, kaolinitic, isohyperthermic |

exchange capacity was lower in the new sample and the base saturation was consequently calculated to be more than 35 percent. Paleudults at the SOR site (Luzon, the Philippines) and at the NAK and BUK sites (Sumatra, Indonesia) were reclassified as Palehumults because the organic carbon was higher than 0.9 percent in the upper portion of the argillic horizon. The reclassification from Paleudults to Palehumults also necessitated a concurrent change in subgroups—from typic to orthoxic.

The Benchmark Soils Project reclassified the Dystrandept sites in the Philippines as belonging to the isohyperthermic rather than the isothermic family on the basis of weather data collected at the sites. Table 4 shows the original and new classification names of the soils.

Reclassification of the Hydric Dystrandepts at PUC, PAL, and BUR from an isothermic to an isohyperthermic soil family meant that these sites were expected to be more suited for maize production but less suited for production of crops such as potato and cabbage than the Hydric Dystrandept family with an isothermic soil temperature regime. Reclassification of the Typic Paleudult at DAV to Ultic Tropudalf meant that this soil was better than previously indicated. Thus, the experimental results obtained at this site were expected to differ from those of the Paleudults.

The reclassification of the three Typic Paleudult sites (SOR, NAK, and BUK) to Orthoxic Palehumults meant that these soils had only

slightly more organic carbon than those that were previously classified. Because both the Typic Paleudalts and the Orthoxic Palehumults have low cation exchange capacity and because, in this case, both soils have nearly similar characteristics, the experimental results obtained at SOR, NAK, and BUK were not expected to differ from the others in the Benchmark Soils Project Paleudult family network.

## Extension of the Sphere of Transferability

A soil classification system such as Soil Taxonomy enables crop requirements to be matched quantitatively to soil characteristics. Crop performance improves as the number of mismatches between crops and soils diminishes, and soil classification enables its users to anticipate mismatches so that corrective measures can be instituted through soil management. While two soils that differ in classification must differ in one or more characteristics, soils that differ in classification can also possess many similar characteristics. It is this commonality of characteristics among soils that differ in classification that enables them to perform alike for certain uses. The situation is illustrated in the Benchmark Soils Project sites where, upon careful analysis, the soils were later shown to differ in classification from what they were originally thought to be. Small differences in soil temperature, base saturation, mineralogy, and organic matter content, and strict adherence to the rules of soil classification resulted in the final classification. A mean annual soil temperature of one degree centigrade or a base saturation difference of one percent was sufficient under certain situations to change the soil taxa. Thus, the sphere of transferability of agrotechnology is not restricted to similar-named kinds of soils but to any soils that possess a common set of characteristics that fulfills the requirements of the technology in question. This implies that if the sphere of agrotechnology transfer is to be enlarged, information on the requirements of each transferable technology must be documented and made available. In the absence of such information, agrotechnology transfer must necessarily be limited to similarly named kinds of soils.

## The Network in Perspective

Three upland soils of the tropics representing (1) "moist and cool," (2) "dry and warm," and (3) "moist and warm" agroenvironments and having the potential to be productive under appropriate management practices were selected to fulfill the general objective of the Benchmark Soils Project. These soils were (1) the thixotropic, isothermic family of Hydric Dystrandepts, (2) the clayey, kaolinitic, isohyperthermic family of Tropeptic Eutrustox, and (3) the clayey, kaolinitic, isohyperthermic family of Typic Paleudults, respectively. A total of 14 soil profiles repre-

senting 24 sites (9 Dystrandepts, 8 Eutrustox, and 7 Paleudults) were collected and compiled by the Benchmark Soils Project to establish the three soil family networks. Of the 24 sites, three of the Dystrandepts and four of the Paleudults were reclassified after a second site check. The Hydric Dystrandepts at the PUC, PAL, and BUR sites belonged to the isohyperthermic rather than the isothermic family. The Typic Paleudult at the DAV site was reclassified as a kaolinitic Ultic Tropudalf. The other Typic Paleudults (SOR, NAK, and BUK), which were reclassified as Orthoxic Palehumults, had characteristics nearly similar to the Typic Paleudults selected for the Project. The experimental results of these three Ultisols were thus expected to be in the range predicted for this soil family.

The transfer of agrotechnology based on soil family was therefore expected to take place in the soils of the Benchmark Soils Project because the soils had similar or nearly similar characteristics. The major exception was the Tropudalf at the DAV site and possibly the isohyperthermic Hydric Dystrandepts in the Philippines if the temperature requirement of the maize used in the study was critical.

## References

Beinroth, F. H. 1979. Laboratory data and descriptions of soils of the Benchmark Soils Project: Vol. 2—Puerto Rico project. BSP Tech. Rept. 5. Dept. Agron. and Soils, College of Agr. Sci., Univ. Puerto Rico, and Dept. Agron. and Soil Sci., College of Trop. Agr. and Human Resources, Univ. Hawaii.

Foote, D. E., E. L. Hill, S. Nakamura, and F. Stephens. 1972. Soil survey of the islands of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii. Soil Conservation Service, U.S. Dept. Agr., in cooperation with Hawaii Agr. Exp. Sta., Washington, D.C.

Ikawa, H. 1979. Laboratory data and descriptions of soils of the Benchmark Soils Project: Vol. 1—Hawaii project. Misc. Pub. 165 (BSP Tech. Rept. 1). Hawaii Agr. Exp. Sta., College of Trop. Agr., Univ. Hawaii.

Sato, H. H., W. Ikeda, R. Paeth, R. Smythe, and M. Tamashiro. 1973. Soil survey of the island of Hawaii, State of Hawaii. Soil Conservation Service, U.S. Dept. Agr., in cooperation with Hawaii Agr. Exp. Sta., Washington, D.C.

Soil Survey Staff. 1951. Soil survey manual. Soil Conservation Service, U.S. Dept. Agr. U.S. Govt. Printing Office, Washington, D.C.

Soil Survey Staff. 1975. Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. Soil Conservation Service, U.S. Dept. Agr. Handbook 436. U.S. Govt. Printing Office, Washington, D.C.

# 4 Research Design and Management

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The basic research approach of the Benchmark Soils Project was established during the Workshop on Experimental Designs for Predicting Crop Productivity with Environmental and Economic Inputs held at the University of Hawaii, May 20–24, 1974. Thirty-eight invited participants as well as members of the Department of Agronomy and Soil Science of the University of Hawaii attended the workshop. These included leading scientists from the U.S. and abroad in the fields of agricultural economics, statistics, soil science, and agricultural research in tropical countries. Workshop participants discussed possible experimental designs and research methodologies that could be used in the crop production research of the project and made recommendations (Silva and Beinroth, 1975).

## Experimental Design

*Rationale.* The major objective of the project was to determine scientifically whether agroproduction technology could be transferred among tropical countries. A soil fertility experiment was selected to provide the data to test the transfer hypothesis. It was decided to keep the experiment relatively simple and to include only two variables. Phosphorus (P) and nitrogen (N) were finally selected as variables because they were controllable, they were important to the test plant (maize), and they were key features of the soil families being studied. This "P by N" experiment is referred to as the "transfer experiment," as it provided data to determine the transferability of agroproduction technology.

Phosphorus was selected as a variable because it is frequently an important limiting factor to crop yields and is sorbed and immobilized to varying degrees in the soil families studied. The soil family name indicates the relative degree of P sorption and immobilization. In the thixotropic, isothermic family of Hydric Dystrandepts, for example, the word "thixotropic" connotes a high capacity to adsorb and immobilize fertilizer P because thixotropic soil materials possess a large surface area per unit weight that has a high affinity for P. Similarly, the names of the Tropeptic Eutrustox and Typic Paleudult families include the term "clayey," which indicates the presence of relatively large mineral sur-

face areas that can immobilize P. Therefore, this variable will reflect both the relative ability of these soil families to sorb P and the amounts of fertilizer P that must be applied to obtain comparable crop growth. Nitrogen was selected as a variable because it is rapidly depleted in tropical soils when the land is cleared and continuously cropped and is often the most limiting nutrient to crop growth.

A randomized complete block design was used. Three replications were recommended by the workshop participants as adequate for estimating the site-specific coefficients of the yield-response relationship to applied P and N. Consideration was given to two replications; the cost of an added replicate is small by comparison to the cost of selecting and establishing a site, when it is understood that many things can affect the survival of plots in the widespread Benchmark Soils Project network.

*Treatment design.* Determination of an optimal treatment design includes selection of (1) the treatment factors, (2) the experimental range of each factor, (3) the levels within the range, and (4) the treatment combinations.

The experimental range of each factor is usually less than the total possible range and depends on the purpose of the experiment and the assumed model. If predictions are based on a quadratic polynomial response surface model, applied levels need to be restricted to a range where yield should increase at a decreasing rate with increasing levels of applied P and N. The Benchmark Soils Project avoided lower levels of applied nutrients where yield is expected to increase at an increasing rate (sigmoidal response curve), as well as higher levels with relatively constant yields. The P response with no applied N can be greatly different from the P response with applied N. To avoid both a sigmoidal response curve for applied P and N and a prediction equation dominated by the interaction component of the model, the practical restriction for the lower range of P and N was not to include zero applied levels of P and N as part of the treatment design. The restriction on the upper range was to avoid high applied levels where yield data would not give information on estimating the positive magnitude of the response curve. In other words, the range of both applied levels is restricted to that in which both economic optimal and biological maximum can be predicted with relatively small standard errors.

The minimum number of levels for estimating a quadratic polynomial response curve with a non-zero intercept is three. With factorials, the number of treatment combinations becomes prohibitive for field experiments with more than seven levels. Five levels represent a compromise. However, a complete factorial with two factors (25 treatment combinations) still requires more treatment combinations than needed to estimate a quadratic polynomial response surface model and have an adequate measure of lack of fit. In addition, if block size and total num-

ber of plots are restricted because of practical and land variability considerations, there is a trade-off between number of treatment combinations and number of replications. Another compromise is therefore to systematically select some of the treatment combinations of the complete 5 × 5 factorial—for example, the center point (the combination of the middle level for both factors), a 2 × 2 factorial of the second and fourth levels, and a 3 × 3 factorial of the lowest and highest levels. With these 13 treatment combinations, the treatment combinations are symmetrical around the middle value and the levels can be equally spaced. For variance consideration, the 3 × 3 treatment combinations should be at the extreme ends of the selected range. In order to guard against bias when the true model is a higher order polynomial response surface, it is best to bring the treatment combinations off the extreme boundaries of the selected range and also to use unequal spacing of the levels. In short, then, the experimental design strategy is to use treatment design for the major control of bias error and to use replication to control variance error (Cady and Laird, 1973).

The treatment design finally recommended by workshop participants was the $5^2$ partial factorial modification by Escobar described in the paper by Laird and Turrent (1981). It was found to be one of the outstanding designs on the basis of (1) appropriateness for use in a graphic estimation of economic optima, (2) magnitude of bias error, (3) number of treatment combinations, (4) flexibility in number of factors and number of levels of each factor, and (5) magnitude of variance error. It also has good coverage of the factor space with its 13 treatments. Figure 1 is a diagram of this design. For convenience, the range is coded as −1 to +1. It should be noted that the coded 0 level is the middle rate of each treatment factor and not the zero level or absence of the factor.

A complete factorial has the advantage that all terms in a polynomial model are orthogonal, e.g., each parameter in the model can be estimated without interference from other terms in the model. The same statement is not true for the 13-point partial factorial. Specifically, the two linear terms are orthogonal to each other and to the interaction term, and, by the −1 to +1 coding, are orthogonal to the intercept and quadratic terms. However, the quadratic terms are not orthogonal to each other. From soil taxonomy considerations of the three soil families, applied P was the more important treatment factor. The N quadratic term can be made orthogonal to the P quadratic term, giving additive sums of squares for P linear, N linear, P quadratic, N quadratic fitted after P quadratic, and the PN interactions. With this concession, the number of treatment combinations was decreased by a factor of nearly two, thereby allowing an increase in the number of replications.

*Treatment combinations.* The experiment was kept manageable by specifying in the treatment design 13 combinations of the 5 levels of each of

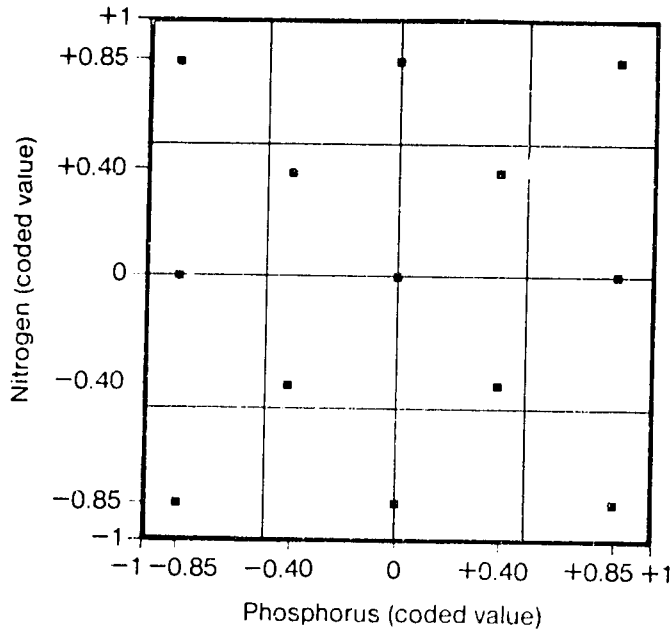


**Fig. 1.** Thirteen treatment combinations of applied phosphorus and applied nitrogen. The actual applied levels are coded on a scale from −0.85 to +0.85.

the two treatment factors, rather than the 25 possible treatment combinations (Table 1). Two additional treatments were included in all experiments: a complete control that received no fertilizer so that the potential productivity of the unfertilized soil could be assessed, and a partial control that received neither N nor P, but did receive the blanket application of potassium (K) and other nutrients applied to the other treatments. The same 15 treatment combinations were used for all three soil families, but the rates of P differed among families according to the levels of P in the soils. At some sites, additional treatment combinations were installed to provide information on the response to N without P, and P without N, as well as on the omission of the blanket fertilizer application.

## Fertilization Rates and Application

Detailed procedures for the management of the transfer experiments, including fertilization, planting, irrigation, pest control, etc., are described in the procedures and guidelines published by the Project staff (Benchmark Soils Project Staff, 1982).

*Nitrogen rates.* The actual levels of N applied were calculated from the

**Table 1. Coded levels of treatment combinations for P × N transfer experiment.**

| Treatment | Phosphorus | Nitrogen |
|---|---|---|
| A | −.85 | −.85 |
| B | −.85 | +.85 |
| C | +.85 | −.85 |
| D | +.85 | +.85 |
| E | −.40 | −.40 |
| F | −.40 | +.40 |
| G | +.40 | −.40 |
| H | +.40 | +.40 |
| J | 0 | 0 |
| K | −.85 | 0 |
| L | +.85 | 0 |
| M | 0 | −.85 |
| N | 0 | +.85 |
| O | zero (complete control) | zero |
| P | zero (partial control) | zero |

Note. All treatments except treatment O received blanket application of K plus other nutrients.

coded values by setting the −1.00 level at 15 kg/ha and the +1.00 level at 200 kg/ha. It was believed that with 15 kg N/ha at least some crop growth would result, which may not be so with zero N. Also, as the 200 kg/ha rate appeared to allow maximum yields of maize in other trials, it was selected as the upper limit of the factor space. The coded 0 level is the middle rate of N and is calculated as (200 − 15)/2 = 92.5 kg N/ha. Since the lowest N level is 15, the 15 is added to 92.5, which equals 107.5 kg N/ha, the middle rate of N. The other treatments are

| Coded level | Calculation | | kg N/ha |
|---|---|---|---|
| +.85 | 92.5(+.85) + 107.5 | = | 186 |
| +.40 | 92.5(+.40) + 107.5 | = | 144 |
| −.40 | 92.5(−.40) + 107.5 | = | 70 |
| −.85 | 92.5(−.85) + 107.5 | = | 29 |

Therefore, the five N treatments are 186, 144, 107, 70, and 29 kg/ha. The same rates of N were used at all sites in the three soil family networks.

*Phosphorus rates.* Actual rates of P to be applied as treatments were established after modified Truog extractable P was determined from the experimental block preplant soil samples. An alternate method was developed to determine soil P after problems arose with the P adsorption procedure of Fox and Kamprath (1970). This method was initially used to measure soil P and was the basis for setting the P increments of

the treatment design. However, because it is difficult to accurately measure low P concentrations in the supernatant solution and the recommended P requirement was apparently inappropriate for maize in the soils studied by the Project, it was necessary to seek an alternate procedure. The extraction methods of Bray and Kurtz (1945), Olsen et al. (1954), and Ayres and Hagihara (1952) were evaluated, and the modified Truog method of Ayres and Hagihara (1952)--[0.02N $H_2SO_4$ + 0.03% $(NH_4)_2SO_4$]--was selected for P extraction. The procedure entailed the development of a P-extraction curve by equilibrating incremental amounts of P with a series of soil samples for 24 hours and then extracting the P adsorbed with modified Truog extractant. Details of the modified Truog method are given in Appendix E. The relationship between applied P, and P extracted, is described by the extraction equation

$$Y = a + b[SQRT(X)]$$

where Y is the added P, a is the intercept, b is the slope of the line and SQRT(X) is the square root of the modified Truog extractable P (ppm).

Earlier work suggested that a critical value of 25 ppm modified Truog extractable P is the upper limit of soil P at or above which no application of P is required and no crop response to P is expected. This was used as the critical level for calculating P rates for the transfer experiments. The amount of P required to give 25 ppm of extractable P, which was set at the +1.00 level, was calculated with the extraction equation. For example, the extraction equation for the PUC-R site in the Philippines (Hydric Dystrandept) is

$$Y = -206 + 82[SQRT(X)]$$

The critical level of 25 ppm is substituted for X and the equation solved for Y to give 204 μg P/g. This is the +1.00 level, while the -1.00 level is 0. Therefore, the coded 0 or middle P level is 204/2, which equals 102 μg P/g. Calculation of the other P levels is shown as

| Coded level | Calculation | | μg P/g soil |
|---|---|---|---|
| +.85 | 102(+.85) + 102 | = | 189 |
| +.40 | 102(+.40) + 102 | = | 143 |
| -.40 | 102(-.40) + 102 | = | 61 |
| -.85 | 102(-.85) + 102 | = | 15 |

Therefore, the five P treatments are 189, 143, 102, 61, and 15 μg P/g soil. The actual amounts of P applied are adjusted for the bulk density of the soil at the site, which is 0.7 g/cm$^3$ at the PUC-R site. Since the

application is made to the top 15 cm of soil, the factor to convert μg P/g to kg P/ha is 1.05 (0.7 × 15). The actual amounts of P applied for the five treatments are

| Coded level | kg P/ha |
|---|---|
| +.85 | 198 |
| +.40 | 150 |
| 0 | 107 |
| -.40 | 64 |
| -.85 | 16 |

*Blanket fertilizer composition and rates.* Potassium and other nutrients required for good crop growth were supplied to all treatments except the complete control. Although the goal was to standardize the blanket application for all sites of a soil family, this was not always possible because of differences in past management. Tissue analyses of the ear leaves at tasseling were checked to assess the adequacy of the blanket application of nutrients. The general range of nutrients and sources of materials used are given in Table 2. Sulfur (S) was applied in areas where only treblesuperphosphate is available to provide adequate S.

*Application of fertilizer.* Nitrogen was applied as urea, while P was applied as superphosphate or treblesuperphosphate. One-third of the N, all of the P, and the blanket fertilizers were broadcast prior to planting and rototilled into the top 15 cm of soil. The remaining N was sidedressed, one-third at 30 days after emergence and one-third at tasseling.

**Table 2. Blanket fertilizer composition and rates.**

| Element | Rate (kg/ha) | Chemical formula |
|---|---|---|
| K | 100-200 | KCl |
| Mg | 100-150 | $MgSO_4 \cdot 7H_2O$ |
| Zn | 15 | $ZnSO_4 \cdot H_2O$ |
| B | 5 | $Na_2B_4O_7 \cdot 5H_2O$ |
| S | 100 | S |
| lime | Variable | $CaCO_3$ |

## Crop and Plot Management

The experimental area was cleared by hand or machine; in some cases grasses were first sprayed with glyphosate. The area was then plowed and plots were laid out in each of the three blocks of a randomized complete block design. Plots were either 3 by 6 m or 3 by 8 m, depending on the total area available.

*Test crop.* Maize (*Zea mays* L.) was recommended as the test crop at all

sites to provide data for the test of transferability. Maize has the advantage of being a short-term crop that is relatively easy to manage, has good disease resistance, is not too photoperiod sensitive, and can be readily harvested for reliable yields. Since it was felt that it would be difficult to find a single maize variety that was well adapted to all countries cooperating in the project, it was decided to use the "best adapted" variety for each country. In this way the true yield potential of the soil family in that country could be properly assessed by a well-adapted variety. The "best adapted" variety was the variety recommended by the local research institutions in the country. The maize varieties initially planted in the transfer experiments of the three soil family networks are summarized in Appendix F.

The decision to use the "best adapted" variety in each country made it necessary to install a variety experiment in each country in which several leading local varieties were compared to ensure that the "best adapted" variety was grown in the transfer experiment. Varieties grown in transfer experiments in other countries of the soil family network were included as well for comparison. The responsiveness of these varieties to applied N and P fertilizer was also assessed.

Pioneer brand variety X304C, which was the test variety in the Tropeptic Eutrustox network, was found to be well adapted to conditions in the other two soil families. Therefore, it was used as the test variety in the Typic Paleudult network beginning in 1980 and in the Philippines Hydric Dystrandept sites beginning in 1981. It was susceptible to downy mildew disease (*Peronosclerospora* spp.) which is prevalent in the Typic Paleudult sites and had to be treated with the fungicide metalaxyl.

*Planting and thinning.* Experiments were planted in both the wet and dry seasons of each year to assess the yield potential of the two seasons, which generally fell within the months of March–May and November–December. Irrigation was provided so that moisture would not be a limiting factor.

Maize seeds were treated with Captan; and where downy mildew (*Peronosclerospora* spp.) occurred, seeds were also treated with metalaxyl before planting. The four rows in each plot were spaced 75 cm apart, and seeds were planted by hand in hills 23 cm apart within rows. Two or three seeds were planted 5 to 7.5 cm deep in each hill. When plants in treatment J (Table 1) had four fully-emerged leaves, they were thinned to one per hill. This gave a population of about 58,000 plants per hectare.

*Irrigation.* Since the objective of the transfer experiment was to provide yield data that reflected N and P rates as well as local soil and climatic conditions, it was necessary to maintain all other non-experimental factors at adequate or near-optimum conditions. Therefore, irri-

Drip irrigation supplied water as needed to maintain adequate soil moisture. Maize growth reflects the differential phosphorus applications in this tracer experiment.

gation was provided to prevent water stress from adversely affecting the results. All plots were supplied with drip irrigation when needed. Biwall or single-wall drip tubing was provided for each row and water was supplied from a nearby river or well. Pumps or elevated water tanks maintained the desired pressure. Drip irrigation was used because of its relatively low water requirement and the fact that, if necessary, water could be transported to a site and applied under drought conditions to save an experiment. Irrigation frequency was determined from tensiometer readings in plots with the [illegible] treatment (table 11). Irrigations were scheduled to maintain a reading of less than 0.7 atmospheres on both the 15 and 45-cm-depth tensiometers.

*Pest control.* Weeds were controlled either by hand weeding or with herbicides. Insects and diseases were controlled with a variety of chemicals, depending on what was available locally for a particular problem. Spraying for insects was started as soon as an infestation was observed, while spraying for diseases was done to prevent the disease during favorable conditions as well as when the disease was observed. The insecticides and fungicides commonly used in the experiments are given in Appendix F. The crops also had to be protected from other pests such as birds, rodents, monkeys, porcupines, wild pigs, and stray cattle. Various devices, including fences, repellents, and baits, were used to minimize damage from these sources.

*Harvest.* The experiment was harvested after physiological maturity had been reached as indicated by formation of the black layer. The border row on each side of each plot was removed along with the one-meter border on each end of the harvest rows. Ears and stalks remaining in the middle two rows were harvested, and the number harvested and their weights were recorded. A total of 34 plants were harvested from the 3 by 6 m plots and 52 plants from the 3 by 8 m plots.

A sample of 8 or 10 ears from the 3 by 6 m plots and the 3 by 8 m plots, respectively, was selected at random from each plot and taken to the laboratory, where filled ear length, shelled grain weight, moisture content, and weight of 100 kernels were determined. A sample of grain was also dried and ground for chemical analysis. A sample of 8 or 10 stalks (stover) was selected at random, chopped, and a subsample taken for moisture determination and chemical analysis.

*Plant sampling.* When 50 percent silking had been attained ear-leaf samples were collected from each plot. Five leaves were collected from each harvest row for a total of 10 leaves per plot. Both fresh and dry weights were determined and the samples were dried, and ground, and shipped to Hawaii for chemical analysis.

*Soil sampling.* Soil samples (0–15 cm) were collected prior to planting to assess the nutrient status of the soil so that adequate nutrients could be supplied to the crop and also to determine the rates of P that should be applied. Post-harvest soil samples were also collected from each plot to assess the nutrients remaining after cropping. Four to eight cores, 0–15 cm deep, were collected from each plot and composited for chemical analysis. The P status of plots was used to reestablish the P rates in experiments where residual and reapplied P made up the P differential. Soil samples were shipped to Hawaii for chemical analysis.

*Data collection and recording.* Phenological data, date of 50 percent emergence, date of 50 percent tasseling, and date of physiologic maturity were recorded for each plot, as was plant height at four weeks after 50 percent emergence, and after 100 percent tasseling. Pest, insect, and disease damage were rated and recorded at 50 percent tasseling. Plot observations were kept in a weekly log and data recorded on specially-prepared data sheets. Forms for planning worksheets, evaluation journals, field data sheets, and weather data sheets were prepared and are presented in Benchmark Soils Project Staff (1982).

## Management Experiments

Management experiments were also carried out at the primary sites to study agronomic problems of local importance and to develop management practices for local farmers with limited resources. The objectives of the management experiments were to provide information to local

government agencies on ways to increase production by improving the availability and utilization of resources, and to provide basic information to local farmers with limited resources for improving crop yields at different levels of management. Information gained from these experiments should eventually lead to a determination of the most economic and efficient agricultural practices for a country and provide information for subsequent soil interpretation and land capability classification.

The management experiments reflected the wide array of transferable information that the project generated. They included tests to determine the limiting nutrients in a soil, the effects of organic manure, the spacing of corn plants, the residual effects of phosphorus, phosphorus placement, response to various sources of phosphorus fertilizer, and comparison of soil family cropping systems. These experiments not only had immediate impact for the in-country small farmer, who readily adopted some of the results, but also carried impact for small farmers living on similar soils in other tropical countries.

In contrast to the transfer experiments, the design of the management experiments was flexible, allowing the Benchmark Soils Project to respond to participating-country priorities. The philosophy of the management experiments was developed at the first annual coordination meeting of the Universities of Hawaii and Puerto Rico in 1976. Details of the management experiments were developed by each participating country; however, the general agronomic practices followed were similar to those described for the transfer experiments.

## References

Ayres, A. A., and H. H. Hagihara. 1952. Available phosphorus in Hawaiian soil profiles. Hawaiian Planters' Record 44:81–99.

Benchmark Soils Project. 1982. Procedures and guidelines for agrotechnology transfer experiments with maize in a network of Benchmark soils. HITAHR Res. Ext. Series 015 (BSP Tech. Rept. 3). Hawaii Inst. of Trop. Agr. and Human Resources, College of Trop. Agr. and Human Resources, Univ. Hawaii.

Bray, R. H., and L. T. Kurtz. 1945. Determination of total, organic and available forms of phosphorus in soils. Soil Sci. 59:39–45.

Cady, F. B., and R. J. Laird. 1973. Treatment design for fertilizer use experimentation. Res. Bull. 26, Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), Mexico D.F.

Fox, R. L., and E. J. Kamprath. 1970. Phosphate sorption isotherms for evaluating phosphate requirements of soils. Soil Sci. Soc. Am. Proc. 34:901–907.

Laird, R. J., and A. Turrent. 1981. Key elements in field experimentation for generating crop production technology. *In* Experimental designs for predicting crop productivity with environmental and economic inputs for agrotechnology transfer. J. A. Silva, ed. Dept. Paper 49. Hawaii Inst. of Trop. Agr. and Human Resources, College of Trop. Agr. and Human Resources, Univ. Hawaii.

Olsen, S. R., C. V. Cole, F. S. Watanabe, and L. A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S. Dept. Agr. Circ. 939. U.S. Govt. Printing Office, Washington, D.C.

Silva, J. A., and E. H. Beinroth. 1975. Report of the workshop on experimental designs for predicting crop productivity with environmental and economic inputs. Dept. Paper 26. College of Trop. Agr., Univ. Hawaii.

*Quantitative Evaluation of the Transfer Hypothesis*

# 5 Development of Transfer Evaluation Methodology

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and
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Agrotechnology transfer is defined by Uehara (1981) as the taking of an agricultural innovation from one location to another where it is likely to succeed. For the transfer experiments of the Benchmark Soils Project, "agricultural innovation" is a soil fertility management package, specifically phosphorus (P) and nitrogen (N) fertilization on maize (*Zea mays* L.). "Taking," or transfer, implies making a quantitative prediction of maize response at "another location" which, for the Benchmark Soils Project, is another environment within the same soil family. "Success" is measured by an acceptable criterion with a known frequency distribution, so that "likely," or the likelihood of a given magnitude of the criterion, can be expressed in terms of probability.

## Concepts of Agrotechnology Transfer Modeling

In the Benchmark Soils Project the basis for accelerated agrotechnology transfer was the soil family. This categorical level of classification in Soil Taxonomy, which carefully defines selected soil and environmental properties associated with plant growth, should allow transfer of agricultural research to be successfully maximized. That is, soils belonging to the same soil family should have similar yield response to an applied agrotechnology.

The Benchmark Soils Project, through a network of integrated experiments in the tropics, was a comprehensive effort to objectively and quantitatively demonstrate transference of maize responses to applied phosphorus and nitrogen. Based on limited experimentation on agroenvironments defined by soil families, crop response at nonexperimental environments in the same soil family can be predicted from a transfer model with only minimal knowledge of the new sites. (The terms agroenvironments, environments, and sites are used interchangeably).

Workshop participants at the time of the project's inception concluded that neither a criterion nor a data analytic methodology was sufficiently developed for quantitatively evaluating Soil Taxonomy as a technology transfer vehicle. An integral part of the Benchmark Soils Project was formulating and testing an acceptable validation statistic, with an associated probability level, for evaluating the predictive ability of an estimated crop response transfer model.

The role of a transfer model in agrotechnology transfer research is schematically presented in Figure 1. The transfer model embodies the information needed to transfer crop response from experimental environments of a specific soil family to new environments of the same soil family. The transfer carrier is the transfer model from which crop response can be predicted. The target population of environments for crop response prediction are all those environments, without concern for geographical boundaries, within the same soil family. The soil and its associated long-term climate are constant inputs. Experimental factors are under the control of the researcher; most are maintained at a constant level. The agricultural innovation to be transferred includes those experimental factors controlled at preselected levels according to a treatment design.

In addition, there are factors that cannot be controlled experimentally but that can be measured either before or during crop growth. If these uncontrolled factors influence the relationship between crop response and treatment factors, their effect has to be included as part of the transfer model. From a Soil Taxonomy viewpoint, there are ideally no factors of an uncontrollable and influential nature. If there are any such factors, however, they need to be measured at the new site. For factors that are measurable or known before the crop is planted, management decisions can be based on the crop response transfer predictions.

As yield is the crop measure of interest, we want to transfer yield response to an applied agrotechnology from specific experimental sites to new sites in the same soil family by predicting yield response for the new sites. For example, for an experiment comparing a newly released cultivar with the traditional cultivar, the simplest transfer model needed to make yield-response predictions at the new sites is the difference in yield between the two cultivars averaged over the experimental sites.

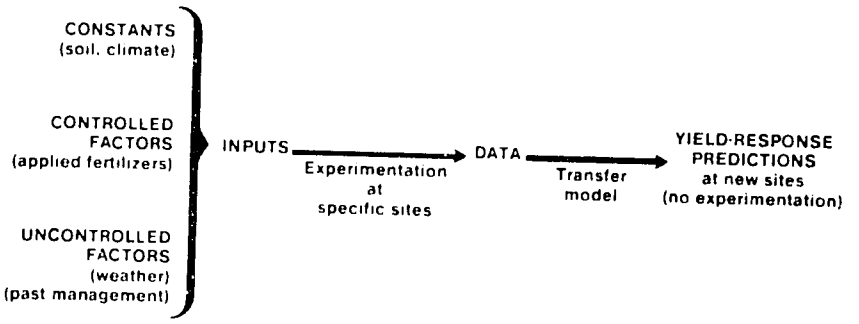


**Fig. 1.** Schematic formulation of a transfer model for predicting crop yield response to input factors.

The transfer model increases in complexity as the treatment design is enlarged or as uncontrolled factors influencing yield response are measured and included in the transfer model.

The premise of this transfer model, then, is the prediction of how much increase in yield can be expected from the application of a technology at a site where the technology has not been applied. Thus, agrotechnology transfer can be viewed as the extrapolation of a response-input relationship, estimated from known experimental situations to other similar conditions.

After yield responses are predicted for the new sites, the predictive ability of the estimated transfer model must be evaluated. One way to evaluate the accuracy of the transfer predictions is to measure actual yield responses at the new sites and to compare them to the transfer predictions and to site-specific predictions based on analysis of the yields measured at the new site.

In the Benchmark Soils Project's evaluation methodology, each experimental site assumes the role of a new site. The transfer model is estimated for the "new" site from the data of the other sites, and yield response is predicted. With a total of k experimental sites, a systematic series of calculations is performed to evaluate the transfer hypothesis. The methodology for the quantitative transfer evaluation is presented in the following outline.

1. Calculate a site-specific prediction equation for each of the k sites based only on the yield data from different plots at that site. The differences between the site-specific predicted yields and the actual yields are called *site-specific residuals*. Various forms of prediction equations, including exponentials and polynomials, can be used to relate yield response to controlled factors.

2. Identify the general nature of and select the best-suited transfer model. The simplest transfer model might include the same components in the site-specific prediction equation of the first step. More complex transfer models can incorporate uncontrolled factor information.

3. Estimate the parameters of the selected transfer model for each set of (k − 1) sites.

4. Predict yields for each plot at one site using the transfer model estimated in Step 3 from the data of the other (k − 1) sites. The differences between the transfer predicted yields and the actual yields are called transfer residuals and are calculated with each site in turn assuming the role of a new site.

5. Compare the transfer residuals with the site-specific residuals for each site. If the two residuals are the same in magnitude, we have evidence of successful transfer for the technology.

The following shows how transfer of one controlled input factor is developed. Evaluation of technology transfer for both applied phospho-

rus (P) and applied nitrogen (N) will be presented later. For each site (i is a subscript index for the sites), the site-specific prediction equation with only the P factor is

$$\hat{y}_i = \bar{y}_i + b_{1i}P + b_{2i}P^2 \qquad (i = 1,2,\ldots,k)$$

where $\hat{y}_i$ is the set of predicted yields for the $i^{th}$ site, $\bar{y}_i$ is the $i^{th}$ site mean yield, $b_{1i}$ is the $i^{th}$ P linear response (an estimate of the straightline relationship between yield and applied P), $b_{2i}$ is the $i^{th}$ P quadratic response (an estimate of the curvature of the relationship between yield and applied P), and k is the number of sites.

## Formulation of a Transfer Model and an Evaluation Criterion

Fundamental to the transfer of an imposed agricultural innovation is the yield metric to be transferred. While total yield is of general interest, a more specific alternative in comparative experimentation and inference is the yield difference, e.g., the difference in yield between no applied P and applied P. A transfer model, then, needs to focus on the yield response to the technology. For several levels of the controlled factor of applied P, the yield response is summarized by the $b_1$ and $b_2$ coefficients of the site-specific response curve. The site mean ($\bar{y}$) determines only the relative position of the response curve, while $b_1$ and $b_2$ determine the shape of the curve and the magnitude of the response. It should also be noted that the individual site mean is not part of the calculation for finding the physical maximum level or the economic optimum level of P application. Consequently, the site mean is subtracted from the plot yields for each site, and a transfer model is formulated as the linear and quadratic terms from the site-specific prediction equation.

One key part of the transfer analysis methodology is the prediction of yield responses for a site not used in the estimation of the transfer model. In turn, each of the k sites assumes a role of a "new" site, and the P yield response is predicted for the plots at each "new" site based on the transfer model estimated from the other (k − 1) sites. Then the estimated transfer model, or the transfer prediction equation for the $i^{th}$ site, is

$$\hat{y}_{[-i]} = b_{1[-i]}P + b_{2[-i]}P^2$$

where the [−i] subscript denotes that the yield response predictions for the $i^{th}$ site are calculated from a transfer prediction equation based on data from the other (k − 1) sites, and where $b_{1[-i]}$ is the average of the site-specific $b_1$ values for the other (k − 1) sites (assuming each site has

the same number of replications). Similarly, for the quadratic term, $b_{2[-i]}$ is the average of the site-specific $b_2$ values for the other (k − 1) sites.

If $b_{1i}$ for each site does not vary from $b_{1[-i]}$ (and $b_{2i}$ does not vary from $b_{2[-i]}$) by more than experimental variability, then the transfer residuals, $y_i - \hat{y}_{[-i]}$, will be of the same general magnitude as the site-specific residuals, $y_i - \hat{y}_i$, which are calculated within each individual site. An evaluation of the predictive ability of an estimated transfer model compares the transfer residuals with the site-specific residuals. With a number of plots at each site, and with several sites, a visual comparison of a transfer residual with a site-specific residual for each plot becomes cumbersome. An acceptable procedure for summarizing is to sum the squared values for both types of residuals. An appealing specific criterion is the ratio of the transfer residual sum of squares to the site-specific residual sum of squares where both sums are pooled over the k sites. The resulting statistic is called the transfer, or prediction (P), statistic

$$P = \frac{\Sigma\,(\text{Sum of squared transfer residuals for the } i^{th} \text{ site})}{\Sigma\,(\text{Sum of squared site-specific residuals for the } i^{th} \text{ site})}$$

In addition, a probability statement of the likelihood of observing a certain magnitude of the summary statistic is also needed for an objective and quantitative evaluation of the predictive ability of the estimated transfer model. With no uncontrolled factors as part of the estimated transfer model, the P statistic is proportional to the F statistic. Specifically,

$$F = \frac{d\,(k-1)\,(P-1)}{pk^2}$$

where p is the number of variables in the estimated transfer prediction equation and d is the number of degrees of freedom in the pooled residual mean square. This F is the same F statistic for testing the equality of site-specific response curves. However, the F and P statistics are not equivalent when the transfer model includes uncontrolled site-factor information.

## Transfer Modeling with Controlled and Uncontrolled Site Factors

The transfer model based on the controlled factors will be satisfactory for transfer of maize response to applied P if the P linear and quadratic response coefficients do not vary from site to site. The $b_{1[-i]}$ is the average of the site-specific $b_1$ coefficients for the other (k − 1) sites and, hopefully, will be equal to the $b_1$ coefficient for the $i^{th}$ site. If the same situa-

tion holds for the P quadratic response coefficients ($b_2$), the transfer residuals would be expected to be the same as the site-specific residuals. A preliminary evaluation can be determined from analysis-of-variance calculations combining the results from all sites (Chapter 14, Cochran and Cox, 1957). Four lines from the combined analysis-of-variance table reflecting the average P linear and quadratic responses and their interactions with sites are presented.

| Source of variation | Degrees of freedom |
|---|---|
| P linear response | 1 |
| P quadratic response | 1 |
| Site × P linear response | (k − 1) |
| Site × P quadratic response | (k − 1) |

The estimated transfer model, $b_{1[-i]}P + b_{2[-i]}P^2$, will not be satisfactory if the magnitude of the two interaction mean squares is large relative to the experimental error term pooled over all the experiments. Large interactions indicate differential P response curves among the sites, i.e., the hypothesis of equal response curves for all sites would be rejected. One immediate ramification is the need for augmenting the transfer model.

The first step in augmenting the transfer model is to identify specific uncontrolled factors measured at each site—called site variables—so that most of the sum of squares for each interaction with (k − 1) degrees of freedom can be associated with a few single degree of freedom interaction contrasts between P response and the identified site variables. Extractable soil P is one uncontrolled factor that can be measured at each site. It can indicate differences among sites due to past management practices, and it can be related to yield response. The measure of extractable soil P used by the Benchmark Soils Project was a modified Truog soil test for P (Appendix E), hereafter referred to as soil P.

The particular form of the transfer model augmentation can be graphically depicted by plotting $b_1$ (and $b_2$) on the ordinate against soil P. Hopefully the systematic trend between $b_1$ (and $b_2$) and soil P can be represented by a straight line, perhaps after rescaling or transforming the soil P values, e.g., the reciprocal of soil P. In terms of the combined analysis-of-variance calculations, the interaction sum of squares between sites and P linear response (or P quadratic response) with (k − 1) degrees of freedom can now be subdivided as a soil P-by-P linear response sum of squares with one degree of freedom and a remainder (lack-of-fit) sum of squares with (k − 2) degrees of freedom.

If the soil P variable accounts for the interaction between sites and P linear response, the remainder mean square is the same magnitude as the pooled experimental error term. When tested by an F statistic, the form of the augmented transfer model can be verified with an F value close to 1. If soil P also accounts for the interaction between sites and the P quadratic response, we then have an indication that the transfer prediction equation, augmented by the appropriate interaction terms, will give more accurate yield predictions than the estimated transfer model without site-variable information. For this situation, the augmented transfer prediction equation can be written in a model format as

$$\hat{y}_{[-i]} = b_{1[-i]}P + b_{2[-i]}P^2 + b_{3[-i]}P{*}SOILP + b_{4[-i]}P^2{*}SOILP$$

where P*SOILP (and $P^2$*SOILP) represent the interaction terms between the linear response to applied phosphorus (and the quadratic response to applied phosphorus) and soil phosphorus. An equivalent form emphasizing the effect of the interaction variables in allowing different shapes of the P response for each site is

$$\hat{y}_{[-i]} = [b_{1[-i]} + b_{3[-i]}SOILP]P + [b_{2[-i]} + b_{4[-i]}SOILP]P^2$$

Expressed in this form, the direct effect of the interaction coefficients on the P linear and quadratic responses may be observed. The two forms of the transfer prediction equation also give a clue to alternative methods of computing the estimated coefficients. The first has a multiple regression format, with four independent variables. Alternatively, the relationships between the site-specific response coefficients, e.g., $b_{1i}$, and the soil P values can be fitted by a straight line. The intercept and slope coefficients will be $b_1$ and $b_3$, respectively.

Introducing site-variable information into the transfer prediction equation allows the P response curve to be unique for the particular site being predicted, even though the regression coefficients are estimated from the other (k − 1) sites. If the evidence for transfer (probability level of the transfer statistic, other data, and economic or agronomic considerations) is sufficiently strong to warrant transfer, then the transfer prediction equation could be used to predict yields for a new site within the soil family. For example, with soil P as a site variable, the $[b_{1[-i]} + b_{3[-i]}$ SOILP] coefficient is the transfer prediction of the P linear response and would be expected to be as close to the actual P linear response for the new site as if an actual experiment had been carried out. The soil P test value would be the only information needed from the new site to predict the yield response to P fertilization.

With an augmented transfer model now formulated, attention shifts to evaluating the predictive ability of the augmented transfer model. We

again turn to the P statistic. Whereas in the previous section, the P statistic and the F statistic for testing the equality of the response curves were equivalent, the two statistics are no longer equivalent when the transfer model has been augmented by interaction terms between site variables and P response. Accounting for the interaction sum of squares between sites and the P response is helpful in identifying important site variables but is not necessarily sufficient to guarantee predictive ability. In short, the correct form of the augmented transfer model is indicated by a combined analysis-of-variance F statistic, while the P statistic summarizes the predictive ability of the transfer model.

The P statistic is a reasonable and appealing summary statistic, and the statistical distribution of the P statistic has been developed (Wood and Cady, 1981). Tables for the distribution of the P statistic are not readily available. The distribution of the statistic depends on the actual values of the measured site variables and needs to be computer generated for each experimental situation. Approximations to the distribution of the P statistic have been developed by Liu and Wood (1985). If the number of sites is greater than 15, the standardized statistic

$$(k-1)^2k^{-2}d(P-1) - 2m$$

has approximately a chi-square distribution with $(k-1)p - m$ degrees of freedom, where p is the number of variables in the estimated transfer prediction equation ignoring interaction terms, k is the number of sites, d is the number of degrees of freedom in the pooled residual mean square, and m is the total number of interactions formed with site variables. Knowledge of the statistic's distribution provides previously unavailable probability levels for evaluating predictive ability of a transfer model.

## References

Cochran, W. G., and G. M. Cox. 1957. Experimental designs. John Wiley and Sons, Inc., New York.

Liu, J. P., and C. L. Wood. 1985. Approximations to the distribution of the prediction statistic. Tech. Rept. 242. Univ. Kentucky.

Uehara, G. 1981. Agrotechnology transfer. *In* McGraw-Hill yearbook of science and technology. McGraw-Hill, New York.

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

*Quantitative Evaluation of the Transfer Hypothesis*

# 6 Transfer of Yield Response to Phosphorus and Nitrogen Fertilizer

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Fifty-four transfer experiments were carried out during 1978–83 on the thixotropic, isothermic Hydric Dystrandept and clayey, kaolinitic, isohyperthermic Typic Paleudult soil families. Seven experiments from each family could not be used in the transfer evaluation because of low treatment mean yields, high coefficients of variation, abnormal patterns of the site-specific residuals, or undue disease and experimental problems.

### Intra-family Transfer of Yield Response to P and N Fertilizer

The data-analytic flowchart of Figure 1 indicates the steps of both the site-specific and transfer analyses. The site-specific prediction equations are estimated second order response surfaces,

$$\hat{y}_i = \bar{y}_i + b_{1i}P + b_{2i}N + b_{3i}P^2 + b_{4i}N^2 + b_{5i}PN$$

where $\hat{y}_i$ is the set of predicted yields for the $i^{th}$ site, $b_{1i}$ and $b_{2i}$ are the $i^{th}$ P and N linear responses, $b_{3i}$ and $b_{4i}$ are the $i^{th}$ P and N quadratic responses, and $b_{5i}$ is the $i^{th}$ PN interaction response. The site-specific residuals are the differences between each field-plot yield and its predicted yield. Examination of the individual residuals for each treatment mean and the graph of the residuals plotted against the predicted values can reveal abnormalities of either the data or the prediction equation, which are sufficient to withhold an experiment from the transfer analysis.

The predicted yields will be the same whether coded or actual applied levels are used. In later analyses, however, each term will need to be centered at zero so that the intercept will be the site mean. In addition, each term needs to be orthogonal to each other term (Wood and Cady, 1981). The orthogonalized values for the response surface model components, details of a site-specific analysis, and a transfer case study are given in Cady et al. (1982).

*Data analysis and transfer modeling.* The combined analysis-of-variance procedure (Chapter 14, Cochran and Cox, 1957) can anticipate an inadequacy of formulating a transfer model with only the terms or com-

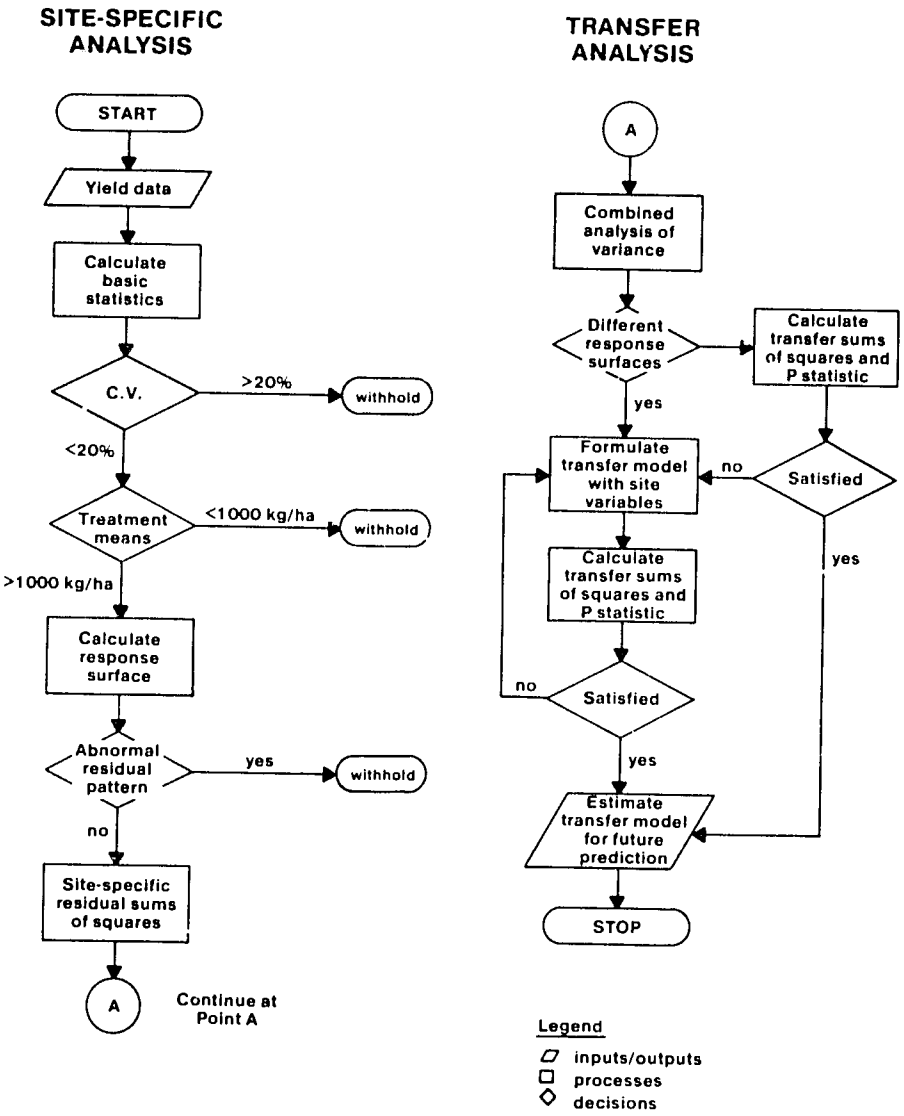


**Fig. 1.** Data-analytic flowchart for evaluation of agrotechnology transfer.

ponents of the second order response surface model. In particular, the site-by-model component mean squares can reveal important interactions between sites and model components. If the interactions are important, the average of the P linear response for (k – 1) sites to predict the P linear response for the $k^{th}$ site will not be sufficient. The need to characterize the site by measuring uncontrolled environmental variables has been recognized. Extractable soil P (modified Truog extractant)

and extractable soil N (2N KCl extractant) measurements on preplant soil samples had been presumed to be important factors in understanding and modeling variability in the site-specific model components. As indicated by plotting, the relationship between the site-specific P linear responses and extractable P, expressed on a reciprocal scale, can be modeled as a straight line.

The relationship between the N linear response and extractable N did not sufficiently explain the interaction due to several inconsistent extractable N values. An indirect measure of plant available soil N, patterned after the procedure developed by Dean (1954), was calculated for each site. Specifically, yield (y axis) was plotted against applied N (x axis). The fitted straight line was extrapolated until the line crossed the x axis (to the left of the y axis). This extrapolated point on the x axis where y equals zero is considered an approximation of preplant extractable soil N. For sites where the extrapolated line did not cross the x axis, extractable soil N was set at a relatively high constant value.

Additional site variables for the P linear and quadratic responses were needed. During the last four growing seasons at three locations in the Typic Paleudult family (BPM, BUK, and NAK), the maize variety was changed and there were irrigation problems during the dry season. Consequently, season (wet and dry), variety (open-pollinated and hybrid), and the interaction between season and variety were introduced as site variables for the experiments from these three locations.

A transfer model (Model 2) for the Typic Paleudults was then formulated with the P, N, $P^2$, $N^2$, and PN components of the second order response surface model and selected interactions between the five response surface model terms and uncontrolled site variables. These included soil phosphorus (SOILP), SEASON, VARIETY and the product of SEASON*VARIETY with the linear (P) and quadratic ($P^2$) responses to applied phosphorus, soil nitrogen (SOILN) with the linear (N) and quadratic ($N^2$) response to applied nitrogen, and both SOILP and SOILN with the interaction response (PN). For Model 2 of the Hydric Dystrandepts, the interaction terms included SOILP and SOILPH (KCl) with P, SOILP with $P^2$, SOILN with N and $N^2$, and SOILP and SOILN with PN. Appendix G presents the site-variable data and site-specific estimates of the second order response surface model.

The choice of modeling the relationships between the response surface components and uncontrolled site factors is influenced by agronomic and practical considerations. For example, the systematic relationship revealed by plotting the site-specific linear responses of applied phosphorus against SOILP is curvilinear with either the SOILP scale or the square root of SOILP. Linear model estimation, such as polynomial or segmented regression, can be used for fitting the interaction relation-

ship. On the other hand, if the relationship is believed to be exponential, a nonlinear estimation method (Allen and Cady, 1982) is needed. However, the exponential relationship can be approximated by the reciprocal transformation of SOILP and fitting a straight line. Preliminary transfer evaluations were carried out with the square root scale of SOILP (Cady et al., 1982) while the reciprocal of SOILP is used in the final evaluation given here.

*Evaluation of the transfer hypothesis.* With the two transfer models now formulated, the remaining steps in the transfer analysis for both soil families were carried out. Plot yields were predicted for each site using the transfer model estimated from the data of the other sites. Transfer residuals were calculated, and compared with the site-specific residuals. The transfer residual sums of squares for each site are given in Table 1 and Table 2 under Model 2. A program for calculating transfer sums of squares is given in Cady et al. (1982). Even though the combined analysis-of-variance table indicated that a transfer model with only the five terms of the second order response model would not be sufficient, transfer (Model 1) sums of squares are also given in Tables 1 and 2.

**Table 1. Site-specific and transfer residual sums of squares (x10³) for Hydric Dystrandepts.**

| Site | Site-specific | Intra-family transfer | | Inter-family transfer |
|---|---|---|---|---|
| | | Model 1 | Model 2 | |
| BURB | 217 | 360 | 257 | 275 |
| BURD | 121 | 204 | 125 | 136 |
| IOLE | 65 | 164 | 76 | 72 |
| IOLK | 165 | 231 | 189 | 174 |
| ITKC | 98 | 268 | 147 | 167 |
| ITKD | 206 | 482 | 235 | 229 |
| ITKE | 142 | [illegible] | 155 | 170 |
| LPHE | 122 | [illegible] | 156 | 154 |
| LPHG | 120 | 508 | 138 | 157 |
| PALE | 62 | 537 | 71 | 174 |
| PALF | 65 | 205 | 89 | 104 |
| PALG | 92 | 294 | 105 | 192 |
| PLPG | 238 | 477 | 289 | 271 |
| PUCK | 58 | 105 | 73 | 101 |
| PUCR | 120 | 370 | 168 | 246 |
| PUCS | 96 | 426 | 128 | 232 |
| Total: | 1988 | 4894 | 2402 | 2854 |
| P statistic: | | 2.4609 | 1.208 | |

Note: Model 1 included the terms for a second order response surface for applied P and N. Model 2 included Model 1 terms plus interaction terms as described in the text. The inter-family transfer residual sums of squares were calculated from the estimated Model 3 of the Typic Paleudults.

**Table 2. Site-specific and transfer residual sums of squares (x10³) for Typic Paleudults.**

| Site | Site-specific | Intra-family transfer | | | Inter-family transfer |
|---|---|---|---|---|---|
| | | Model 1 | Model 2 | Model 3 | |
| BAKA | 180 | 228 | 193 | 193 | 218 |
| BAKC | 146 | 211 | 161 | 161 | 185 |
| BAKE | 181 | 407 | 211 | 215 | 221 |
| BAKF | 146 | 381 | 196 | 198 | 214 |
| BPMA | 332 | 422 | 351 | 352 | 436 |
| BPMC | 174 | 216 | 204 | 225 | 429 |
| BPMD | 252 | 403 | 269 | 276 | 526 |
| BUKC | 116 | 157 | 127 | 125 | 241 |
| BUKD | 181 | 215 | 252 | 193 | 253 |
| BUKE | 245 | 285 | 282 | 279 | 287 |
| BUKF | 53 | 73 | 80 | 78 | 148 |
| BUKG | 194 | 241 | 212 | 289 | 218 |
| BUKH | 196 | 396 | 256 | 397 | 251 |
| CAMA | 117 | 415 | 128 | 137 | 122 |
| CAMB | 192 | 429 | 196 | 197 | 215 |
| CAMC | 178 | 433 | 206 | 203 | 230 |
| NAKA | 128 | 176 | 152 | 146 | 282 |
| NAKD | 336 | 409 | 355 | 399 | 582 |
| NAKJ | 115 | 209 | 132 | 139 | 419 |
| NAKN | 62 | 181 | 77 | 110 | 221 |
| NAKO | 167 | 356 | 228 | 249 | 205 |
| NAKP | 150 | 397 | 172 | 262 | 184 |
| SORA | 55 | 244 | 72 | 73 | 352 |
| SORB | 159 | 448 | 218 | 221 | 428 |
| Total: | 4055 | 7331 | 4729 | 5117 | 6867 |
| P statistic: | | 1.808 | 1.166 | | |

Note: Model 1 included the terms for a second order response surface for applied P and N. Model 2 included Model 1 terms plus interaction terms as described in the text. Model 3 included the same terms as Model 2 of the Hydric Dystrandepts as described in the text. The inter-family transfer residual sums of squares were calculated from the estimated Model 2 of the Hydric Dystrandepts.

The P statistic for the Typic Paleudults is calculated by taking the ratio of the sum of the 24 transfer sums of squares to the sum of the 24 site-specific residual sums of squares. This equals 1.166 for Model 2 (Table 2). The distribution theory of the P statistic and a procedure for calculating the probability level of a P statistic value when the transfer model includes interaction terms with site variables has been given by Wood and Cady (1981). The probability of observing a P statistic value of 1.166 or larger on chance alone is 0.62. Approximately six out of 10 times, a P value of 1.166 or larger would occur on chance alone. These odds are judged to be sufficiently likely that the increase in the transfer sum of squares relative to the site-specific sum of squares may be attrib-

uted to random variability. Whereas the transfer predictions are judged to be the same as site-specific predictions within random variability for Model 2, the same conclusion cannot be reached for Model 1 where the probability of observing a P value of 1.808 or larger on chance alone is less than 0.001.

For the Hydric Dystrandepts (Table 1), the probability of observing a P value of 1.208 or larger on chance alone is 0.20. If these odds are judged likely, then the transfer predictions are interpreted to be similar to site-specific predictions within random variability. If not, the transfer hypothesis is not supported, or if possible, the transfer model will need to be modified. For the Hydric Dystrandepts, improved transfer predictions can be achieved by introducing a season variable for applied N, and by subdividing the relatively large range of soil P into two or three segments with subsequent fitting of relationships within each segment (Cady et al., 1982).

The procedure for calculating the probability level of a P statistic value is computationally tedious. An alternative is the standardized statistic (Chapter 5)

$$(k-1)^2 k^{-2} d(P-1) - 2m$$

where k is the number of sites, d is the number of degrees of freedom in the pooled residual mean square, and m is the total number of interactions between the five response surface model terms and uncontrolled site variables. This statistic has approximately a chi-square distribution with $(k-1)p - m$ degrees of freedom where p is five, or in general, the number of variables in the estimated transfer model ignoring the interaction terms.

For the Typic Paleudults the calculated value of the standardized statistic is

$$(23)^2(24)^{-2}(792)(1.166-1) - 2(12) = 96.74$$

with $(24-1)(5) - 12 = 103$ degrees of freedom. Tables of the chi-square distribution, or a procedure from SAS (1982), may be utilized for finding the probability of observing a P statistic value of 96.74 or larger on chance alone as 0.65 (or 0.08 for the Hydric Dystrandepts with d = 544). Differences between true and approximate probabilities decrease as number of sites increase. With fewer sites the approximation will tend to underestimate the true probability level as occurred with the Hydric Dystrandepts (Liu and Wood, 1985).

*Comparison of transfer and site-specific yield response predictions.* The P statistic is a single summary statistic and, with the probability level, gives an overall evaluation of transfer. The closeness of the transfer and site-specific predicted values is reflected in the form of a ratio and does not

show directly a measure of the difference between transfer predictions and site-specific predictions in units of kg/ha.

If the predicted yield responses for each site are plotted against both dimensions of applied P and N, then the response surface for the estimated transfer model can be graphically compared with the site-specific response surface. Numerically, the actual magnitudes of the differences between the site-specific predictions, based on site-specific data, and the transfer predictions, based on data from other sites, are given in Tables 3 and 4. The tabular values are absolute differences in units of kg/ha, averaged over combinations of applied P and N.

More specifically, the increase in predicted yield from a specified P application can also be calculated. Transfer predicted yield responses can be compared with those from site-specific data. Given in Tables 3 and 4 are predicted yield increases (kg/ha) from a P application of 60 kg/ha relative to a P application of 20 kg/ha. The magnitude of the

**Table 3. Site-specific and transfer P response predictions (kg/ha) and differences (kg/ha) for Hydric Dystrandepts.**

| | Average absolute difference | | Applied P yield response predictions | | |
|---|---|---|---|---|---|
| Site | Intra-family | Inter-family | Site-specific | Transfer | Difference |
| BURB | 210 | 276 | 1302 | 1175 | 127 |
| BURD | 72 | 169 | 1267 | 1322 | -55 |
| IOLE | 117 | 158 | 126 | 175 | -49 |
| IOLK | 186 | 141 | | | |
| ITKC | 214 | 255 | 291 | 75 | 216 |
| ITKD | 168 | 108 | 30 | 368 | -338 |
| ITKE | 152 | 182 | 278 | 212 | 66 |
| LPHE | 139 | 209 | 520 | 412 | 108 |
| LPHG | 61 | 167 | 216 | 273 | -56 |
| PALE | 159 | 391 | 2352 | 2482 | -130 |
| PALF | 214 | 245 | 1624 | 1887 | -263 |
| PALG | 149 | 413 | 2050 | 1918 | 133 |
| PLPG | 247 | 178 | 76 | 198 | -122 |
| PUCK | 165 | 256 | 1171 | 1021 | 150 |
| PUCR | 210 | 432 | 1473 | 1178 | 295 |
| PUCS | 224 | 458 | 1651 | 1729 | -78 |
| Average: | 168 | 253 | | | |
| Range: | 61–247 | 108–458 | | | |

Note: Each average absolute difference between transfer predictions and site-specific mean predictions (kg/ha) was averaged over 121 grid points formed by combinations of 11 equally spaced lines for both applied P and N. The intra-family (inter-family) differences were based on Model 2 of the Hydric Dystrandepts (Model 3 of the Typic Paleudults). The yield response prediction is the predicted response to a 60 kg P application compared with a 20 kg P application based on transfer Model 2 for the Hydric Dystrandepts with 108 kg N/ha. Predictions were not calculated if the site-specific response curve in the range of 20 to 60 kg P application was not realistic.

**Table 4. Site-specific and transfer P response predictions (kg/ha) and differences (kg/ha) for Typic Paleudults.**

| | Average absolute difference | | Applied P yield response predictions | | |
|---|---|---|---|---|---|
| Site | Intra-family | Inter-family | Site-specific | Transfer | Difference |
| BAKA | 132 | 229 | 1221 | 1262 | -41 |
| BAKC | 150 | 262 | 1250 | 1206 | 44 |
| BAKE | 205 | 307 | 611 | 585 | 26 |
| BAKF | 258 | 318 | 519 | 714 | -195 |
| BPMA | 108 | 359 | 1334 | 1334 | 0 |
| BPMC | 200 | 635 | 1144 | 1475 | -331 |
| BPMD | 142 | 655 | 2059 | 2216 | -157 |
| BUKC | 114 | 440 | 1459 | 1189 | 270 |
| BUKD | 313 | 667 | 1710 | 1166 | 544 |
| BUKE | 225 | 575 | 1830 | 2127 | -297 |
| BUKF | 183 | 403 | 988 | 662 | 326 |
| BUKG | 140 | 171 | 1838 | 1754 | 84 |
| BUKH | 290 | 239 | 2135 | 1635 | 500 |
| CAMA | 116 | 155 | 746 | 626 | 120 |
| CAMB | 69 | 209 | 134 | 162 | -28 |
| CAMC | 194 | 255 | | | |
| NAKA | 148 | 419 | 1685 | 1551 | 134 |
| NAKD | 140 | 522 | 1258 | 1079 | 179 |
| NAKJ | 100 | 597 | 2084 | 2126 | -42 |
| NAKN | 135 | 491 | 778 | 870 | -92 |
| NAKO | 269 | 251 | 2227 | 2230 | -3 |
| NAKP | 162 | 164 | 2350 | 2235 | 114 |
| SORA | 133 | 668 | 2189 | 2324 | -135 |
| SORB | 280 | 599 | 1788 | 1859 | -71 |
| Average: | 175 | 400 | | | |
| Range: | 69-313 | 155-668 | | | |

Note: Each average absolute difference between transfer predictions and site-specific mean predictions (kg/ha) was averaged over 121 grid points formed by combination of 11 equally spaced levels for both applied P and N. The intra-family (inter-family) differences were based on Model 2 of the Typic Paleudults (Model 2 of the Hydric Dystrandepts). The yield response prediction is the predicted response to a 60 kg P application (108 kg N) compared with a 20 kg P application based on transfer Model 2 for the Typic Paleudults. Predictions were not calculated if the site-specific response curve in the range of 20 to 60 kg P application was not realistic.

average absolute differences, and also the differences in applied P yield response predictions, are sufficiently small in general so that the transfer predictions could be used in practice even if a site-specific experiment had not been carried out.

## Inter-family Transfer of Yield Response to P and N Fertilization

An interesting auxiliary question is whether an estimated transfer model, based on data from one soil family, could effectively predict yield

response for another family. A summary statistic analagous to the intra-family transfer or prediction P statistic, is the ratio of the sum of the transfer sums of squares for each family to the sum of the site-specific sums of squares. The distribution of this inter-family transfer statistic is known for the case of two soil families where a common transfer model has been formulated (Wood, 1980).

Transfer Model 2 of the Hydric Dystrandepts and Model 3 of the Typic Paleudults include the terms for a second order response surface for applied P and N plus seven interaction terms, SOILP and SOILPH with P, SOILP with $P^2$, SOILN with N and $N^2$, and SOILP and SOILN with PN. Based on the data from each family, a family transfer model is estimated and used to predict yield response to applied P and N for environments of the other soil family. The inter-family transfer sums of squares are given in Tables 1 and 2. Then, the inter-family prediction statistic is calculated as

$$\frac{2854 + 6867}{1988 + 4055} = 1.6097$$

The probability of observing a value of 1.6097 or larger on chance alone is less than 0.001. The actual magnitude (kg/ha) of the absolute differences between the site-specific predictions and the inter-family predictions, averaged over combinations of applied P and N, have been calculated and are presented in Tables 3 and 4. Based on the inter-family prediction statistic and as evidenced by the average absolute difference between transfer and site-specific response surfaces, inter-family transfer of applied P and N is not supported.

The major component of the estimated inter-family transfer models in determining the magnitude of yield response is the linear response to applied P as influenced by the level of soil phosphorus. This relationship is shown in Figure 2, where site-specific P linear responses are plotted against the reciprocal of SOILP as measured by Truog. The figure reflects a larger P linear response for the Hydric Dystrandepts at almost all soil P values and the difference between the two lines is increasing with decreasing Truog values. The two estimated straight lines (with standard errors of the coefficients) are

$$\underset{(74)}{0.9276} + \underset{(544)}{8966}(1/\text{SOILP})$$

for the Hydric Dystrandepts and

$$\underset{(203)}{43.59} + \underset{(913)}{6084}(1/\text{SOILP})$$

for the Typic Paleudults. The difference in the slopes of the relationship between P linear response and the reciprocal of soil P can be statistically evaluated and are statistically different ($p < 0.05$).

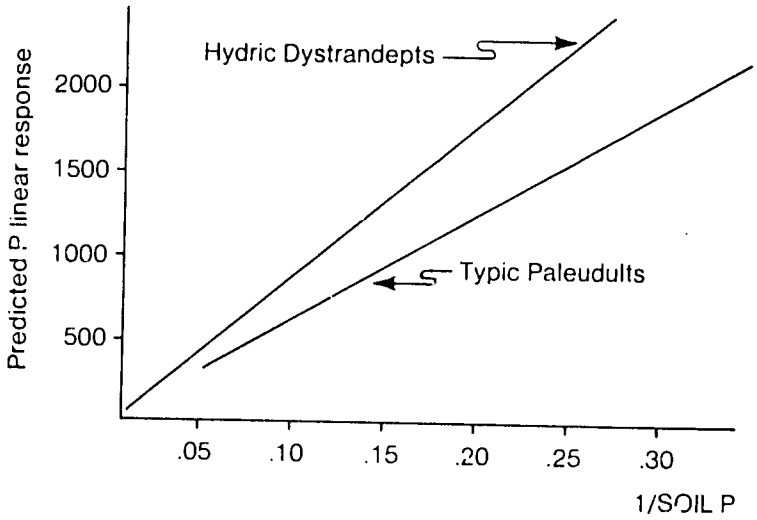


**Fig. 2.** Estimated relationship between site-specific P linear responses and the reciprocal of SOILP. The slopes for the two lines are 8966 kg/ha (Hydric Dystrandepts) and 6084 (Typic Paleudults). Differences in the predicted P linear response between the two soil families are 246 and 678 kg/ha for 1/SOILP values of 0.10 and 0.25, respectively.

The applied P and N treatment design of the Hydric Dystrandepts and Typic Paleudults was also used in Hawaii on a third soil family, the Tropeptic Eutrustox. The range and distribution of SOILP values for 12 Tropeptic Eutrustox experiments was not sufficient to estimate a Tropeptic Eutrustox transfer model and quantitatively evaluate intra- and inter-family transfer. However, estimated transfer models for the Hydric Dystrandept and Typic Paleudult families were used to predict yield response for the 12 experiments on the Tropeptic Eutrustox. Table 5 compares site-specific sums of squares with inter-family transfer sums of squares.

The ratios of inter-family transfer residual sum of squares to site-specific residual sum of squares vary from 1.1 to 6.5 (Table 5). Larger ratios are associated with sites with large yield response to applied P or N. Based on these ratios, and the average absolute differences between transfer and site-specific predictions, yield response to applied P and N from the Hydric Dystrandepts and Typic Paleudults generally cannot be transferred to the Tropeptic Eutrustox soil family.

**Table 5. Site-specific and inter-family transfer residual sums of squares (x10⁴) and transfer P response predictions.**

| Site | Site-specific | Inter-family transfer H.D. | Inter-family transfer T.P. | Average absolute difference H.D. | Average absolute difference T.P. |
|---|---|---|---|---|---|
| MOLA | 110 | 164 | 175 | 509 | 521 |
| MOLB | 196 | 390 | 357 | 854 | 814 |
| MOLJ | 93 | 125 | 115 | 451 | 424 |
| MOLL | 244 | 299 | 268 | 710 | 650 |
| MOLM | 46 | 131 | 92 | 485 | 384 |
| MOLN | 160 | 228 | 277 | 591 | 628 |
| MOLR | 244 | 371 | 401 | 760 | 795 |
| WAIA | 132 | 185 | 207 | 574 | 620 |
| WAIB | 105 | 215 | 189 | 617 | 592 |
| WAID | 167 | 259 | 242 | 537 | 507 |
| WAIF | 130 | 603 | 561 | 1059 | 1031 |
| WAIG | 70 | 458 | 401 | 863 | 796 |
| Total | 1697 | 3428 | 3285 | | |

Note: Model 3 of the Hydric Dystrandepts (H.D.) and Model 4 of the Typic Paleudults (T.P.) from Table 6 were used for the inter-family transfer predictions of Tropeptic Eustrustox sites. Each average absolute difference between transfer and site-specific mean predicitons (kg/ha) was averaged over 121 grid points formed by combination of 11 equally spaced levels for both applied P and N.

## Soil-based Technology Transfer for Applied P and N

Previous sections have demonstrated the feasibility of within-soil-family transfer of applied P and N. At identified new sites it is possible to predict yield responses to applied P and N without carrying out an experiment at each site. The new sites may or may not be from the same country or from countries where Benchmark Soils Project sites were located. The important element is that the new sites have been identified as belonging to a specified soil family and that a preplant soil sample is available.

For example, suppose that yield response predictions to applied P and N are needed for a newly identified Typic Paleudult site. From the Benchmark data, an estimated Typic Paleudult transfer model is available. Three steps are then followed.

1. Based on preplant soil samples, the Truog extraction curve (Chapter 4) including Truog with no P added, extractable N, and bulk density are determined.

2. The preplant sample information is converted into P code (PCODE) and N code (NCODE) scales for direct input in the estimated transfer model for prediction.

3. Yield response is predicted for the new site from the estimated transfer model.

As the first example, consider the question, what will be the addi-

tional yield response of 60 kg/ha of applied P compared to a 20 kg/ha application? An applied N level of 108 kg/ha will be used. The following sequence of steps is outlined.

1. From the preplant soil sample information, suppose that the extractable Truog is 4, the extraction curve is PADDED = -30 + 16*SQRT(TRUOG), where SQRT is square root, the extractable N is 4, and the bulk density (BD) is 1.0.

2. a. Convert the 20 and 60 kg/ha to ppm by

$$\text{ppm} = 20/(1.5*1.0) = 13.33$$
$$\text{and ppm} = 60/(1.5*1.0) = 40$$

where 1.5 is the conversion constant and BD = 1.0.

b. For convenience, the range of the PCODE scale is from -1 to +1. A PCODE of -1 corresponds to a PADDED of 0 ppm, and a PCODE of +1 corresponds to a TRUOG of 25. Then, PADDED at TRUOG = 25 is

$$-30 + 16*\text{SQRT}(25) = 50 \text{ ppm}$$

Using linear interpolation, 40 ppm (60 kg/ha application) corresponds to a PCODE = 0.6. Algebraically,

$$\text{PCODE} = -1 + (1/25)(\text{PADDED})$$

Similarly, 13.33 ppm (20 kg/ha application) corresponds to a PCODE of (13.33 - 25)/25 = -0.47.

c. In the Benchmark Soils Project, each experiment in the Typic Paleudult soil family received the same rates of applied N. An applied N level of 108 kg/ha corresponds to an NCODE of 0.

d. In the Benchmark Soils Project, extractable N (EXTN) was determined with a 2N KCl extractant. However, the SOILN variable used in the transfer model was based on a crop-modeled value as described in an earlier section because of problems with extractable N determinations for certain sites. Based on Benchmark data, a relationship between SOILN and EXTN was calculated to be SOILN = 2.35 EXTN. For an EXTN value of 4, SOILN is equal to 9.4.

e. From the previous steps we have the two PCODE values corresponding to the 20 and 60 kg/ha P application rates, an NCODE value corresponding to the 108 kg/ha N application, a TRUOG or SOILP value of 4 (or 1/SOILP = 0.25), and SOILN = 9.4. We also need to calculate the PCODE and NCODE values for the quadratic P and N terms in the transfer model. From Cady et al. (1982),

$P^2$ = PCODE (P quadratic) = $(PCODE)^2 - (4.975/13)$ and
$N^2$ = NCODE (N quadratic) = $(NCODE)^2 - BP^2 - (4.975/13)$

where B is a constant equal to 0.21535 and (4.975/13) is the average of the squared PCODE (or NCODE) values in the treatment design. Then,

$P^2$ = -0.0227 for PCODE = 0.6,
$P^2$ = -0.1618 for PCODE = -0.47,
$N^2$ = -0.3778 for PCODE = 0.6 and NCODE = 0, and
$N^2$ = -0.3478 for PCODE = -0.47 and NCODE = 0.

3. In Table 6 are the estimated coefficients for two Hydric Dystrandept transfer models (with and without a preplant pH value) and three Typic Paleudult transfer models. Model 2 of the Typic Paleudults utilizes interaction variables between P linear (and P quadratic) and SEASON, VARIETY, and SEASON•VARIETY. In the intra-family transfer evaluation these interaction variables pertained only to specific experimental circumstances in the Sumatra sites and, hence, should not be included in the family prediction equation in general. Models 3 and 4 do not include these interaction variables; the difference between Models 3 and 4 is the inclusion (Model 3) or exclusion (Model 4) of the

**Table 6. Soil family estimated transfer model coefficients.**

| | Hydric Dystrandepts | | Typic Paleudults | | |
|---|---|---|---|---|---|
| Variables | Model 2 | Model 3 | Model 2 | Model 3 | Model 4 |
| P | 3129 | 0.9276 | -4.859 | 1276 | 43.59 |
| N | 1163 | 1163 | 1293 | 1293 | 1293 |
| $P^2$ | -143.6 | -143.6 | 327.9 | 243.1 | 243.1 |
| $N^2$ | -742.1 | -742.1 | -686.8 | -686.8 | -686.8 |
| PN | 213.6 | 213.6 | 95.14 | 95.14 | 95.14 |
| P•1/SOILP | 9483 | 8966 | 6063 | 5361 | 6084 |
| P•SOILPH | -736.0 | | | -242.9 | |
| P•SEASON | | | 273.9 | | |
| P•VARIETY | | | 121.1 | | |
| P•SEASON•VARIETY | | | 211.7 | | |
| N•SOILN | -52.81 | -52.81 | -62.38 | -62.38 | -62.38 |
| $P^2$•1/SOILP | -8441 | -8441 | -7871 | -7695 | -7695 |
| $P^2$•SEASON | | | -224.6 | | |
| $P^2$•VARIETY | | | -69.62 | | |
| $P^2$•SEASON•VARIETY | | | -321.4 | | |
| $N^2$•SOILN | 31.15 | 31.15 | 20.99 | 20.99 | 20.99 |
| PN•1/SOILP | 2178 | 2178 | 2621 | 2621 | 2621 |
| PN•SOILN | -21.13 | -21.13 | -22.29 | -22.29 | -22.29 |

preplant pH (SOILPH) interaction variable, a term important in the Hydric Dystrandepts.

Using Model 2, with a value of 0 for SEASON and VARIETY, the difference between the predicted yields at 20 and 60 kg/ha P application is 1403 kg/ha, whereas for Models 3 and 4, the predicted differences are 1434 and 1455 kg/ha, respectively.

The preceding example required the extraction curve for the new site. If existing laboratory and field data are available for a soil family, yield response to applied P and N can be predicted for a new site without determination of the extraction curve. The calculations follow a sequence of five steps.

1. The Truog extraction curve is expressed as

$$\text{P-added} = A + B[\text{SQRT}(X)]$$

where SQRT(X) is the square root of P-extracted (ppm) as determined by the modified Truog extraction procedure, and A and B are the intercept and slope, respectively, of the estimated straight-line relationship. With no P-added, the SQRT(X) is equal to the negative value of the ratio of A to B, and is a calculated measure of the square root of soil P (SOILP). When (−A/B) is plotted against the square root of SOILP, as determined directly in the laboratory, the expected straight-line relationship with zero intercept and a slope of one is supported by the data from the 24 Typic Paleudult sites used in the transfer evaluation. The estimated slope of the line through the origin is 1.05 with a standard error of 0.0287.

2. Within a soil family, the individual site extraction curves are expected to have a common slope (B value) but different intercepts (A values). In addition, the intercepts should be linearly related to SOILP. For the Typic Paleudults, this straight-line relationship, estimated by regressing the intercept on SOILP for 24 sites, is

$$\underset{(12.03)}{A = 41.66} - \underset{(4.711)}{45.466} * \text{SQRT(SOILP)}$$

where the values in the parentheses are estimated standard errors. For a given SOILP value, a soil family A value may be calculated. The expectation that the individual site extraction curves would have a common slope (B value) is not supported by the data from the 24 Typic Paleudult sites. The B value depends on SOILP. The relationship may be estimated, or alternatively, a soil family B value for a given SOILP value may be calculated from the relationship developed in step 1,

$$-(A/B) = \text{SQRT}(X) = \text{SQRT(SOILP)}$$

Soil family extraction curves for selected SOILP values are estimated as

| SOILP | A | B |
|---|---|---|
| 4 | -49.26 | 24.63 |
| 8 | -86.92 | 30.73 |
| 16 | -140.18 | 35.05 |

3. With the assumption that a SOILP value of 25 corresponds to a PCODE value of one and by substituting 25 into each of the above Typic Paleudult extraction curves, P-added values at a PCODE of one are calculated. Dividing these values by two will give P-added values at a PCODE of zero. For the same selected values of SOILP,

| | P-added (ppm) | |
|---|---|---|
| SOILP | PCODE = 1 | PCODE = 0 |
| 4 | 73.89 | 36.94 |
| 8 | 66.73 | 33.37 |
| 16 | 35.05 | 17.52 |

4. PCODE values for various P-added values may then be calculated by linear interpolation. For example, PCODE for a P-added value of 10 is (10 - 36.94)/36.94 = -0.73. The following table can be calculated.

| | PCODE | | |
|---|---|---|---|
| P-added (ppm) | SOILP = 4 | SOILP = 8 | SOILP = 16 |
| 10 | -0.73 | -0.70 | -0.43 |
| 20 | -0.45 | -0.40 | 0.14 |
| 30 | -0.18 | -0.10 | 0.71 |
| 40 | 0.08 | 0.20 | 1.28 |
| 50 | 0.35 | 0.50 | |
| 60 | 0.62 | 0.80 | |
| 70 | 0.89 | 1.10 | |

Similarly, values of P-added can be calculated for preselected values of PCODE. For example,

| | P-added (ppm) | | |
|---|---|---|---|
| PCODE | SOILP = 4 | SOILP = 8 | SOILP = 16 |
| -0.85 | 5.5 | 5.0 | 2.6 |
| -0.40 | 22.2 | 20.0 | 10.5 |
| 0 | 36.9 | 33.4 | 17.5 |
| 0.40 | 51.7 | 46.7 | 24.5 |
| 0.85 | 68.4 | 61.7 | 32.4 |

Rates of applied P in kg/ha for a given site can then be calculated as the product of P-added (ppm), 1.5 and the soil bulk density.

5. Yield response to various levels of applied P and N can be predicted using the same methodology as the previous example of this section. The resulting yield response surfaces, based on Model 2 of the Typic Paleudults (Table 6), are shown in Figure 3 for SOILP values of 4, 8, and 16 ppm, and SOILN values of 4 and 20 ppm.

## Development of a Transfer Model for Agrotechnology Transfer

Transfer of fertilizer N and P rates is presented in the previous section using the transfer equations of the Benchmark Soils Project. The key requirement, in addition to soil classification according to Soil Taxonomy, is a measure of soil N and soil P at the site to which the technology is being transferred. Soil analytical methods should be the same as those used in development of the transfer equation since its coefficients are for the specific analytical method employed.

In general, if one wishes to develop and estimate a model for transfer of crop response to one or more experimentally controlled management factors in a particular agricultural area, the following steps must be observed.

1. From an available soil survey and on-site reconnaissance, select a soil that is representative of the major soil in the area that will serve as a benchmark soil.

2. Classify this soil to the family level according to Soil Taxonomy.

3. Identify other areas in the same soil family that have a range of characteristics for the family and select experimental sites.

4. Determine soil levels of critical nutrients for each experimental site using standard analytical methods.

5. Conduct similar experiments with the same management factors and specific crop at each experimental site. Measure other limiting factors at each site and incorporate their effects on the yield response-controlled factors relationship into the transfer function. Otherwise, any potentially limiting factors are experimentally maintained at levels opti-

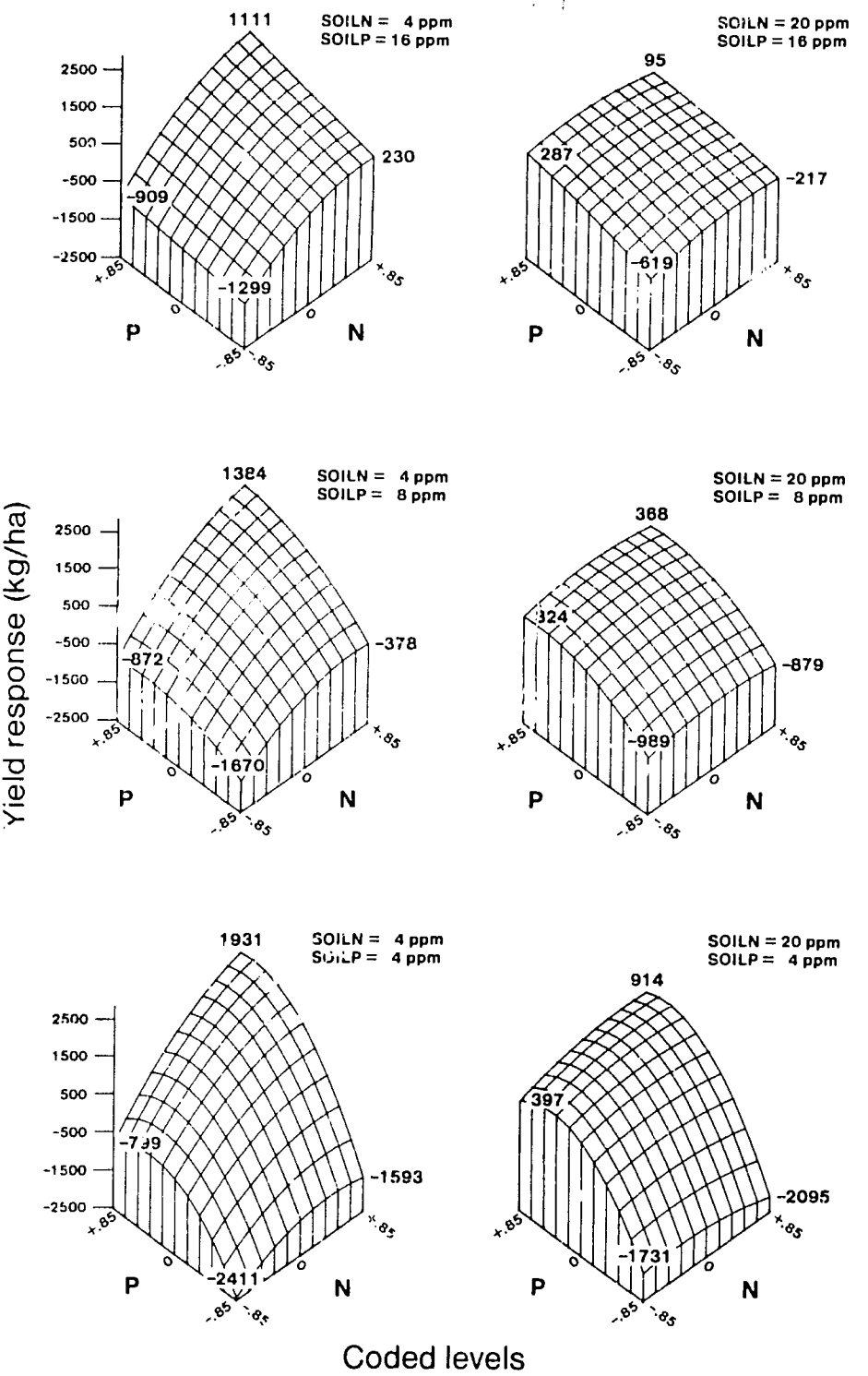


Fig. 3. Predicted yield response to applied P and N.

mal for crop growth. General crop and plot management of the experiments should be similar at all sites to prevent other factors from influencing yield. Weather conditions at sites are monitored to quantify environmental conditions affecting crop growth. The occurrence and severity of damage from insects, diseases, and other pests also need to be recorded.

6. Estimate a yield response prediction (transfer) equation with combined data from the sites. Include in the equation variables for the controlled factors, and uncontrolled but measured environmental variables such as soil or weather which interact with the controlled factors.

7. Evaluate the predictive ability of the transfer equation using the transfer evaluation methodology developed in the previous chapter.

8. The resulting transfer equation may be used to transfer yield response to other areas of the same soil family.

In developing a transfer model for a soil family, sufficient experimental sites must be selected to cover the range of conditions within the soil family. Environmental factors such as temperature, rainfall, and solar radiation, and soil characteristics such as particle size, parent material, and mineralogy can vary within a soil family and can have measureable effects on crop response to certain management practices. Proper selection of experimental sites will result in a transfer equation which is applicable over the range of conditions within a soil family. On the other hand, if a transfer equation is developed from experiments on sites representing a limited range of conditions for the soil family, it may predict very well for similar sites, but very poorly for sites of the same family with characteristics not included in the range of conditions sampled.

Innovations such as the introduction of a new variety may be transferred on the basis of experiments on a limited number of sites so long as the sites represent the major environmental and soil factors of the area to receive the variety. Crop growth requirements generally cross soil family boundaries and there is a range of soil conditions over which a crop can grow well. This can include several soil families, all having the essential land qualities for that crop as implied by the concept of the sphere of transferability (Chapter 1).

The outlined procedure for transferring agrotechnology can differ in the amount of information required and the precision of the prediction. For example, a simpler analogue procedure would include the experimental phase but not measurement and modeling of the uncontrolled variables. Either procedure generates a set of recommendations for the improved management practices. These recommendations are not necessarily the final answer to the problem, but serve as first approximations to the optimum management practices. It is expected that some modification will be necessary to adjust for site-specific conditions as well as for the availability of required resources. However, the agrotech-

nology transfer will have achieved the initial increase in yield and moved production from its position on a low yield plateau. The "fine tuning" needed should require considerably less time and other resources than that needed for a large site-specific experimentation program. This will bring about an acceleration of the increase in production with its resulting influence on a country's economic and social condition.

## References

Allen, D. M., and F. B. Cady. 1982. Analyzing experimental data by regression. Van Nostrand Reinhold, New York.

Cady, F. B., C. P. Y. Chan, C. L. Garver, J. A. Silva, and C. L. Wood. 1982. Quantitative evaluation of agrotechnology transfer: A methodology using maize response to phosphorus on Hydric Dystrandepts in the Benchmark Soils Project. HITAHR Res. Series 015 (BSP Tech. Rept. 6). Hawaii Inst. of Trop. Agr. and Human Resources, College of Trop. Agr. and Human Resources, Univ. Hawaii.

Cochran, W. G., and G. M. Cox. 1957. Experimental designs. John Wiley and Sons, Inc., New York.

Dean, L. A. 1954. Yield-of-phosphorus curves. Soil Sci. Soc. Am. Proc. 18: 462–466.

Liu, J. P., and C. L. Wood. 1985. Approximations to the distribution of the prediction statistic. Tech. Rept. 242. Univ. Kentucky.

SAS Institute, Inc. 1982. SAS user's guide. Statistical Analysis System Institute, Inc., Cary, North Carolina.

Wood, C. L. 1980. On inter-family transfer of agrotechnology. Tech. Rept. 125. Univ. Kentucky.

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

*Matching Maize Requirements to the Agroenvironment*

# 7 Agroenvironments for Maize Production

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Breeding programs that permit adaptation of the maize (*Zea mays* L.) genotype to specific environments make it possible to produce maize from the equator to near 50 degrees north or south latitude. To match maize requirements to agroenvironments is not, however, a simple task. The first step is to categorize the range of ecological, climatic, and edaphic environments—or environmental niches—in which it is possible to grow maize. In the Benchmark Soils Project, the soil family category of Soil Taxonomy defined these niches. This chapter relates the soil-climate characteristics and soil properties used in the definition of soil taxa to maize performance across the three tropical soil family network of the Benchmark Soils Project.

Climate was incorporated into the definitions of the taxa of Soil Taxonomy as soil moisture and soil temperature regimes. The importance of these soil-climate regimes in a multicategorical classification system such as Soil Taxonomy is evidenced by the use of soil moisture regimes to define taxa at the order level in the case of the Aridisols and of most suborders of all other orders. According to Smith (Leamy, 1984), the use of soil moisture and soil temperature regimes was a natural substitute for the concept of zonal and intrazonal soils since neither was based on soil properties and, hence, neither would be tenable in a natural classification system. Soil temperature regimes are used to define all soil family categories and some of the higher categories in Soil Taxonomy.

Not surprisingly, consideration of crop production strongly influenced the definition of both soil moisture and soil temperature regimes. The following are the definitions of the various soil moisture and soil temperature regimes in Soil Taxonomy.

## Soil Moisture Regimes

There are seven soil criteria that are elements of five quantitatively defined soil moisture regimes in Soil Taxonomy (Soil Survey Staff, 1975). Probability values of the three soil water states—dry, moist, and wet—are computed in percentages to determine the aquic, paraquic, udic, perudic, ustic, xeric, and aridic/torric soil moisture regimes. A

soil is considered dry if the amount of extractable or available water is zero at a suction or tension of 15 bars or more. This value corresponds to the early concept of the permanent wilting point used by plant physiologists. A soil is considered wet if water is held by the soil under a positive pressure or zero tension, i.e., a water-saturated soil. A soil is considered moist if water can be extracted from a confined soil sample with a tension between 0 and 15 bars. The amount of water available for the plant to extract, however, varies with soil properties.

The number of days that each of these water states exists in a given soil within a specified depth provided a basis for defining soil moisture regimes. Generally, most soils alternately have all three states over a period of time. Some soils, however, are predominantly wet or dry. The specified depth within a soil profile that is used to determine the water content is referred to as the soil moisture control section and is described in detail in Soil Taxonomy. The definitions of the soil moisture regimes listed below are simplifications of those compiled by Beinroth (1983).

*Soil water tension equal to 0*

AQUIC — In most years, the soil is saturated with oxygen-depleted water at some season of biologic activity, but the water table may be lower in another season.

*Soil water tension between 0 and 15 bars*

UDIC — In most years, the soil moisture control section is never dry in any part for as long as 90 cumulative days, but it is not aquic.

USTIC — In most years, the soil moisture control section is dry in some part for more than 90 cumulative days, but it is dry for less than half the growing season in all parts in the temperate or middle latitudes. In the tropics or lower latitudes, the moisture control section is moist in some part for more than 90 consecutive days in most years, but may be dry in all parts for more than 90 days, or even for more than 180 days, cumulative.

XERIC — In six or more years out of 10, the moisture control section is continuously moist for more than 45 days in all parts in winter and is continuously dry in all parts in summer for more than 45 days, and the soil temperature is thermic, mesic, and frigid. This regime is restricted to temperate conditions.

*Soil moisture tension greater than 15 bars*

ARIDIC/TORRIC In most years, the soil moisture control section is dry in all parts more than half the growing season and is not moist in some part for as long as 90 consecutive days during the growing season.

## Soil Temperature Regimes

Soil Taxonomy defines and describes ten soil temperature regimes. Reported mean annual soil temperature values are representative of temperatures at a depth of 50 cm. Where directly measured values over a period of years are unavailable, a fairly reliable estimate can be made from the mean annual air temperature. Because there is a direct relationship between the mean annual air temperature and the soil temperature at 50 cm, the mean annual soil temperature can be estimated by adding 1 °C to the mean annual air temperature. At this depth, diurnal fluctuations are minimized and the influence of seasonal changes can be measured.

Definitions for each regime were determined from experiences and observations of the growing period of major agricultural crops. For instance, the 8 °C and 22 °C isotherms represent the range of temperature for production of small grains in the central and mid Western areas of the United States, commonly referred to as the corn belt. The limit of 22 °C in the eastern part of the United States separates the citrus and the winter vegetable belts.

For crop production in most temperate areas, there is a distinct and measurable temperature difference between summer and winter. Soil temperature regimes for which the mean winter and summer temperatures differ by more than 5 °C are categorized in Soil Taxonomy as

| Regime | Mean annual soil temperature |
|---|---|
| Pergelic | < 0 °C (permafrost or dry frost is present) |
| Cryic | 0 °C to 8 °C |
| Frigid | 0 °C to 8 °C (warmer than cryic summer temperatures) |
| Mesic | 8 °C to 15 °C |
| Thermic | 15 °C to 22 °C |
| Hyperthermic | >22 °C |

The latter three are those of interest for agricultural planning and development in both temperate and tropical locations. In tropical and subtropical areas, where the mean winter and summer soil temperatures generally do not differ by more than 5 °C, the iso prefix is added to

the nomenclature of the warmer temperature regimes. Cold and warm temperatures associated with winter and summer have no meaning in the tropics. Instead, wet and dry seasons appear more appropriate where such distinct seasons occur. The extent of the wet and dry seasons affects crop production in the tropics whereas the period of frost to frost determines the growing season in temperate areas.

## Moisture and Temperature Regimes of the Three Soil Families

The soil moisture and soil temperature regimes of the three soil families studied by the Benchmark Soils Project are part of their taxonomic nomenclature. There are two soil moisture regimes—the udic and the ustic—and two soil temperature regimes—the isothermic and the isohyperthermic—among the three soil families. The key words for soil moisture regimes in the nomenclature are Hydric and Paleudults for the udic and Eutrustox for the ustic moisture regimes. Simply stated, the soil moisture and soil temperature regimes of the three soil families can be expressed as being (1) moist and cool for the Hydric Dystrandepts, (2) dry and warm for the Tropeptic Eutrustox, and (3) moist and warm for the Typic Paleudults. The latter would correspond to the conditions of the humid tropics, while the others would correspond to conditions of the tropical uplands and savannas, respectively.

Rainfall and temperature records collected at each of the sites are summarized in graphical form and are presented in the following sections according to soil family. Because the Benchmark Soils Project soil family network extended over country boundaries, the data sets have been summarized by soil family and country. These records were collected from 1976 through the close of field activities in 1983.

Table 1 is a summary of mean daily values of weather data recorded at each site over a number of years by soil family. Air temperature, relative humidity, wind speed, wind direction, and rainfall were collected with a battery-operated weather station. Supplementary rainfall and maximum and minimum temperature data were also collected as a back-up during any period of mechanical failure. Global solar radiation data were measured and recorded with a silicon pyranometer sensor and mechanical integrator. Weather data summaries by experiment are reported elsewhere (Benchmark Soils Project, 1979; 1982); daily weather data are maintained on tape.

In this and the following section of this chapter, we will review the recorded data in relation to both the soil moisture and soil temperature regimes as designated in the classification of soils by criteria established in Soil Taxonomy. In addition, we will consider the appropriate use of wet and dry seasons in describing the planting seasons of the transfer experiments.

*Hydric Dystrandepts: isothermic, udic regime.* The nine experimental sites

**Table 1. Summary of mean daily weather variables, latitude, and elevation of the Benchmark Soils Project's sites.**

| Site | Years | TMAX (°C) | TMIN (°C) | TAVG (°C) | RH (%) | SOLAR (ly/day) | WIND (km/hr) | LAT (deg) | ELEV (m) |
|---|---|---|---|---|---|---|---|---|---|
| **Hydric Dystrandepts** | | | | | | | | | |
| *Hawaii* | | | | | | | | | |
| HAL | 5 | 24.2 | 16.7 | 20.5 | 80 | 407 | 10.8 | 20N | 500 |
| IOLE | 6 | 24.1 | 16.1 | 20.1 | 77 | 379 | 12.3 | 20N | 550 |
| KUK | 8 | 25.3 | 17.7 | 21.5 | 77 | 386 | 9.1 | 20N | 400 |
| *Indonesia* | | | | | | | | | |
| ITKA | 5 | 26.0 | 15.7 | 20.8 | 77 | 354 | 5.6 | 6S | 1280 |
| LPH | 5 | 27.2 | 16.3 | 21.7 | 81 | 337 | 3.7 | 6S | 1100 |
| PLP | 2 | 28.7 | 16.1 | 22.4 | 79 | 383 | 3.1 | 6S | 1250 |
| *Philippines* | | | | | | | | | |
| BUR | 6 | 28.6 | 21.2 | 24.9 | 81 | 318 | 10.6 | 13N | 425 |
| PAL | 6 | 31.2 | 21.4 | 26.3 | 78 | 325 | 6.0 | 13N | 300 |
| PUC | 7 | 31.2 | 21.6 | 26.3 | 78 | 341 | 7.6 | 13N | 350 |
| **Tropeptic Eutrustox** | | | | | | | | | |
| *Hawaii* | | | | | | | | | |
| MOL | 6 | 27.5 | 19.3 | 23.4 | 83 | 476 | 18.9 | 21N | 275 |
| WAI | 6 | 28.7 | 19.8 | 24.2 | 70 | 398 | 8.0 | 21N | 150 |
| *Brazil* | 3 | 31.7 | 16.4 | 24.1 | 67 | 421 | 1.9 | 15S | 510 |
| *Puerto Rico* | 3 | 29.3 | 20.3 | 24.7 | 73 | 424 | 4.5 | 18N | 130 |
| **Typic Paleudults** | | | | | | | | | |
| *Cameroon* | | | | | | | | | |
| BAK | 3 | 33.8 | 22.1 | 27.9 | 80 | 268 | 1.3 | 5N | 170 |
| CAM | 4 | 33.7 | 22.5 | 28.1 | 77 | 316 | 2.0 | 5N | 180 |
| *Indonesia* | | | | | | | | | |
| BUK | 5 | 34.0 | 22.0 | 28.0 | 68 | 431 | 4.5 | 3S | 200 |
| BPMD | 5 | 34.2 | [illegible] | 27.7 | 69 | 393 | 1.8 | 3S | 50 |
| NAK | 5 | 34.8 | [illegible] | 28.6 | 65 | 406 | 3.8 | 3S | 40 |
| *Philippines* | | | | | | | | | |
| DAV | 6 | 33.9 | 22.4 | 28.1 | 71 | 422 | 5.7 | 7N | 50 |
| SOR | 3 | 31.0 | 22.4 | 26.7 | 75 | 371 | 8.1 | 13N | 80 |

Note: For Brazil and Puerto Rico data represent three sites each in the area of Jaiba in Minas Gerais, Brazil, and Isabela, Puerto Rico. The weather variables include maximum, minimum, and average temperatures, relative humidity, solar radiation, and wind speed.

of the thixotropic, isothermic Hydric Dystrandept soil family network were situated on slopes of dormant or extinct volcanoes in insular geographic settings. There were three sites per country. In both the United States (Hawaii) and the Philippines, the three sites were in relatively closer physical proximity to one another than were those in Indonesia.

Mean annual temperatures recorded at each site are shown graphically by country in Figure 1. Sites in Hawaii and Indonesia have isothermic temperature regimes whereas sites in the Philippines have decidedly isohyperthermic regimes as their mean values are greater

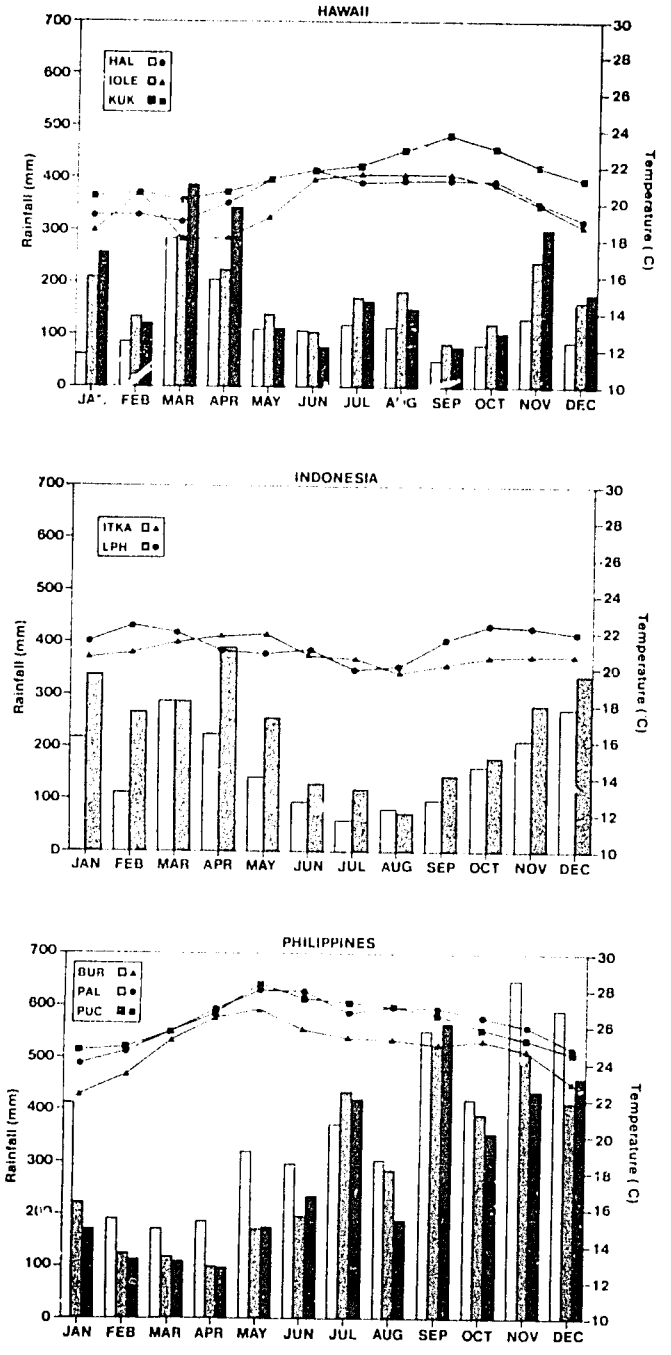


**Fig. 1.** Mean monthly rainfall and air temperatures for the Hydric Dystrandept network.

than 22°C. Temperature differences within a particular country were attributed to differences in elevation and position in the landscape and to both latitude and elevation among countries.

All nine sites were considered to be udic. Adequate rainfall distribution throughout the year prevented the soil moisture control section from becoming dry for more than 90 days in a year (Figure 1). The cumulative annual rainfall increased from less than 2000 mm for sites in Hawaii to more than 3000 mm for those in the Philippines. The range of cumulative rainfall values and its distribution throughout the year cannot be determined from the criteria for the udic moisture regime. Data collected from three geographic locations for this one family likely represents a range or sub-range within a family.

Transfer experiments were planted in both the wet and dry seasons. For the most part, the planting periods of May and June corresponded to the dry season in both Hawaii and Indonesia, but corresponded to the wet season in the Philippines. Similarly, the plantings during the period from late November to early January corresponded to the wet seasons in both Hawaii and Indonesia and the dry season in the Philippines. Interestingly, though, the Philippines and Hawaii are both in the northern hemisphere and Indonesia is in the south.

*Tropeptic Eutrustox: isohyperthermic, ustic regime.* Both sites in Hawaii were part of a network that included both Puerto Rico and Brazil. Data sets for these latter sites are reported by Beinroth (1982) in the Final Report of the University of Puerto Rico Benchmark Soils Project.

Recorded temperature and rainfall data over the six year period (Figure 2) indicate that both sites are in the isohyperthermic temperature range with an ustic moisture regime, where the soil moisture control

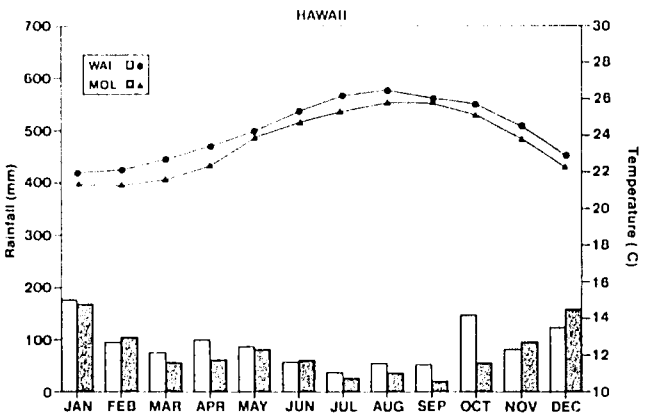


**Fig. 2.** Mean monthly rainfall and air temperatures for the Hawaii sites of the Tropeptic Eutrustox network.

section is dry in some or all parts for 90 days or more cumulative days in a year. This generally occurs from July to September.

There is a distinct temperature pattern for both locations. The wetter months also correspond to the relatively cooler periods of the year. With sufficient moisture and the prevailing tradewinds, the resulting cooler soil temperatures were adequate for potato production (Manrique et al., 1984). In almost all instances, potato production should be very poor or nonexistent in an isohyperthermic and ustic environment. From the data shown in Figure 2, temperature at both sites could be classified as thermic during the months from December to March and hyperthermic from April to November. The wet season corresponded to the thermic period and the dry season to the hyperthermic. The dry season of the Hydric Dystrandepts and Typic Paleudults were considerably wetter than the wet season of the Tropeptic Eutrustox.

*Typic Paleudults: isohyperthermic, udic regime.* Temperature data collected at each of the seven locations of the Typic Paleudult network (Figure 3) reflect the isohyperthermic regime of this soil family with values ranging from 25° to 30°C. Six of the seven sites were geographically situated in nearly similar latitudinal positions from the equator. The BUK, BPMD, and NAK sites in South Sumatra, Indonesia, were at latitude 3S; CAM and BAK in Cameroon were at 5N; the DAV site in the Philippines was at 7N; and the SOR site in the Philippines was located in southern Luzon at 13N. The low elevation of each site and their low latitudinal position likely contributed to the consistently warmer temperatures.

The mean annual temperatures of the seven Paleudult sites were very similar. However, the same isohyperthermic temperature regime of the Eutrustox family had a mean annual value of nearly 5°C lower than the Paleudults. Perhaps another temperature regime may be needed to distinguish sites with temperatures in excess of 22°C.

Rainfall distribution records (Figure 3) indicate that all seven sites have a udic moisture regime. Occurrence of wet and dry seasons were similar for the sites in the northern latitudes. The dry season in Cameroon, however, began in late October while that in the Philippines was generally in late December. The wet season usually started in May for both locations. The wet and dry seasons were at just the opposite time in Indonesia. As in the Dystrandept network, the rainfall distribution records and cumulative amounts of rainfall show the range of both within the udic moisture regime of this soil family.

## Weather: A Site Factor in Crop Response

The integrated effects of meteorological parameters on crop growth and development were considered components of the uncontrolled variables

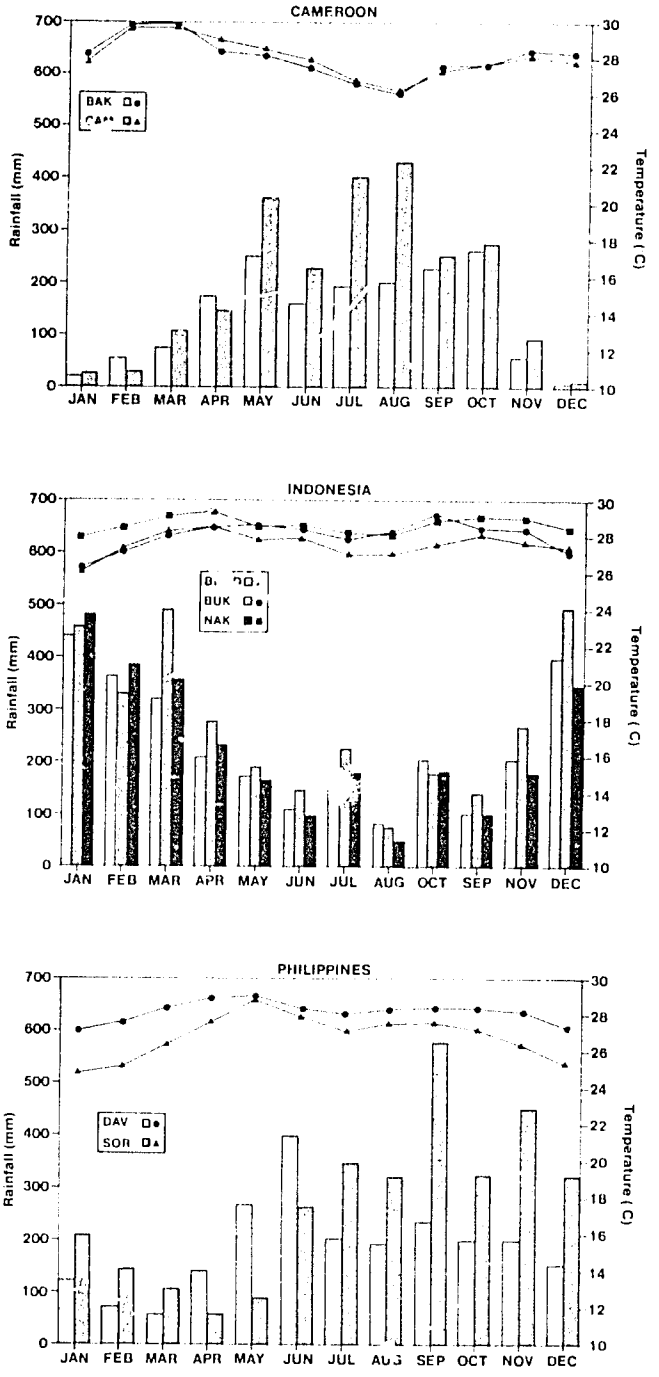


**Fig. 3.** Mean monthly rainfall and air temperatures for the Typic Paleudult network.

or site factors for a particular location. Meteorological data collected over an extended period of time are used to provide quantifiable values with which to define the climatic regimes at these locations. These statistics are useful in determining the moisture and temperature regimes associated with Soil Taxonomy, but they are not adequate for use in interpreting temporal effects of soil moisture and temperature on crop response. Climate is an important site factor in determining whether a particular crop may be grown with some degree of success in the location where the climatic data were collected. However, crops respond to weather and not to climate. The relatively short growing season of maize and most other food crops requires the monitoring and recording of daily meteorological phenomena or weather.

It is essential to remember, however, that information on soil climate can serve only to improve the selection of suitable crops and appropriate management alternatives. From the weather data presented in Figures 1 to 3, climate, and weather in particular, is a site factor in crop response and performance. The variable range of the weather parameters within a soil family network makes it a potentially important site factor to consider in the transfer process.

Both soil temperature and soil moisture were considered as uncontrollable site factors and important to the classification of soils at each site. However, the potential loss of experimental results due to lack of soil moisture weighed heavily in deciding to install a drip irrigation system to supplement rainfall at each experimental site. Hence, it was not possible to evaluate the effect of soil moisture regimes directly with crop performance in the transfer experiments. Therefore, in the planning and implementation of transfer experiments and in the interpretation of results from these experiments, soil moisture was assumed to be a nonconstraining variable during the growth and development of the maize crop. Extended droughts that severely limited sources of irrigation and intense storms were duly recognized in experiments affected by such natural phenomena. Wind as a site factor was not obvious in most experiments except in the instance of catastrophic events such as typhoons that devastated experimental sites in the Philippines.

At least two sets of transfer experiments were planted each year—one each in the wet and dry seasons. The effect of weather statistics as site factors can be better evaluated by examining both crop performance, e.g., grain yield, and crop efficiency, e.g., length of the growing season.

The average number of days to harvest for each soil family and sites within the family was obtained from summarized data reported earlier (Benchmark Soils Project, 1979; 1982). Harvest dates should not be confused with date of physiological maturity for the entire experiment. In most instances, those plots with higher input levels reached physiological maturity earlier than the control and low treatment plots. For

logistical reasons, harvest dates were scheduled when the low treatment plots were ready for harvest.

Intuitively, the dry season is comprised of those months with the greatest potential for plant growth with respect to available natural energy. Except for the Typic Paleudult sites in Indonesia (Table 2), all locations had higher grain yields in a shorter duration in the dry season. Lower dry season yields in South Sumatra were attributed to the shortage of water for irrigation.

The influence of both the soil moisture and soil temperature regimes during the growing seasons is shown by the earlier maturity date of the maize crop in the warm and moist agroenvironment of the Typic Paleudults (Table 2). More time was required for maize planted in the cooler Hydric Dystrandepts and the warmer Tropeptic Eutrustox. However, average yields in the latter ustic family were higher than in the other two udic family networks.

Days to maturity for maize within a family were less by a month or more for the Hydric Dystrandepts in the Philippines, the Tropeptic Eutrustox in Puerto Rico, and the Typic Paleudults in Cameroon. These locations had relatively higher mean minimum temperatures and rainfall than other sites within their respective soil family. Minimum and maximum temperatures in the Philippine sites were 3° to 5°C greater than those recorded in Hawaii and Indonesia.

**Table 2. Summary of the seasonal effects on the time of planting to harvest and average grain yields.**

| | | Dry | | Wet | |
|---|---|---|---|---|---|
| Site | Maize variety | Days to harvest | Average yield | Days to harvest | Average yield |
| **Hydric Dystrandepts** | | | | | |
| Hawaii | H610 | 150 | 8758 | 180 | 7418 |
| Indonesia | H6 | 150 | 6773 | 150 | 5115 |
| Philippines | UPCA-1 | 120 | 6052 | 127 | 4574 |
| **Tropeptic Eutrustox** | | | | | |
| Brazil | X304C | 150 | 7597 | 180 | 7514 |
| Hawaii | X304C | 150 | 9522 | 180 | 8858 |
| Puerto Rico | X304C | 120 | 8458 | 120 | 8183 |
| **Typic Paleudults** | | | | | |
| Cameroon | X304C | 90 | 6810 | 105 | 5707 |
| Indonesia | H6, X304C | 120 | 6178 | 135 | 7508 |
| Philippines | Tiniguib, X304C | 120 | 6652 | 120 | 6176 |

The influence of both sunlight and temperature on crop response can be studied with the use of heat or thermal units. The concept of thermal units is commonly used in temperate areas to relate the phenological development of a crop to weather parameters in order to determine the suitability of a particular genotype to a geographic location. The number of daily thermal units (DTU) was calculated using the equation

$$DTU = [(Tmax - Tmin)/2] - 8$$

where Tmax and Tmin are the daily maximum and minimum air temperatures, respectively, and 8 was the base temperature used for maize. Using this equation, mean DTU values of approximately 1100 and 2400 were computed for the phenological stages from planting to 50 percent tasseling and from planting to physiological maturity or harvest.

The results indicate that a genotype like X304C, a variety used at sites across the three soil families, will require nearly 1100 DTU to initiate tasseling and about 2400 DTU to reach maturity no matter where it's grown. However, the period of time necessary for the plant to accumulate these values would be a function of location and associated site variables. By growing a common variety in each soil family network and by optimizing most soil-related factors, a comparison of time necessary to accumulate these DTUs could be made.

Results on number of days from planting to tasseling were: 56 days for the Paleudults, 68 days for the Dystrandepts, and 71 days for the Eutrustox. The days to harvest followed the same order: 117 days for X304C grown in the Paleudults, 129 days in the Dystrandepts, and 155 days in the Eutrustox.

The udic, isohyperthermic regime of the Typic Paleudults would, on the surface, appear to be most conducive for maize production and the ustic, isohyperthermic would be the least. This conclusion would be correct only if qualified with statements related to the differential measures taken to minimize the effects of soil constraints.

An understanding of the integral relationship between real time weather parameters such as solar radiation, rainfall, and maximum and minimum temperature with soil moisture and soil temperature regimes defined in Soil Taxonomy is essential to matching crop requirements with soil and climatic characteristics. Reasonably good predictions on potential crop performance and length of its growing season can then be made.

The usefulness of the soil family and its associated properties for prediction of crop performance is quite evident. Even with knowledge of the range and variability of site factors related to weather, a generally reliable statement can be made regarding maize performance in each of the three soil families. However, to assess the effect of any one meteoro-

logical parameter to crop response or performance is very difficult. The collective and integrated effects of all meteorological parameters and edaphic characteristics associated with a site have far greater impact on crop performance. In the following section, edaphic or soil characteristics associated with the soil family will be reviewed.

## Soil Properties, Land Quality, and Maize Production

A wealth of information is available in the literature relating maize production to soil properties. Much of the earlier work evaluated maize production and grain yield in relation to soil properties and variables associated primarily with nutrients such as nitrogen, phosphorus, and potassium. These properties include texture, structure, and water-holding capacity. In fact, according to Larsen and Hanway (1977), soil properties are usually so interrelated that interpretation is difficult. However, with a systematic approach these interrelationships of soil properties can be organized to allow a better assessment or prediction not only of maize production but of production of other crops. The use of Soil Taxonomy and its soil family category allows agricultural scientists to now group soils not only on soil characteristics alone but also on climatic characteristics to determine their implications for crop, soil, and water management.

One purpose for assembling high-quality pedologic and climatologic data is to enable a soil interpreter to predict reasonably accurate soil and crop performance data. A key element in obtaining interpreted performance data is to match land qualities to crop requirements. 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 discussion, land qualities and the concomitant soil management requirements of importance to maize production are estimated from the differentiae defining a soil family and the accessory properties of the taxon.

## Characteristics of the Three Soil Families

*Thixotropic, isothermic family of Hydric Dystrandepts.* Phosphorus deficiency is the most frequently encountered limitation for maize produc-

tion 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 becomes "fixed" and is 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, nutrient deficiency can be corrected, 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 g 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.

*Clayey, kaolinitic, isohyperthermic family of Tropeptic Eutrustox* The amounts of phosphorus available depend on past management and on the nature of the parent rock. The amount 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.

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 very heavy rainfall. The high water permeability of Eutrustox and the level topography further reduce the erosion hazard. Hail is extremely rare. In an isohyperthermic soil temperature regime, storms and torrential rains, however, are severe hazards to crop production.

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 fertilizer is required for sustained crop production.

Eutrustox are readily workable due to the stability of soil aggregates. When dry, 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.

*Clayey, kaolinitic, isohyperthermic family of Typic Paleudults.* Because these soils are highly leached of bases and have little or no weatherable minerals, there is good crop response to phosphorus, nitrogen, lime, and the macro- and micronutrient fertilizers. Compared with the Dystrandepts, moderate amounts of fertilizer phosphorus are required. Subsoil acidity and low fertility are the major constraints to crop production in this soil. These soils require nutrients such as potassium, calcium, and magnesium because bases have been leached from them. Because of the clayey particle-size class, the subsoil has a high moisture-storage capacity.

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.

Aluminum toxicity must 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 1200 kg $CaCO_3$/ha is generally applied to neutralize 1 meq of extractable aluminum. Complete fertilizers containing nitrogen, potassium, phosphorus, magnesium, and the micronutrients must be added.

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 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 it is very difficult to reestablish vegetation 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 the hazard of 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 plant diseases (Chapter 8).

In summary, the agroenvironment, as used in the context of the Benchmark Soils Project, is an environmental niche for agricultural production described by the nomenclature used in Soil Taxonomy. Soil properties and soil climate criteria used to define the soil family category were used to characterize an agroenvironmental niche. These properties are referred to collectively as site characteristics and have measurable values that can be related to requirements for maize production.

Although Soil Taxonomy defines boundary values for the range of soil temperature and soil moisture regimes, the user should be cognizant that these are average or representative values. There are a range of values for temperature and moisture (rainfall) that are used to obtain these average values as shown for the three soil families of the Benchmark Soils Project. Results over the life of the project indicate that maize production was best in the clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox (ustic), provided sufficient moisture is available. This was followed by the clayey, kaolinitic isohyperthermic Typic Paleudults (udic), provided soil acidity and plant nutrients are not limiting factors. Finally, the thixotropic, isothermic Hydric Dystrandepts (udic) had the next best maize production, provided soil acidity and phosphorus are not constraints.

Soil constraints can, by inference, be identified from information contained in soil surveys and the resulting soil classification. Both serve as a basis for establishing a soil resource inventory that can be related to land qualities for land evaluation and land use. Based on similarity of soils and the agroenvironment defined by the soil family, the concept of analogue transfer can be utilized effectively by users for agricultural planning and development.

## References

Beinroth, F. H. 1982. Research on the transfer of agrotechnology, final report of the Puerto Rico Benchmark Soils Project, 1975–1981. Dept. Agron. and Soils, College of Agr. Sci., Univ. Puerto Rico.

Beinroth, F. H. 1983. The stratification of the agroenvironment by Soil Taxonomy. *In* A multidisciplinary approach to agrotechnology transfer: Proceedings of a Benchmark Soils Project/Hawaii Institute of Tropical Agriculture and Human Resources Workshop. G. Uehara, ed. HITAHR Res. Ext. Series 026 (BSP Tech. Rept. 7). Hawaii Inst. of Trop. Agr. and Human Resources, College of Trop. Agr. and Human Resources, Univ. Hawaii.

Benchmark Soils Project. 1979. Development of the transfer model and soil taxonomic interpretations on a network of three soil families. Progress Report 2 (Jan. 1978–June 1979). Dept. Agron. and Soil Sci., College of Trop. Agr. and Human Resources, Univ. Hawaii, and Dept. Agron. and Soils, College of Agr. Sci., Univ. Puerto Rico.

Benchmark Soils Project. 1982. Assessment of agrotechnology transfer in a network of tropical soil families. Progress Report 3 (July 1979–Sept. 1982). Dept. Agron. and Soil Sci., College of Trop. Agr. and Human Resources, Univ. Hawaii, and Dept. Agron. and Soils, College of Agr. Sci., Univ. Puerto Rico.

Larson, W. E., and J. J. Hanway. 1977. Corn production. *In* Corn and corn improvement. G. F. Sprague, ed. Agronomy 18:625–669.

Leamy, M. L. 1984. Conversations in taxonomy. *In* Guy D. Smith discusses Soil Taxonomy. J. F. Brasfield, ed. Soil Survey Horizons. Soil Sci. Society of America. Madison, Wisconsin.

Manrique, L. A., G. Y. Tsuji, G. Uehara, and R. L. Fox. 1984. Winter and summer performance of potato (*Solanum tuberosum*) in isohyperthermic regimes. Am. Potato J. 61:41–56.

Shaw, R. H. 1977. Climatic requirements. *In* Corn and corn improvement. G. F. Sprague, ed. Chap. 10. Agronomy 18:591–623.

Soil Survey Staff. 1975. Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. Soil Conservation Service, U.S. Dept. Agr. Handbook 436. U.S. Govt. Printing Office, Washington, D.C.

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*Matching Maize Requirements to the Agroenvironment*

# 8 Maize Production in Three Benchmark Environments

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Maize (*Zea mays* L.) with its many diverse types is a widely distributed food crop cultivated in a range of agroenvironments from the equatorial tropics to latitudes of 50 degrees in the temperate zone. Grain yields, however, vary considerably among the different regions of the world as well as among countries. In temperate-zoned countries, such as the U.S. or Yugoslavia, where maize production is modernized and characterized by high inputs, yields range from 4 to 6 metric tons per hectare. In contrast, yields of only 1 metric ton per hectare are quite common in many of the less developed countries (LDC) in tropical and subtropical Asia and Africa that practice traditional, low-input farming (Bottrell, 1979).

Improvement of agricultural productivity in the LDC implies a change from a natural resource-based agriculture to a science-based agriculture. This transformation can be catalyzed if the LDC can capitalize on the full range of scientific knowledge and agricultural expertise generated elsewhere in the world. Since agricultural research and production technology are very location-specific with respect to the environmental variables of soil and climate, any systematic method for transferring information must incorporate these two variables if there are to be meaningful and applicable transfers to the LDC. Soil Taxonomy, the U.S. system of soil classification, combines both into one comprehensive system and consequently has the potential for facilitating "horizontal" transfers of knowledge—i.e., the transfer of experience from one experiment station to another at a scientific level. Horizontal transfers specifically involve soil management and crop production practices such as fertilization, tillage, irrigation, crop species selection, crop protection, and stand establishment (Beinroth et al., 1980).

In the lifetime of the Benchmark Soils Project—from 1975 to 1983—maize fertility experiments were planted throughout sites of three soil family networks encompassing six countries. In addition, maize variety and other management experiments were conducted (Beinroth, 1982; Benchmark Soils Project, 1978a, 1979, 1982a). All of this represents a tremendous amount of field research experience. While the major emphasis of the project was to quantify the relationship of crop

response-to-soil management input, much knowledge was also gained in the area of maize production. Sites within a soil family network were recognized to behave as a single management unit, thus leading to a better understanding of the kinds of information that are transferable among soils of the same soil family taxa. In this chapter, agronomic experiences of the Benchmark Soils Project are related in the context of the distinct agroenvironments of the three soil family networks in order to demonstrate the inherent potential of Soil Taxonomy to facilitate the transfer of agroproduction technology amoag tropical and subtropical countries.

## X304C—A Well-Adapted Variety

It would have been advantageous if at the start of the project in 1975 there already was available a proven, well-adapted maize variety for each soil family network. This would have eliminated any variation in yield responses caused by differential genotype responses to the controlled variables of nitrogen and phosphorus in the transfer experiment. After five years of field experimentation, however, the project had just about identified a "universal" variety, and surprisingly the search was not too painstaking. By 1981 a single variety was being planted in transfer experiments throughout all sites of, not one, but two soil family networks and in half of the sites in the third network. This was Pioneer brand variety X304C.

X304C was first tested in a maize variety trial at the Tropeptic Eutrustox site of Isabela, Puerto Rico, in mid-1976. It yielded 9.8 metric tons/ha of grain, which was the highest of 16 varieties. In subsequent trials in Puerto Rico and Brazil, X304C was consistently ranked in the top three category and, on this basis, was selected as the test variety for these two countries in late 1977 (Beinroth, 1982).

In mid-1978 the Tropeptic Eutrustox sites of Molokai and Waipio in Hawaii became operational. On the strength of its performance in Puerto Rico and Brazil and its reputation of being a consistent performer in trials conducted by the University of Hawaii Agricultural Experiment Stations, X304C was also selected as the test variety for these sites. Mean grain yields were very satisfactory in the first transfer experiments, reaching 9.1 and 10.0 metric tons/ha at the Molokai and Waipio sites, respectively. The Tropeptic Eutrustox network thus became the first to plant a single variety throughout all sites.

Results of additional variety trials on the other soil families (Santoso, 1981) were indeed very encouraging and opened the way for planting X304C at the Typic Paleudult sites in Barombi Kang, Cameroon, and in Bukit Kemuning, Indonesia, in November 1980. A year later all the Typic Paleudult sites had converted to X304C. Moreover, X304C was

also outperforming the local selections in paired transfer experiments in the Hydric Dystrandept network. With such results, X304C displaced the local variety at all of the Philippines' Hydric Dystrandept sites in 1981.

The wide adaptability of X304C is quite intriguing. It is a tropical single cross hybrid that has been commercially available for approximately 16 years through Pioneer Hi-Bred International. It is known for its above-average tolerance to insect pests and to heat and drought stress. It is also resistant to southern corn leaf blight, southern rust, and corn stunt diseases. Several major attributes of this hybrid were recognized by the Benchmark Soils Project personnel:

1. Seeds are commercially available and are of high quality.
2. It is uniform in emergence and tasseling.
3. The stalk is strong and not prone to lodging.
4. It is less sensitive to seasonal changes than other hybrids.
5. The hard, flint kernels are resistant to damage caused by grain bugs, ear rot fungi, and birds.
6. It is moderately resistant to northern corn leaf blight.
7. It is susceptible to downy mildew but the disease may be controlled with metalaxyl, a systemic fungicide applied to the seed.

## Maize Pests

*The case of the downy mildews.* The downy mildews are a very destructive pest of maize in the tropical regions. Of the nine species that are known to infect maize, four species are of major economic importance in the tropics (Weltzien, 1981; Shurtleff, 1980). *Peronosclerospora sorghi* (Western and Uppal) C. G. Shaw, commonly called Java downy mildew, is a systemic fungus of great importance in Indonesia, where it can reduce grain yields by as much as 40 percent. *P. Philippinensis* (Weston) C. G. Shaw, known as Philippine downy mildew, occurs in India, Indonesia, Nepal, and possibly Africa, but is most damaging in the Philippines, where its incidence may commonly be as high as 80–100 percent with yield losses of 40–60 percent (Kenneth, 1981). This disease is so serious that the major criterion for varietal adaptation to localities in the Philippines is whether the variety is downy mildew resistant or not (PCARR, 1976).

It is no wonder that in 1974, before field experimentation began, the project staff in the Philippines and Indonesia was advised by consultants that this devastating fungal disease would render maize unsuitable as a test crop. However, it turned out that the Hydric Dystrandept network first established by the Benchmark Soils Project in these countries had an environmental quality that did not permit the downy mildew organism to flourish. Downy mildew is not a problem in isothermic (soil

Downy mildew (*Peronosclerospora* spp.) caused severe damage to maize in the warm, humid environment of the Typic Paleudults, but relatively slight damage in the cool, moist environment of the Hydric Dystrandepts.

temperature regime of 15–22°C) environments. On the other hand, in the second network of sites established in the clayey, kaolinitic, isohyperthermic family of Typic Paleudults, this disease was a serious pest. The isohyperthermic (greater than 22°C soil temperature regime) and udic regimes favored this organism.

The lesson learned by the Benchmark Soils Project personnel is supported by epidemiological information for *P. philippinensis*. Optimum conditions for conidial production, germination, and infection are free moisture on the leaves at night with air temperatures of 21–26°C (Shurtleff, 1980). If soil-borne oospores are a major source of inoculum, Kenneth (1981) concluded that long-term optimum conditions for downy mildew epidemics include soil temperatures up to 32°C, wet and warm nights, and a wetness period at temperature ranges up to 30°C during daytime.

In a sense the project staff rediscovered what has been known to plant pathologists. What is new is that we are now able to relate what is known to pathologists to named kinds of soil environments. It is know-

ing these kinds of relationships that enable people to transfer knowledge and experience among widely separated locations in the tropics. We can now state with some degree of confidence that downy mildew will not be a serious problem in any soil with an isothermic or cooler temperature regime, but is a potential problem in environments with isohyperthermic (warm) and udic (humid) regimes.

*Survey of pest occurrence.* The Benchmark Soils Project experience with the downy mildews brought on a quick realization that the soil family unit could be used for transferring information other than that directly related to soil management. To further substantiate the soil family's utility in transferring information about crop protection, a survey on maize pests throughout the Benchmark sites was compiled in 1982.

In the survey the pests were given a severity rating of "M" if they were present at the site but were of minor importance, and a "S" rating if they posed a major threat to the crop and could cause appreciable losses (greater than 5 percent) in grain yields. There were a few problems in completing the survey, such as proper identification of the pests and subjective biases in the observer's qualitative ratings, but nevertheless, the survey was effective in summarizing the experiences of the Benchmark Soils Project personnel and the distribution and importance of maize pests in the networks.

Pest problems usually differ considerably from region to region, but there are some pests that are widely distributed throughout the maize-growing regions of the world (Bottrell, 1979). In the survey, earworms, cutworms, grasshoppers, and aphids were found to be common to all sites. However, only one particular species, the corn leaf aphid (*Rhopalosiphum maidis* Fitch), was identified at all the sites. In general, these insects were of minor importance with the exception of earworms, which caused serious infestations at times in the Philippines and Cameroon.

When all the sites of the three networks across the four collaborating countries were considered, the stratification of maize pests by soil family was not evident. The region-specific nature of many of the pests plus the qualitative nature of the ratings were the major constraints. For example, the stratification of downy mildew by soil family could not be completely verified since the disease is nonexistent in Cameroon (Typic Paleudult network) and Hawaii (Hydric Dystrandept network). Needless to say, comparisons between soil family networks within a country showed a higher degree of stratification. The survey results for the individual locales of Hawaii, Indonesia, and the Philippines are presented in the following sections. Cameroon, which had its share of pest problems (corn earworms, corn borers, rodents, and birds), has been excluded in the discussion since sites of only one network existed in the country.

*Hawaii.* All the maize diseases recognized in Hawaii, except for common smut (*U. maydis*), occurred at all sites of both soil families (Table 1). However, the severity of the disease attacks was generally greater in the cool and moist environment of the Hydric Dystrandepts. Common smut, which favors dry conditions and temperatures between 26 and 34°C, was noticeably absent in the cool, moist environment of the Dystrandept sites.

Disease ratings within a soil family network were very similar if not the same. The only differences were in severity ratings for northern leaf blight (*H. turcicum*) and common maize rust (*P. sorghi*) for the Tropeptic Eutrustox sites. Northern leaf blight may have been more prevalent at Molokai since the air temperature there was slightly cooler than at Waipio. Severe outbreaks of rust at the Waipio site usually occurred during the dry season months when calm to moderate winds, high relative humidities, and warm temperatures prevailed. The high wind speeds of Molokai, a characteristic of that site, may have been a deterring factor to rust infection since this disease was observed only after wildcane windbreaks were established. It should be noted that rust infestations, which are enhanced by cool temperatures (16–23°C) and high relative humidities (Shurtleff, 1980), were not a problem in the Hydric Dystrandept sites because the maize variety H610 used in the transfer experiment was rust-resistant.

The seasonal variation in weather had a pronounced effect on the incidence of disease infection at sites of both soil families. For example, outbreaks of northern leaf blight disease, which is promoted by moder-

**Table 1. Maize disease incidence and severity rating for four Hawaii sites.**

| Disease | Tropeptic Eutrustox | | Hydric Dystrandepts | |
|---|---|---|---|---|
| | MOL | WAI | IOLE | KUK |
| Common smut (*Ustilago maydis* [DC] Cda.) | M | M | O | O |
| Ear rots (*Gibberella roseum* f. sp. *cerealis* [Cke.] Snyd. and Hans.) (*Fusarium moniliforme* Sheld) (*Penicillum oxalicum* Currie and Thom) | M | M | S | S |
| Common maize rust (*Puccinia sorghi* Schw.) | M | S | M | M |
| Northern leaf blight (*Helminthosporium turcicum* Pass.) | S | M | S | S |
| Stalk rots (*Gibberella zeae* [Schw.] Petch) (*Diplodia maydis* [Berk.] Sacc.) | M | M | M | M |

Key: "O" = pest not observed at site
"M" = pest of minor importance
"S" = pest of major importance

ate temperatures (18–27°C) and heavy dews, were more prevalent during the wet season at the Tropeptic Eutrustox sites. Interestingly, blight infestations at the Hydric Dystrandept sites were less severe during the wet season because the accompanying cooler air temperatures were below optimal. However, ear rots became a major problem, especially *G. roseum*, which thrives in cool, wet weather (Shurtleff, 1980).

The insect pests were much more stratified by soil family than the diseases (Table 2). The corn planthopper (*P. maidis*), found at low elevations on all the major islands of Hawaii, did not usually extend into the isothermic sites of Iole and Kukaiau, which were located at elevations of approximately 500 meters. Sightings of planthoppers at Iole occurred only twice during unusually dry periods of summer. Red spider mites (*T. cinnabarinus* and *T. tumidus*) thrived in hot and dry weather conditions like that found at the Eutrustox sites. Mites were usually seasonal at these sites with few infestations during the cooler months of the wet season. Fire ants (*S. geminata*), although not a primary pest of maize, were a common nuisance in the plots at the Eutrustox sites as they enlarged the emitter orifices of the drip irrigation tubing. Their nesting range excluded the cool and constantly moist soil environment of the Hydric Dystrandept sites. The Chinese rose beetle (*Adoretus sinicus* Burmeister) was potentially very destructive at the Eutrustox sites, especially at Waipio. Beetle population numbers were not as high at the Dystrandept sites, probably because of the cool environment.

The only destructive insect at the Dystrandept sites was the cutworm (*Agrotis* sp.). Larvae numbers in newly planted experimental blocks

**Table 2. Maize insect incidence and severity rating for four Hawaii sites.**

| | Tropeptic Eutrustox | | Hydric Dystrandepts | |
|---|---|---|---|---|
| **Insects** | **MOL** | **WAI** | **IOLE** | **KUK** |
| Corn planthopper (*Peregrinus maidis* Fitch) | S | S | M | O |
| Red spider mite (*Tetranychus cinnabarinus* Boisduval) (*Tetranychus tumidus* Banks) | S | S | O | O |
| Ants (*Solenopsis geminata* [fabricius]) | M | M | O | O |
| Chinese rose beetle (*Adoretus sinicus* Burmeister) | S | S | M | M |
| Cutworms (*Agrotis* sp.) | M | M | S | S |
| Aphids (*Rhopalosiphum maidis* Fitch) | M | M | M | M |
| Corn earworm (*Heliothis zea* Boddie) | M | M | M | M |

Key: "O" = pest not observed at site
"M" = pest of minor importance
"S" = pest of major importance

**Table 3. Persistent weeds at Hawaii sites by soil family.**

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

were high, especially at the Iole site, and if not controlled, losses of seedlings reached as high as 10 percent. The thick, grassy vegetation growing in blocks prior to planting probably supported a high population of this pest. Larvae carryover at the Eutrustox sites was negligible since vegetative growth was sparse because of the dry conditions.

Since the two soil families are in distinct climatic zones, the weed species of each soil family were very different (Table 3). Weeds of the Tropeptic Eutrustox sites are adapted to dry habitats, whereas those of the Hydric Dystrandepts prefer moist environments. *Bidens pilosa* L., *Emilia sonchifolia* L., *Digitaria sanguinalis* (L.) Scop., and *Sonchus oleraceus* L. have wide ecological adaptations and were found in both soil families.

Hurdus (1979) quantitatively characterized the weed communities at the Molokai and Waipio sites and found that the weed species of these two Tropeptic Eutrustox sites were very similar. Of the 17 weed species found on Molokai, 12 also occurred at Waipio, Oahu. *B. pilosa*, *S. oleraceus*, and *Trichachne insularis* were found in all of the 18 areas sampled at both sites, for a constancy rating of 100 percent. A fourth species, *Rhynchelytrum repens*, had a 94 percent rating and three other species had percentages higher than 65: *E. sonchifolia*, 72 percent; *Ipomea triloba*, 72 percent; *Waltherici americana*, 67 percent.

*Indonesia.* As previously discussed, downy mildew (*Peronosclerospora* spp.) was prevalent at the Typic Paleudult sites but not at the Hydric Dystrandept sites (Table 4). Only at one Hydric Dystrandept site, LPH, were there occurrences, and even then, the damage was less than 1 percent. The downy mildew infestations were more severe during the wet months of December and January. Two other diseases, common

**Table 4. Maize disease incidence and severity rating for six Indonesian sites.**

| | Hydric Dystrandepts | | | Typic Paleudults | | |
|---|---|---|---|---|---|---|
| Disease | ITKA | PLP | LPH | NAK | BUK | BPMD |
| Downy mildews (*Peronosclerospora maydis* [Rac] C. G. Shaw) (*P. philippinensis* [Weston] C. G. Shaw) | O | O | M | S | S | S |
| Common maize rust (*Puccinia sorghi* Schw.) | O | O | O | M | M | M |
| Common smut (*Ustilago maydis* [DC] Cda.) | O | O | O | M | M | M |
| Southern leaf blight (*Helminthosporium maydis* Nisik) | S | S | S | M | M | M |
| Stalk rots (*Gibberella zeae* [Schw.] Petch) (*Diplodia maydis* [Berk.] Sacc.) | M | M | M | O | O | O |

Key: "O" = pest not observed at site
"M" = pest of minor importance
"S" = pest of major importance

maize rust (*P. sorghi*) and common smut (*U. maydis*), were also specific to the warmer Typic Paleudult sites.

Southern leaf blight (*H. maydis*) and the stalk rots (*Gibberella* sp. and *Diplodia* sp.), on the other hand, were found to be greater pests in the Hydric Dystrandept network. Incidences of both diseases were more severe during the drier months. The occurrence of the stalk rots in the Dystrandept sites could possibly be related to the heavy southern leaf blight infestations that predispose the plants to stalk rot (Shurtleff, 1980).

The majority of the insects in Indonesia were common to both families and only of secondary importance. The corn borer (*Ostrinia nubilalis*) was noticeably absent at the Hydric Dystrandept sites, although outbreaks did occur at the LPH site when insecticides were not applied. The test variety X304C for the Typic Paleudult sites was also much more susceptible to borer attack at hard dough stage than the local variety H6 grown at the Hydric Dystrandept sites. Corn earworm (*H. zea*) and aphid (*R. maidis*) infestations increased during the dry season.

*The Philippines.* Downy mildew (*P. philippinensis*), a major disease problem in the Philippines, was a severe problem only at the Typic Paleudult sites. Minor infestations were observed in two instances at the PUC and PAL sites of the Hydric Dystrandept network. Weather data collected at these two sites showed that they are actually in the isohyperthermic, rather than isothermic, temperature regime. The other dis-

Corn earworm (*Heliothis zea* Boddie) was a destructive pest across the three soil family networks.

eases observed in the Philippines were the same as listed for Hawaii (Table 1) but also included southern leaf blight *(H. maydis)* and pythium root rot (*Pythium* sp.). These diseases, all deemed of minor importance, were found at all sites of both soil families with greater infestations occurring during the wet season.

Similarly, there was no clear-cut stratification between soil families with respect to insect pests. The degree of damage caused by some insects (borers and earworms) were associated more with the prevailing weather conditions, particularly rainfall, at tasseling time. Corn earworm (*Helicoverpa armigera* Hubner) and corn seedling maggot (*Atherigona oryzae* Mallock) were pests of major importance. Corn borer attacks were the most severe and could cause an estimated 60 percent loss in yields. Cutworms, grasshoppers, and aphids *(R. maydis)* were minor pests at all sites.

## Soil Fertility Management

*Phosphorus.* The phosphorus-sorption curves of selected sites of the Hydric Dystrandept and the Tropeptic Eutrustox networks presented in Figure 1 illustrate two points. First, sites of the same soil family dis-

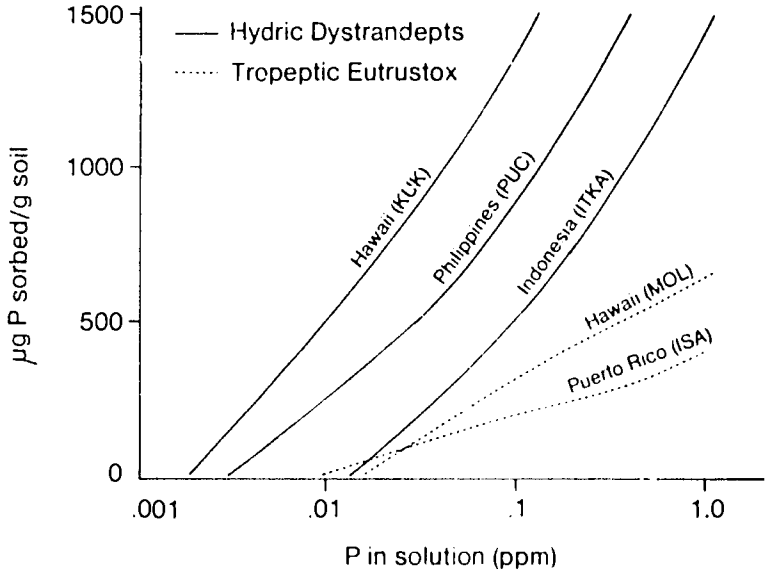


**Fig. 1.** Phosphorus-sorption curves.

played similar behavior regarding phosphorus retention as indicated by the similarity of the shape of the curves. The displacement of the curves to the right was due to differences in the initial phosphorus levels in the soil caused by previous management practices. Second, the family of Hydric Dystrandepts, as its thixotropic property implies, can adsorb greater quantities of phosphorus than the Tropeptic Eutrustox and Typic Paleudult families.

The phosphorus fertility status of the experimental sites within a family network varied as a result of prior cropping practices. High levels of residual phosphorus could even be found at sites of the Hydric Dystrandepts in Hawaii and Indonesia where intensive cropping of sugarcane and vegetables involved heavy applications of fertilizer and animal manure, respectively. Newly-opened sites with no previous cropping history, such as in Jaiba, Brazil, of the Tropeptic Eutrustox family, generally had the lowest levels of available phosphorus. As such, the response of maize to applied phosphorus fertilizer was site-specific. Figure 2 shows the range of the phosphorus linear response coefficients of transfer experiments using a modified Truog test (Appendix E) to measure available phosphorus at Hydric Dystrandept sites.

The amount of phosphorus applied at the middle coded level is listed for several sites of the three networks in Table 5. The rates were determined by the modified Truog extraction curve method using the value of 25 ppm as the +1 coded value (Chapter 4). As can be expected, much more phosphorus was required in the Hydric Dystrandepts than in the

other two families. Sites with already high available phosphorus required very little or no phosphorus at all.

*Potassium.* Sites of the Tropeptic Eutrustox network did not respond to applications of potassium fertilizer. Potassium was originally a treatment factor in the transfer experiments for this network, but the results of the first six maize experiments conducted at the Isabela, Puerto Rico, and Jaiba, Brazil, sites showed no yield response to potassium applications ranging from 20 to 230 kg K/ha. In fact, yields at times declined with applications greater than 125 kg K/ha (Benchmark Soils Project, 1978a). Similar results were also obtained at Waipio, Hawaii, in a NPK management experiment.

The exchangeable K level of the surface horizon was approximately 0.5 meq/100 g soil for the Brazil and Puerto Rico sites. The K levels were much higher for the Hawaii sites, ranging from 1.0 to 2.5 meq K/100 g soil, where previous management practices included heavy fertilization. Because the Eutrustox soils have limited quantities of potassium-containing materials and their crop production potential is high, the available potassium supply can become depleted quite rapidly with continuous cropping.

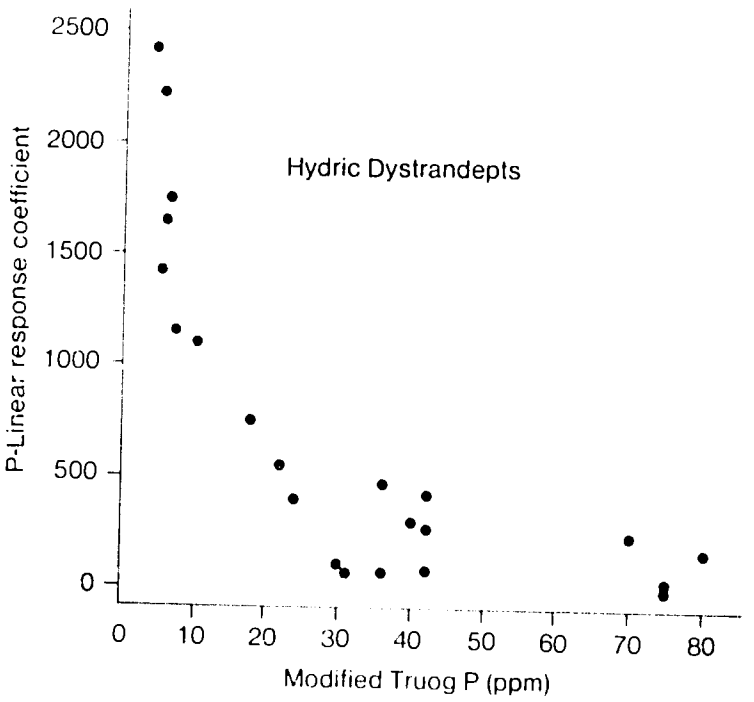


**Fig. 2.** Relationship between site specific P linear response coefficients and extractable soil phosphorus.

**Table 5. Extractable soil phosphorus (Soil P) and phosphorus (P) required at the middle applied P rate for three sites of each soil family.**

| Hydric Dystrandepts | | Typic Paleudults | | Tropeptic Eutrustox | |
|---|---|---|---|---|---|
| Soil P (ppm) | P (μg/g) | Soil P (ppm) | P (μg/g) | Soil P (ppm) | P (μg/g) |
| 3.7 | 103 | 2.9 | 44 | 8.5 | 25 |
| 6.7 | 17 | 5.7 | 25 | 17 | 12 |
| 15 | 22 | 19 | 12 | 25 | 0 |

Unlike the Tropeptic Eutrustox family, the Hydric Dystrandepts and the Typic Paleudults responded to applications of potassium. Management experiments conducted in Indonesia and the Philippines indicated that an application rate of 100 kg K/ha was necessary to obtain maximum maize yields (Benchmark Soils Project, 1978a). Potassium, however, was not as limiting as nitrogen and phosphorus at these sites. In general, exchangeable K levels for the surface horizon of these two soils were approximately 0.1 to 0.3 meq K/100 g soil. Higher levels were measured if the site had a history of heavy fertilization.

*Lime.* The application of lime was initially considered as a treatment factor in the transfer experiment for the Hydric Dystrandept network. However, like potassium in the Eutrustox network, lime was found to have no effect on maize performance in this network. In some cases, yield losses occurred when application rates reached 1200 kg $CaCO_3$/ha or more.

The soil reaction of the Hydric Dystrandepts was generally strongly acid, ranging in pH (water) from 4.6 to 5.6. In spite of this and a base saturation of only 2 to 15 percent, the level of extractable aluminum was low with the exchangeable calcium level correspondingly high. Extractable aluminum levels were less than 0.1 meq/100 g soil for the Hawaii and Indonesia sites and somewhat higher at 1 meq/100 g soil for the Philippines sites. Exchangeable calcium, on the other hand, ranged from 2 to 6 meq/100 g soil which was sufficient to supply adequate amounts of calcium to the crop (Benchmark Soils Project, 1978a).

Aluminum toxicity was not a problem in the other two networks. The pH of the Typic Paleudults ranged from 4.5 to 5.5, and the Tropeptic Eutrustox with its higher base saturation had a pH range of 5.0 to 6.0. Exchangeable calcium levels of the surface 15 cm generally ranged from 2 to 8 and 4 to 10 meq/100 g soil, respectively.

As a precautionary measure to ensure that soil acidity did not become a limiting factor in the transfer experiment, if warranted, lime as $CaCO_3$ was included in the preplant blanket fertilizer application. In

the Hydric Dystrandept network, lime was applied only when the KCl-extractable aluminum content was greater than 30 percent of the effective cation-exchange capacity. The lime rate was based upon one-and-a-half times the amount of extractable aluminum. The high buffering capacity of this soil made liming impractical to achieve a designated pH level of around 5.5 to 6.0.

In contrast, lime application for the Typic Paleudults and the Tropeptic Eutrustox, which have a much lower cation exchange capacity, was based on the amount required to raise soil pH to 5.5. It was necessary to apply lime only at the Hawaii and Puerto Rico sites where past management practices significantly lowered the surface pH. For example, at the Calero site (ISA-3) in Puerto Rico a history of ammonium sulfate fertilization for sugarcane production resulted in a pH as low as 4.2. The application of lime at a rate of 6 meq Ca/100 g soil adjusted the pH to 6.0 and resulted in much improved maize yields (Bemroth, 1982).

## Crop Management

The transfer experiment was designed so that all controllable factors such as irrigation, plant protection, plant density, and other nutrients were maintained near optimum levels for clarity of the treatment effects of applied phosphorus and nitrogen fertilizer. Field operations, data collection, and data processing followed standardized procedures and guidelines (Benchmark Soils Project, 1982b) to ensure the similarity of

In this transfer experiment at the Sorsogon site in the Philippines, application of P was necessary to obtain high yields. The -0.85 P plot received 12 kg and the opt P plot 82 kg P/ha. Both plots received 186 kg N/ha.

management practices throughout all sites of a family network. To say the least, the implementation of the transfer experiment was an enormous task, and the successful quantitative verification of the transfer hypothesis marks this effort as a significant milestone in agronomic field research history.

The establishment of a good stand of maize plants in the experimental plots was the first step to attain results of high quality. It involved many operations such as land clearing, ground preparation, planting, and irrigating. The experiences encountered by project personnel in one soil family network were not necessarily the same in another network, and thereby clearly demonstrated that each soil family grouping was indeed a distinct management unit.

*Land preparation.* Site clearing and the initial preparation of the land was accomplished by machinery, while regrowth of vegetation in areas designated as experimental blocks was usually cleared manually with implements such as machetes, rakes, and hoes. Land clearing was a much more difficult task in the Hydric Dystrandept and Typic Paleudult networks where the moist environment supported luxuriant growth of the weedy vegetation. One of the hardest weeds to remove was a grass, *Imperata cylindrica*, which was the dominant plant species in the acid, infertile Typic Paleudult sites in Indonesia and, to a lesser degree, in the Philippines. Glyphosate herbicide was used extensively at most sites to kill the weed growth prior to clearing; however, its effectiveness was somewhat compromised in the moist environments of the Hydric Dystrandepts and Typic Paleudults.

The workhorse of the Benchmark Soils Project was the walking tiller that was powered by a 5 horsepower gasoline engine and equipped with slashing rotors for tilling the soil. Preparation of the seedbed was by far the easiest in the Hydric Dystrandepts. This soil of low bulk density was tilled quite effortlessly, and even under wet conditions its nonsticky consistency allowed tillage operations to continue with good results. In the Philippines and Indonesia approximately 50 percent fewer manhours were required to till a transfer block of a Hydric Dystrandept soil than a Typic Paleudult soil.

The workability of the Typic Paleudult and Tropeptic Eutrustox soils was highly dependent on their moisture content. Dry soils were hard, and two tillage passes were sometimes necessary to reach the desired plow depth of 15 cm, while wet soils were just too sticky to work. In any case, tillage at either end of the moisture scale resulted in a very cloddy seedbed. The ideal moisture content for tillage in the Tropeptic Eutrustox soil is near 15-bar tension (21 percent w/w) (Beinroth, 1982). At the Tropeptic Eutrustox sites in Hawaii dry blocks were often sprinkle irrigated to soften the soil three to four days prior to tilling. In Brazil and Puerto Rico no till practices were employed when planting residual

phosphorus follow-up experiments. Maize yields did not seem adversely affected, and experiments conducted at Isabela, Puerto Rico, showed that yields from no-till plots were as high as yields from conventional tillage plots (Beinroth, 1982).

*Planting.* The transfer experiments were planted during the dry and wet periods of the year. Planting times, whether dry or wet season, generally fell in the paired months of March-May and November-December. Maize crops planted during the wet season were always susceptible to damage caused by cyclonic storms in Hawaii, Puerto Rico, Indonesia, and especially the Philippines, which lies in the typhoon belt. Moreover, during the years 1982 and 1983 severe, prolonged droughts were experienced at the Typic Paleudult sites in Indonesia and the Philippines. Information about catastrophic weather events that have an effect on the production potential of the land cannot be extracted from the soil family name. However, the land's relative susceptibility to drought can be inferred from the temperature regime. That is, a constantly warm environment (e.g., isohyperthermic) should be more sensitive to periods of dryness than a cooler environment (e.g., isothermic) assuming they are in the same moisture regime.

The maize seeds were planted by hand at all of the sites. Seeds were drilled either in holes made with a dibble stick or in furrows made with a furrowing implement. Whatever the method, this task was easiest to perform in the moist, light soils of the Hydric Dystrandepts. Dibble holes were almost impossible to make in the loose, dry soil of the Tropeptic Eutrustox or in the wet, sticky Typic Paleudult soil. To cut uniformly deep furrows in the Tropeptic Eutrustox soil, the furrowing implement had to be much heavier than that used in the Hydric Dystrandepts and thereby required much more draft power to pull it. The optimum planting depth was 5 to 7.5 cm. Deep plantings were desirable at the Tropeptic Eutrustox sites, since the surface soil dried rapidly, and at the Hydric Dystrandept sites, since the light, ash soil offered less physical support. Also, seeds planted shallowly were subject to rodent and bird attacks. For obvious reasons it was much easier to achieve a uniform planting depth in the Hydric Dystrandept soil.

The population density of the maize crop in the transfer experiments was 58,000 plants/ha. This rate of planting was a fairly standard practice among maize researchers in Hawaii and the Philippines at the time field experimentation began. Subsequent density trials conducted under irrigated conditions in the three networks indicated that this population was indeed near optimum for the different test varieties in both the wet and dry seasons and at low and high soil fertility levels (Benchmark Soils Project, 1978b). In the Tropeptic Eutrustox sites, where solar radiation levels are high, lodging was still a major problem at densities greater than 60,000 plants/ha (Beinroth, 1982).

Preserving the condition of the seedbed was always a major concern since planting involved a lot of foot traffic over the plots. Compaction was a serious problem in the clayey soils of the Typic Paleudults and the Tropeptic Eutrustox when they were in a moderately moist to wet condition. The stickiness of the soils also made it very difficult to work. In contrast, problems arose in the Hydric Dystrandept soil when the soil was dry. The planters would sink ankle deep into the powdery dry soil, leaving behind them a very rough surface. Fortunately, wet planting conditions were rarely experienced in the usually dry environment of the Tropeptic Eutrustox, and likewise, dry planting conditions were rarely experienced in the usually wet environment of the Hydric Dystrandepts.

*Irrigation.* Immediately after planting, a drip irrigation system was installed and water was usually delivered to the plots a day later. Normally, there was adequate moisture in the soil of the Typic Paleudults and Hydric Dystrandepts for seed germination, so the first watering was critical only at the Tropeptic Eutrustox sites. Moreover, since the loose surface soil dried very rapidly to a depth of 7–10 cm in this warm and dry environment, it was very important to set the drip laterals directly over the rows for optimum wetting of the seeds and to irrigate frequently during the first week. If such precautions were not taken, the emergence of the seedlings was erratic and resulted in a non-uniform stand. Overhead sprinklers were used very effectively at the Tropeptic Eutrustox sites in Hawaii to wet the surface layer for uniform seedling emergence.

As can be inferred from the soil family names, the irrigation requirements were much greater for the Tropeptic Eutrustox network than for the other two networks. For example, an average of 220 hours of irrigation time per crop (range 160–270 hours) was required at the Tropeptic Eutrustox sites in contrast to 40 hours per crop (range 5–75 hours) at the Hydric Dystrandept sites in Hawaii during the period 1980–83. This difference in irrigation requirements is illustrated in Figure 3 for the cropping year 1981, in which the annual rainfall was average for the Molokai site but less than average for the Kukaiau site. Although the summer months at Molokai were wetter than usual, the water application rates were still high in this isohyperthermic environment.

The actual amounts of irrigation water applied to two corn crops at the Tropeptic Eutrustox site in Waipio, Hawaii, were 310 and 325 mm. The rainfall during these two cropping periods was 160 and 110 mm, respectively. In Isabela, Puerto Rico, experiments conducted in the dry season showed that irrigation had only moderate effects on maize yields in two out of three years of testing. Isabela, although classified in the ustic moisture regime, is near udic with an annual rainfall of 1660 mm and an indistinct dry season. The present definition of the ustic soil

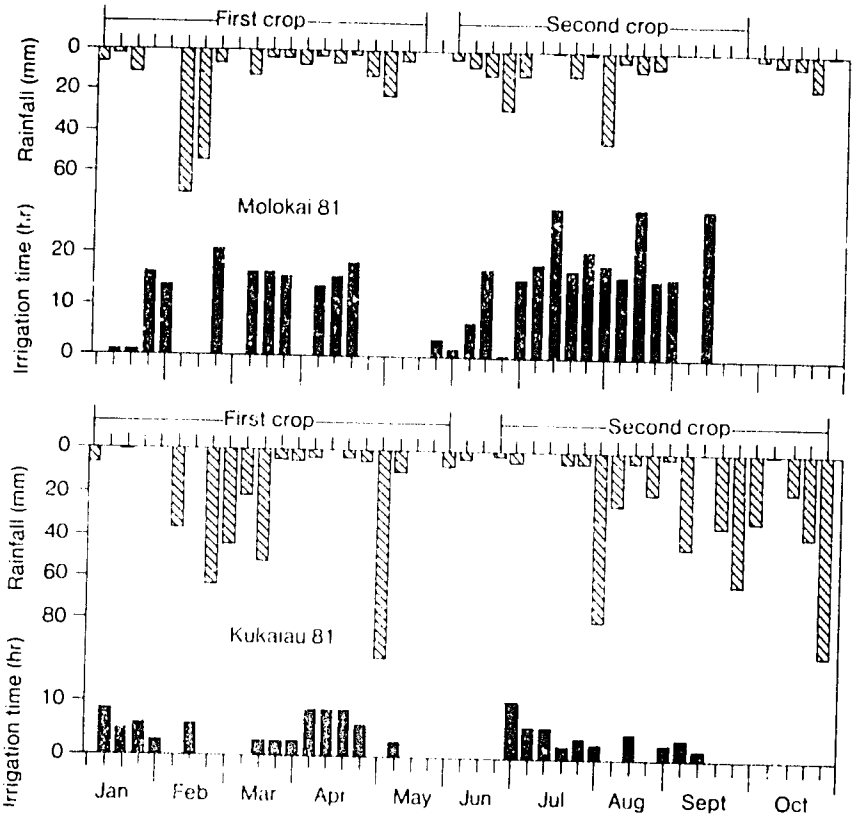


**Fig. 3.** Weekly rainfall and irrigation schedule for 1981 maize crops at the Molokai and Kukaiau sites in Hawaii.

moisture regime should be revised to allow for more meaningful and useful agricultural interpretations; the introduction of a "udi-ustic" regime needs to be considered (Beinroth, 1982).

*Crop Protection.* The application of agrichemicals was the primary strategy for protecting the maize crop in the transfer experiments. In all, approximately ten widely available pesticides formed a basic core from which crop protection programs were developed. Since these individual chemicals were especially effective in controlling a spectrum of target pests, the pesticide programs were very similar for the networks within a country. A few variations did exist because of the differences in the occurrence of major pests between soil family networks. A prime example was the mandatory treatment of maize seeds with metalaxyl fungicide for downy mildew control at the Typic Paleudult sites while none was required at the Hydric Dystrandept sites in the Philippines and Indonesia. In some instances, the same kind of control measure

was practiced in both networks but for different target pests. Such was the case with carbofuran, which was applied in the planting furrow to control planthoppers at the Tropeptic Eutrustox sites and cutworms at the Hydric Dystrandept sites in Hawaii.

The seasonal distribution of rainfall had a direct impact on the pesticide spraying program at all of the sites. During the wet season frequent fungicide applications were necessary not only because fungal infestations increased, as previously discussed, but also because the foliar sprays did not remain on the crops for very long. As can be expected, the pest control programs were least effective in the wetter Hydric Dystrandept and the Typic Paleudult networks where frequent rains often hampered spraying operations. On the other hand, during the dry season insect problems were more prevalent, warranting an increase in insecticide applications. Fortunately, better results were usually achieved at this time.

The implication here is that foliar applied contact pesticides are not suitable for environments of the udic moisture regime but are better suited for environments of the ustic moisture regime. Alternate methods to protect crops in the udic environments include the selection of resistant varieties, biological controls, and systemic pesticides. The systemics applied with the soil, such as metalaxyl and carbofuran, were very effective in both the Hydric Dystrandept and Typic Paleudult networks.

Before crop emergence a herbicide application of either alachlor or an alachlor-aatrex mixture was applied to the experimental block at most of the sites. The herbicide needed to be watered into the seed germination zone for best results. Rainfall could often be depended upon to do this at the Typic Paleudult and Hydric Dystrandept sites; however, irrigation was necessary at the Tropeptic Eutrustox sites. Weed growth during the cropping period was primarily controlled by hand weeding. Cultivation with a hoe was easiest in the light soils of the Hydric Dystrandepts; the cool air temperatures also made this task much more pleasant to perform in this soil family than in the others.

Precautionary steps were also taken to protect the experiment from the elements of wind and rain, especially during severe storms. To prevent washouts in the plots, water diversion ditches were dug around each replicate of a block. In Hawaii, the erosion hazard was much greater in the Hydric Dystrandept sites than in the Tropeptic Eutrustox sites. This was primarily because of the greater intensity and frequency of rainstorms and the greater slope of the land. To protect plants from lodging, rows were hilled up at 30 days to give the stalks additional support. This operation was not done, however, in the Tropeptic Eutrustox sites since the soil was just too hard to make it practical. In Indonesia plants were individually tied to wire supports stretched along the row,

and at the Molokai site in Hawaii wildcane windbreaks were established around the experimental sites.

## References

Beinroth, F. H. 1982. Research on the transfer of agrotechnology, final report of the Puerto Rico Benchmark Soils Project, 1975–1981. Dept. Agron. and Soils, College of Agr. Sci., Univ. of Puerto Rico.

Beinroth, F. H., G. Uehara, J. A. Silva, R. W. Arnold, and F. B. Cady. 1980. Agrotechnology transfer in the tropics based on Soil Taxonomy. Adv. in Agron. 33:303–339.

Benchmark Soils Project. 1978a. Research on agrotechnology transfer in the tropics based on the soil family. Progress Report 1 (through Dec. 1977). Dept. Agron. and Soil Sci., College of Trop. Agr., Univ. Hawaii, and Dept. Agron. and Soils, College of Agr. Sci., Univ. Puerto Rico.

Benchmark Soils Project. 1978b. Crop production and land capabilities of a network of tropical soil families. Annual Report (Oct. 1, 1977–Sept. 30, 1978). Dept. Agron. and Soil Sci., College of Trop. Agr. and Human Resources, Univ. Hawaii.

Benchmark Soils Project. 1979. Development of the transfer model and soil taxonomic interpretations on a network of three soil families. Progress Report 2 (Jan. 1978–June 1979). Dept. Agron. and Soil Sci., College of Trop. Agr. and Human Resources, Univ. Hawaii, and Dept. Agron. and Soils, College of Agr. Sci., Univ. Puerto Rico.

Benchmark Soils Project. 1982a. Assessment of agrotechnology transfer in a network of tropical soil families. Progress Report 3 (July 1979–Sept. 1982). Dept. of Agron. and Soil Sci., College of Trop. Agr. and Human Resources, Univ. Hawaii, and Dept. Agron. and Soils, College of Agr. Sci., Univ. Puerto Rico.

Benchmark Soils Project. 1982b. Procedures and guidelines for agrotechnology transfer experiments with maize in a network of Benchmark soils. HITAHR Res. Ext. Series 015 (BSP Tech. Rept. 3). Hawaii Inst. of Trop. Agr. and Human Resources, College of Trop. Agr. and Human Resources, Univ. Hawaii.

Bottrell, D. B. 1979. Guidelines for integrated control of maize pests. FAO Plant Productional Protection Paper 18. Food and Agriculture Organization of the United Nations, Rome.

Hurdus, A. 1979. Similar weed species found at Tropeptic Eutrustox sites. Benchmark Soils News 3:2. Dept. Agron. and Soil Sci., College of Trop. Agr. and Human Resources, Univ. Hawaii.

Kenneth, R. G. 1981. Downy mildews of graminaceous crops. *In* The downy mildews. D. M. Spencer, ed. Academic Press, London.

Philippine Council for Agriculture and Resources Research. 1976. The Philippines recommends for corn 1976. Los Baños, Laguna, Philippines.

Santoso, Djoko. 1981. Performance of maize varieties in three tropical soil families and their response to N and P fertilization. M.S. thesis. Univ. Hawaii.

Shurtleff, M. C., ed. 1980. Compendium of corn diseases, 2nd ed. The American Phytopathological Society. St. Paul, Minnesota.

Weltzien, H. C. 1981. Geographical distribution of downy mildews. *In* The downy mildew. D. M. Spencer, ed. Academic Press, London.

PART II

# ADDITIONAL AGROTECHNOLOGY TRANSFER STUDIES

Phosphorus Management in Benchmark Soils

Crop Performance in Benchmark Environments

Utilization of the Benchmark Soils Network

Matching Crops and Environments by Soil Taxonomy

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*Phosphorus Management in Benchmark Soils*

# 9 Comparison of Phosphate Rock Sources in Two Benchmark Soils

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and
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Large areas of currently cultivated or potentially arable land in the nonarid upland regions are occupied by soils for which phosphorus (P) deficiency is the factor most limiting crop production. Thus, finding economical methods to overcome P deficiency is an integral part of any solution to the problems of agricultural development in most developing countries of the tropics.

A possible strategy for overcoming P deficiency in acid soils of the tropics is direct application of indigenous phosphate rock. Direct application saves the cost of acidulation required for production of superphosphate or other soluble P fertilizers. In addition, the use of indigenous resources avoids the use of foreign exchange reserves for importing fertilizer P. Phosphorus requirements for plant growth are a function of soil properties. Furthermore, the form in which P is applied affects both its reactions with the soil and its availability to plants. Therefore, soils of different properties necessitate different strategies of P fertilization.

To evaluate these strategies on selected sites of the Benchmark experimental network, a collaborative research project between the Benchmark Soils Project and the International Fertilizer Development Center (IFDC) was initiated in early 1979. Field experiments were conducted on P sources at a Hydric Dystrandept site in the Philippines and a Typic Paleudult site in Indonesia.

## Phosphate Rocks

The most important phosphate minerals are members of the apatite group, which is the tenth most abundant mineral in the earth's crust (McClellan and Lehr, 1969). The most important sedimentary deposits of apatite in the world belong to the series called francolites. Members of this series vary with respect to the degree of substitution of carbonate for phosphate, as indicated by the formula

$$Ca_{10-a-b}Na_aMg_b(PO_4)_{6-x}(CO_3)_xF_{2+0.4x}$$

Lehr and McClellan (1972) found that as the substitution of carbonate increases, the solubility of the minerals in extractant solutions, such as

citrates, also increases. Thus, apatitic phosphate rocks with greater levels of carbonate substitution are expected to be more effective as direct-application P fertilizers. The maximum observed value of x in the formula was 1.4 (Lehr and McClellan, 1972).

Soil properties also affect the dissolution and ultimately the availability of P to plants. Soil acidity as expressed by pH is the most widely-recognized factor and its relationship to the effectiveness of directly-applied phosphate rock was demonstrated by Truog (1916) and Peaslee et al. (1962), among others. Also, the Ca saturation of the soil exchange complex influences phosphate rock effectiveness (Khasawneh and Doll, 1978). Other soil properties that correlate with P sorption capacity affect the rate of dissolution of phosphate rock. These properties are exchangeable Al and free iron (Chu et al., 1962; Smyth and Sanchez, 1982). However, the relationship of these properties to the availability of P from phosphate rock (as opposed to the dissolution of the rock) has yet to be clarified. In summary, the factors that affect the effectiveness of phosphate rock as directly-applied fertilizer are (1) the mineralogy of the apatite that affects reactivity, (2) soil properties, including pH as well as other properties that affect phosphate rock dissolution and P mobility in the soil, and (3) crop characteristics.

The relationship between soil properties and phosphate rock dissolution and subsequent P availability is complex. Within groups of soils that have similar mineralogy and organic matter properties, but with a range in a few chemical properties (e.g., pH), it may be possible to relate phosphate rock effectiveness to one or two commonly measured soil properties such as pH or Ca saturation. However, over all soils in the world or subsets of soils with a broad range in many properties, predicting phosphate rock performance based on commonly measured soil properties becomes a futile exercise. The practical solution to this problem is to group soils into categories with similar properties using Soil Taxonomy. Within the soil family it should be possible to identify relationships between phosphate rock performance and commonly measured soil properties and thereby provide a means for transfer of phosphate rock management. Additional information on the two soil families used in this study appears in Chapters 3 and 7.

## Phosphorus Fertilizer Materials

For this study phosphate rocks that had been well characterized in other studies were used. The chemical formulas of the apatites in the two rocks (North Carolina and Central Florida) are given in Table 1. There is a clear difference in the degree of carbonate substitution of the two rocks. The North Carolina rock has a degree of carbonate substitution

**Table 1. Apatite formulas for two phosphate rocks (courtesy of the International Fertilizer Development Center).**

| Phosphate rock | Apatite Formula |
|---|---|
| North Carolina | $Ca_{9.74}Na_{0.34}Mg_{0.43}(PO_4)_{5.7}(CO_3)_{0.3}F_{2.46}$ |
| Central Florida | $Ca_{9.54}Na_{0.19}Mg_{0.08}(PO_4)_{5.76}(CO_3)_{0.24}F_{2.46}$ |

**Table 2. Characteristics of seven phosphorus fertilizer source materials used in the Dystrandept (Philippines) and Paleudult (Indonesia) experiments.**

| Fertilizer material | Total $P_2O_5$ (%) | Solubility Water (% of total $P_2O_5$) | Solubility NAC (% of total $P_2O_5$) | Particle size |
|---|---|---|---|---|
| Simple Superphosphate (SSP) | 18 | 83.7 | 11.8 | Non-granular |
| Triple Superphosphate (TSP) | 46 | | | Conventional granular |
| North Carolina P rock | | | | |
| finely ground (NCf) | 29 | nil | 18.0 | 90%<0.06 mm |
| minigranular (NCm) (3% KCl binder) | 29 | nil | 19.5 | 0.1–0.3 mm |
| Central Florida P rock | | | | |
| finely ground (CFf) | 33 | nil | 11.2 | 80%<0.11 mm |
| minigranular (CFpam) partially-acidulated (20% $H_3PO_4$) | 39 | 48.5 | 11.0 | 0.1–0.3 mm |
| Fused Magnesium Phosphate (FMP) | 20 | nil | 36.5 | 0.9 mm |

Note: The International Fertilizer Development Center (IFDC) supplied the North Carolina and Central Florida materials and the others were obtained locally. The analyses were courtesy of Dr. L. L. Hammond, (IFDC). The neutral ammonium citrate (NAC) solubility determination utilized 100 ml 1N NAC/1g of fertilizer (65°C, 1 hour agitation). The TSP was assumed to meet international standards of >80% water and approximately 15% NAC soluble.

approaching the limit, as suggested by Lehr and McClellan (1972), of 1.4 moles per apatite formula. It is, therefore, a high reactivity rock. The Central Florida rock has an intermediate level of carbonate substitution and is, therefore, moderately reactive.

Table 2 describes all of the P materials used in the experiments in terms of pertinent chemical and physical properties. A soluble, acidulated, phosphate material was used as a standard in each case. In the Hydric Dystrandept experiment in the Philippines simple superphos-

phate (SSP) was used; and in the Typic Paleudult experiment in Indonesia triple superphosphate (TSP) was used, since these were the commonly available materials in the respective local economies.

Both phosphate rocks were each used in a finely-ground form and also in a modified form. The North Carolina rock was used in a physically modified form, i.e., minigranules were made from the finely ground material using KCl as the binding agent (Table 2), in order to determine whether minigranulation reduces agronomic effectiveness. The Central Florida rock was also used in the minigranular form, however, it had also been partially acidulated (20 percent) with $H_3PO_4$, i.e., 20 percent of the acid necessary to make TSP was added during the minigranulation process. The acidulation products served as the binding agent for granulation. The objective of this treatment was to determine whether partial acidulation adequately increased the effectiveness of this moderately reactive rock, whose particle size range and solubility data are presented in Table 2.

In the Philippines fused magnesium phosphate (FMP) was used at three of the four rates. FMP is a phosphate fertilizer prepared by fusion of phosphate rock with a natural magnesium silicate, such as olivine or serpentine, at temperatures of 1450°C to 1550°C. In addition to P, this material contained 10 percent Mg, 22 percent Ca, and 15 percent Si.

## Research Methodology

Selected chemical properties of soil samples from the two experimental sites are presented in Table 3. The analysis of samples taken immediately before planting the first crop are considered to be more representative of the chemical environment during the period of the experiments reported here than the classification samples. Comparison of pH values both in water and KCl show the Typic Paleudult to be slightly more acid than the Hydric Dystrandept; however, the Typic Paleudult is higher in bases. The P sorption levels of the Hydric Dystrandept are approximately eight times that of the Typic Paleudult at equal P solution concentrations.

For both the Hydric Dystrandept experiment and the Typic Paleudult experiment a split-plot experiment was used, with phosphorus rates as the main plots in a randomized complete block design and phosphorus sources as the subplots. For the first plantings most of the main plots also contained a phosphorus control. For subsequent replantings these controls were selectively used for reapplication of superphosphate to provide a comparison with the residual effects of the sources. Because of the reduced yields of second season residual treatments, selected treatments received reapplications of P sources for the third season. For purposes of analysis of variance, a four rate (main plot) by five source (sub-

**Table 3. Chemical properties of the surface soil at the two experimental sites.**

| | | Hydric Dystrandept (Philippines) | | Typic Paleudult (Indonesia) | |
|---|---|---|---|---|---|
| | | a | b | a | b |
| Sampling interval (cm) | | 0–17 | 0–15 | 0–12 | 0–15 |
| Exchangeable bases (meq/100g) | Ca | 3.84 | 0.97 | 7.44 | 2.23 |
| | Mg | 0.64 | 0.59 | 1.14 | 1.09 |
| | K | 0.27 | 0.08 | 0.76 | 0.27 |
| | Sum | 4.75 | 1.64 | 9.34 | 3.59 |
| Extractable Al (meq/100g) | | 1.29 | — | 0.05 | — |
| Al saturation | | 21% | — | 1% | — |
| pH in $H_2O$ | | 5.4 | 5.15 | 4.82 | 4.96 |
| pH in KCl (1N) | | 4.5 | 4.61 | 4.16 | 4.53 |
| Delta pH | | —0.9 | —0.54 | —0.66 | —0.43 |
| Extractable P (ppm) | | | | | |
| Modified Truog | | — | 4.1 | — | — |
| Bray I (7:1) | | — | <0.2 | — | 1.4 |
| Bray I (30:1) | | — | 7.5 | — | — |
| P sorption | | | | | |
| μg P/g to attain | | | | | |
| 0.01 μg P/ml | | | 200 | | 25 |
| 0.2 μg P/ml | | | 2656 | | 350 |

Note: The data in column (a) were determined from classification samples taken before sites were cleared (Ikawa, 1979) and those in column (b) are mean values for samples taken after clearing the experimental area but before planting the first crop.

plot) factorial with three replications was maintained throughout both experiments. General management of the experiments was similar to the transfer experiments of the Benchmark Soils Project (Chapter 4). Based on the subplot experimental error (MS) from the split-plot analyses of variance the Bayesian Least Significant Difference (BLSD) at the 5 percent level was calculated (Duncan, 1965) as the square root of $(2MS/3)(1.721)^2(F/F-1)$ where F is the ratio of the P-source mean square to the subplot experimental error mean square (MS) and 1.721 is the appropriate value of the t statistic.

The experimental crop was maize, except in the second crop of the Paleudult when soybeans were planted to avoid a downy mildew attack on the maize. To assure that no nutrient other than P limited crop yield, basal applications of N, K, Mg, S, Zn, and B were made throughout

the period of the experiments. Additional information on the phosphate materials and the experiments is given by Harris (1983).

## Comparison of Phosphorus Sources

Grain yields are presented in Figure 1 for the three harvests on the two soils. For the first crops on the two soils, large differences in yield between sources is evident on the Dystrandept, whereas there are no significant differences between superphosphate and the other sources on the Paleudult. On the Dystrandept the order of diminishing effectiveness of sources is FMP > SSP = NCf = NCm = CFpam > CFf. The superiority of FMP is clearly evident and this effect is not attributable to the Mg which it supplies because of the fact that all of the treatments received 75 kg Mg/ha as sulfate at planting. The marked difference between the North Carolina rock and the Central Florida rock on the Dystrandept demonstrates the difference in reactivity of the two rocks; however, on the Paleudult the effect of apatite reactivity is not evident, indicating that soil properties can overcome the reactivity effect. Due to borer infestation after tasseling and a typhoon during the later part of the growing season, yields were low at the Dystrandept site and a yield plateau was not evident.

For the second crop, new applications of superphosphate were made to selected control plots to permit a comparison with the residual effect of the other treatments. On the Dystrandept, differences in residual effects for the different sources are evident. Also, the relative residual effect of the rock sources compared to the residual effect of SSP is higher at the low rates.

On the Paleudult (where soybeans were planted for the second crop) no significant differences between the residual effects of the rock sources and superphosphate are evident. This is consistent with the observed absence of differences between sources for the first crop on this soil.

Due to the more rapid disappearance of the residual effects on the Dystrandept, as compared with the Paleudult, reapplication of treatments was necessary for the third crop on the Dystrandept. On the Paleudult, reapplications of all of the sources were made only for the lowest P treatment (10 kg P/ha), to which 70 kg P/ha was applied to permit comparison with the residual effects on the treatments which had received 80 kg P/ha for the first crop. The results in Figure 1 for the third consecutive season show no significant differences between sources on the Paleudult even for the treatments which received fresh applications of 70 kg P/ha. In contrast, some differences are evident for the reapplications on the Dystrandept (Figure 1). For the treatments at the highest rate CFf had significantly lower yields than those of the other P sources which indicated that partial acidulation improved the performance of the Central Florida Rock. Yields of the FMP treatment

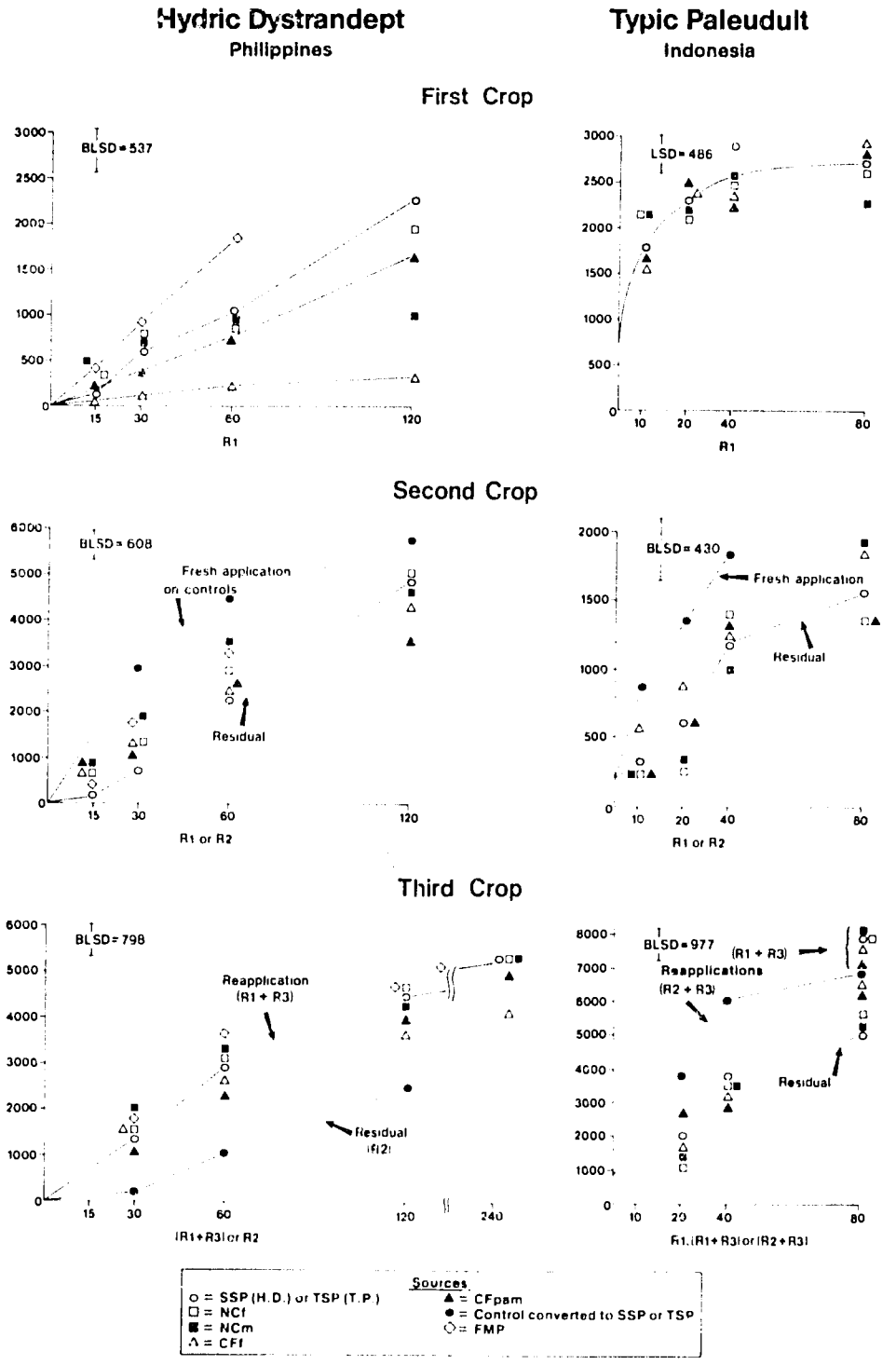


**Fig. 1.** Yield is maize grain except for the second crop on the Paleudult (soybean). Phosphorus rates (kg P/ha) are identified by R1, R2, and R3 which are respectively the rates applied for the first, second, and third crops.

were consistently higher than those of SSP all along the response curve. This is similar to the result observed in the first crop.

With respect to the modified rock sources on the Dystrandept (which is the soil that showed differences between sources), minigranulation of the highly-reactive North Carolina rock did not reduce effectiveness, thus confirming the agronomic viability of this process. For the moderately-reactive Central Florida rock, partial acidulation did improve the effectiveness relative to the untreated rock; however, the increase in effectiveness was not sufficient to make it equal to superphosphate or the untreated North Carolina rock.

The results of the experiments on the Paleudult indicate that it is a soil well suited to the direct application of phosphate rock of high and intermediate reactivity, and suggest that it may also be adapted for phosphate rocks of low reactivity. In comparison, the Dystrandept requires highly reactive phosphate rock to produce yields comparable to those with superphosphate. Considering the chemical properties presented in Table 3, the difference in the response to the phosphate rocks in the two soils can be related to the fact that the Paleudult had a slightly lower pH and a considerably lower P sorption capacity than the Dystrandept. These results provide a sound basis for further research on the relationship between response to phosphate rocks and soil properties that correspond to Soil Taxonomy classification categories.

## References

Chu, C. R., W. W. Moschler, and G. W. Thomas. 1962. Rock phosphate transformations in acid soils. Soil Sci. Soc. Am. Proc. 26:476–478.

Duncan, D. B. 1965. A Bayesian approach to multiple comparisons. Technometrics 7:171–222.

Harris, D. J. 1983. Evaluation of phosphorus fertilizer materials on two Benchmark soils of the tropics. Ph.D. dissertation, Univ. Hawaii.

Ikawa, H. 1979. Laboratory data and descriptions of soils of the Benchmark Soils Project: Vol. 1—Hawaii project. Misc. Pub. 165 (BSP Tech. Rept. 1). Hawaii Agr. Exp. Sta., College of Trop. Agr., Univ. Hawaii.

Khasawneh, F. E., and E. C. Doll. 1978. The use of phosphate rock for direct application to soils. Adv. in Agron. 39:159–206.

Lehr, J. R., and G. H. McClellan. 1972. A revised laboratory reactivity scale for evaluating phosphate rocks for direct application. Bull. Y-43. Tennessee Valley Authority, Muscle Shoals, Alabama.

McClellan, G. H., and J. R. Lehr. 1969. Crystal chemical investigation of natural apatites. Am. Mineralogy 54:1374–1391.

Peaslee, D. E., C. A. Anderson, G. R. Burns, and C. A. Black. 1962. Estimation of relative value of rock phosphate and superphosphate to plants on different soils. Soil Sci. Soc. Am. Proc. 26:566–570.

Smyth, T. J., and P. A. Sanchez. 1982. Phosphate rock dissolution and availability in Cerrado soils as affected by phosphorus sorption capacity. Soil Sci. Soc. Am. J. 46:339–345.

Truog, E. 1916. The utilizing of phosphate by agricultural crops, including a new theory regarding the feeding power of plants. Res. Bull. 41. Wisconsin Agr. Exp. Sta., Madison, Wisconsin.

*Phosphorus Management in Benchmark Soils*

# 10 Evaluation of Residual Phosphorus in Two Benchmark Soils

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Response to phosphorus (P) fertilizer application is affected by the availability of residual P from prior incorporation of P sources. This was encountered in the Benchmark Soils Project soil family network where soils differed in their history of P application and level of residual P. Since agroenvironments differed at experimental sites, it was impossible to assess the effects of varying residual P levels. This study was undertaken to determine the effects of different levels of residual P on soil test P values and on the yield response to newly applied fertilizer P within a constant agroenvironment.

Evaluations of residual P usually include an assessment of changes in factors which affect P availability. These include intensity and quantity factors and the buffer power of a soil, measured after fertilizer P application. The intensity factor is evaluated by measuring P concentration in the soil solution or in a soil extract of 0.01*M* $CaCl_2$ with a solution:soil ratio of 10 or less. The quantity factor is assessed by (1) isotopic dilution techniques, (2) resin extraction, or (3) chemical extraction with an acid or alkaline solution. A P-sorption curve provides the relationship of the intensity and quantity factors, and thus an estimate of the buffer power of a soil. An extraction curve, on the other hand, depicts the relationship of the quantity factor and P added, and an index of the buffer power. Biological procedures have also been used to evaluate the agronomic value of residual P, through experimentation in both the greenhouse and field.

Many studies have been devoted to the evaluation of residual P (Barrow, 1980). The present investigation includes studies on (1) change in extractable soil P with time, (2) maize response to P applications at different levels of residual P, (3) calibration of soil test values, (4) P-sorption and extraction curves, and (5) evaluation of phosphorus reapplication methodology.

## Establishment of Residual Soil P Levels

Experiments on maize response to P application to soils with varying levels of residual P were conducted on a Typic Paleudult at Nakau (NAK), Sumatra, Indonesia, and on a Tropeptic Eutrustox at Mauna

Loa, Molokai (MOL), Hawaii (Widjaja-Adhi, 1983). These soils are described in Chapter 3. A range of residual soil P levels was established by allowing different rates of applied P to equilibrate to the point where slow reactions approached a "steady state" and then superimposing on each residual P level (main plot) a range of freshly applied P in subplots in a split-plot experiment. In order to establish the desired range of residual soil P, an amount of P was applied that was calculated to give the proper soil P level after 4 to 6 months of equilibration. This was done using the P-sorption curve procedure of Fox and Kamprath (1970) which indicated that for the Typic Paleudult site, a soil solution P level of 0.01 μg P/ml, could be attained by the addition of 120 μg P/g soil or 240 kg P/ha. A range of soil P was achieved by applying 0, x/4, x/2, and 3x/4 of the P fertilizer (x) required to attain the external P requirement (0.01 μg P/ml) or the amount to produce maximum yields. It was assumed that final P represents 35 percent of the initial P in the soil solution after 4–6 months of equilibration, based on a laboratory study of Munns and Fox (1976). For the Typic Paleudult site, the P rates were 0, 60, 120, and 180 kg P/ha which was applied 15 months before the maize was planted. For the Tropeptic Eutrustox site, it was estimated that 60 kg P/ha was required to achieve maximum yield. Therefore, P rates of 0, 15, 30, and 45 kg P/ha were applied 8 months prior to the maize experiment. Sorghum was grown during establishment of residual soil P levels at both sites. At the time maize was planted it was assumed that residual soil P levels had essentially reached a "steady state." Fertilizer rates for the second application were 0, 10, 20, 40, and 80 kg P/ha for the Paleudult, and 0, 10, 20, 40, and 60 kg P/ha for the Eutrustox.

Each experiment was installed as a split plot, with the residual levels as main plots in a randomized complete block design and the reapplied rates randomized within each main plot. The 20 treatments, with four replications, are then factorial combinations of the four residual levels and five reapplied rates. General management of the experiments was similar to that of the transfer experiments of the Benchmark Soils Project (Chapter 4).

## Change in Extractable Soil P With Time

Composite samples were taken at the Paleudult site from each main plot after harvest of the sorghum crop and its ratoons, and similar samples were taken after harvest of the maize crop from each subplot that did not receive fertilizer P. The decrease in residual P from the application of 60 to 180 kg P/ha was 1.25 to 1.75 mg P/g soil/100 days under sorghum, and 2.0 to 5.0 mg P/g soil/100 days under maize (Figure 1).

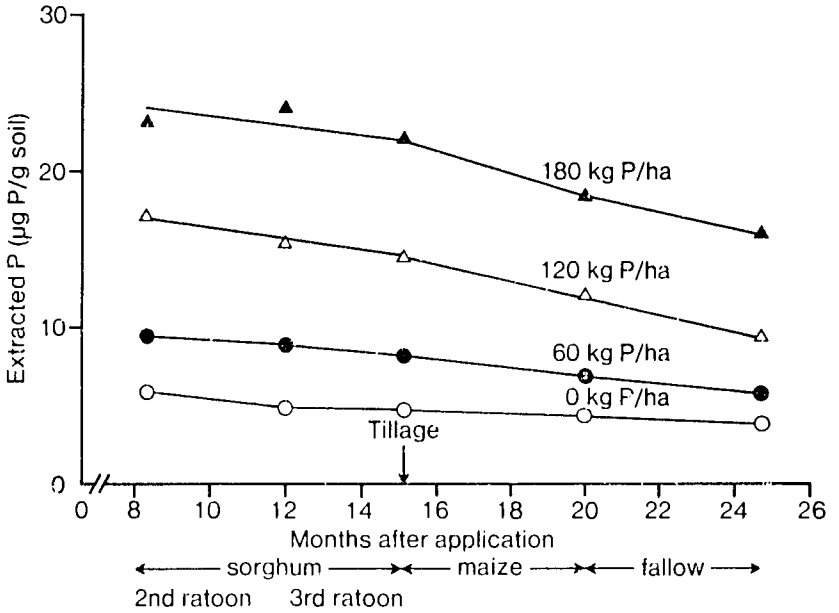


**Fig. 1.** Changes in modified Truog extractable P of residual P on the Typic Paleudult.

The higher rate of decrease in extractable P under maize was probably due to cultivation of the soil prior to planting the maize crop. This cultivation mixed particles which were differentially saturated with P. This brought about a re-equilibration that enhanced the slow reactions which converted extractable forms of P into non-extractable forms and resulted in a more rapid decrease in extractable P. The modified Truog extractable P in plots that received 120 kg P/ha was initially high, but declined to the critical level of soil P (12 µg P/g) within 2 years.

At the Eutrustox site, composite samples were taken from each main plot every 4 weeks during the sorghum crop. Modified Truog P was determined and found to decrease with time in all treatments receiving P (Figure 2). In the treatment that did not receive P fertilizer, extractable P increased slightly due to the decomposition of fresh organic matter incorporated into the soil during land clearing and preparation. In the P fertilized main plots this release of P by organic matter decomposition was probably masked by the magnitude of the slow reactions of P. The modified Truog extractable P levels in plots that received 30 kg P/ha or more remained above the critical level (18 µg P/g) for the entire 28 week period of the experiment. The soil P status under a cropping system depends on the rate of P application and the intensity of crop cultivation.

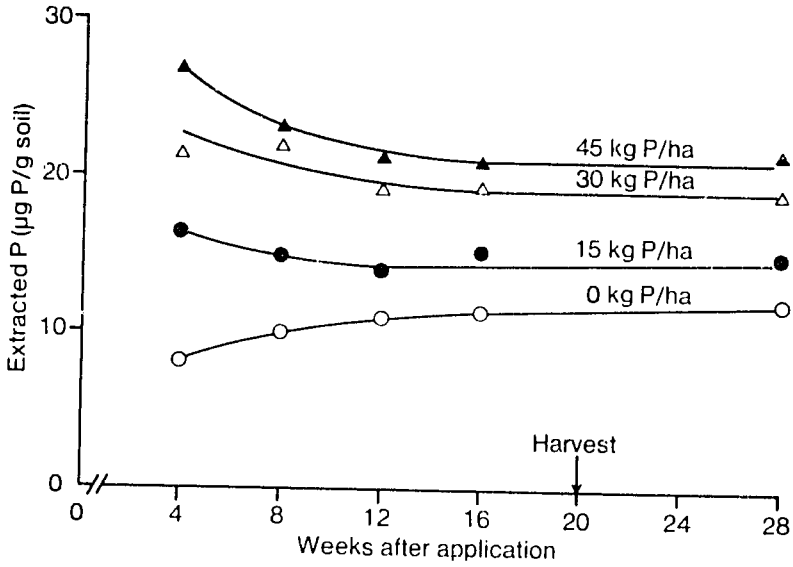


**Fig. 2.** Changes in modified Truog extractable P of residual P on the Tropeptic Eutrustox.

## Maize Response to P Application at Different Levels of Residual P

Maize response to the second P application varied with established soil P levels (Figure 3). The response curve of main plot A (Paleudult), previously unfertilized, was steeper than that of main plot B, which previously received 60 kg P/ha. The curve of main plot C, that received 120 kg P/ha was almost flat and there was no response in main plot D, that received 180 kg P/ha, since yields of all rates of freshly applied P were on the yield plateau. A similar trend was apparent for the Eutrustox, but with some variations. The yield response curve for main plot A (unfertilized) was steeper than those for the other treatments and yields for the two highest P rates were on the yield plateau in main plot D (45 kg P/ha). There was more variation in the yield response of the B (15 kg P/ha) and C (30 kg P/ha) main plots. Generally, in both soils the higher the level of residual P, the smaller the yield response to P application.

## Calibration of Soil Test Values

Composite soil samples taken from each main plot before the second P fertilizer application were analyzed for extractable P using modified Truog (100:1 solution:soil ratio), Bray-1 (30:1), Bray-1 (10:1), and Olsen (20:1) extractants. The soil test values for each extractant were arranged in ascending order, along with their associated maximum

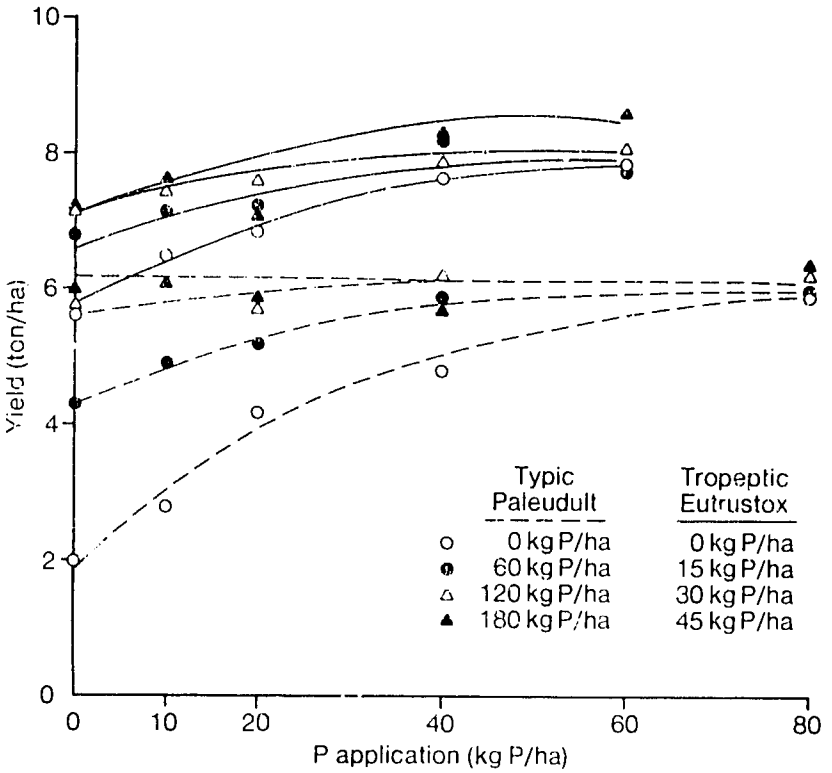


**Fig. 3.** Maize response to P application at different levels of residual P on the Typic Paleudult (dashed) and Tropeptic Eutrustox (solid).

change in yield, which is the difference between the highest yield of a treatment within each main plot and the yield of the control plot of that main plot. A variance analysis method, modified by Nelson and Anderson (1977) was used to partition the soil test values into classes. The soil test values were grouped into three classes using prescribed principles for constructing the boundaries of the subgroups. These are high, moderate, and little/no response to P application. The tentative partition of soil test values for maize response to P application resulting from this analysis is shown in Table 1 for the Typic Paleudult and Tropeptic Eutrustox. It is apparent that interpretation of the modified Truog and Bray-1 (30:1) values can not be transferred between the two soils since the critical levels above which there is little or no response to P application are 12 and 18 μg P/g with modified Truog, and 16 and 21 μg P/g with Bray-1 (30:1) for the Typic Paleudult and Tropeptic Eutrustox, respectively. Critical levels for the Olsen and Bray-1 (10:1) methods, on the other hand, are comparable for the two soils; but their range of values is narrow, indicating a lack of sensitivity to variations in soil P.

**Table 1. Tentative partition of soil test values (μg P/g) for maize response to P application on the Typic Paleudults and Tropeptic Eutrustox.**

| Soil Test | Soil family | Maize response to P | | |
|---|---|---|---|---|
| | | High | Moderate | Little |
| Modified Truog (100:1, 30 min) | Paleudult | <6 | 6–12 | >12 |
| | Eutrustox | <12 | 12–18 | >18 |
| Bray-1 (30:1, 1 min) | Paleudult | <8 | 8–16 | >16 |
| | Eutrustox | <14 | 14–21 | >21 |
| Bray-1 (10:1, 5 min) | Paleudult | <5 | 5–10 | >10 |
| | Eutrustox | <5 | 5–9 | >9 |
| Olsen (20:1, 30 min) | Paleudult | <3.5 | 3.5–7.0 | >7.0 |
| | Eutrustox | <5.0 | 5.0–7.0 | >7.0 |

## P-sorption and Extraction Curves

A P-sorption curve for each main plot sample was determined with the procedure of Fox and Kamprath (1970). P-sorption data are presented as a semi-log plot for both sites in Figure 4. Slopes of the sorption curves for the Paleudult site are all curvilinear, but differ slightly, especially for lower levels of sorbed P. Curves for the Eutrustox site, on the other hand, were curvilinear as well as linear for some treatments and differed markedly at the lower levels of sorbed P. This reflected the greater variability in the P status of the plots. Less P was required to attain a given level of P in solution (0.02 μg P/ml) for plots with higher levels of residual P.

A modified Truog-extraction curve was also determined for each main plot. P-extraction curve data were averaged over replications and plotted in Figure 5. The extraction curves for main plots A, B, C, and D were parallel (only A and D are shown in Figure 5). The slopes ($b_1$) of the curves varied slightly (2.2 to 2.4) for the Paleudult, while those for the Eutrustox site had a wider range and larger values (2.7 to 3.5). These slopes indicate the amount of P required to bring about a unit increase in extractable P. The value of ($1-1/b_1$) is equal to the P retention coefficient of the soil.

Both P-sorption and extraction curves shifted to the right as the level of residual P increased, so that less P was required to bring P in the soil solution or extractable P to the desired external P requirement or "critical level" of extractable P.

## Evaluation of Phosphorus Reapplication Methodology

The effect of residual P on maize response to freshly applied P made it necessary to develop a procedure for determining P reapplication rates

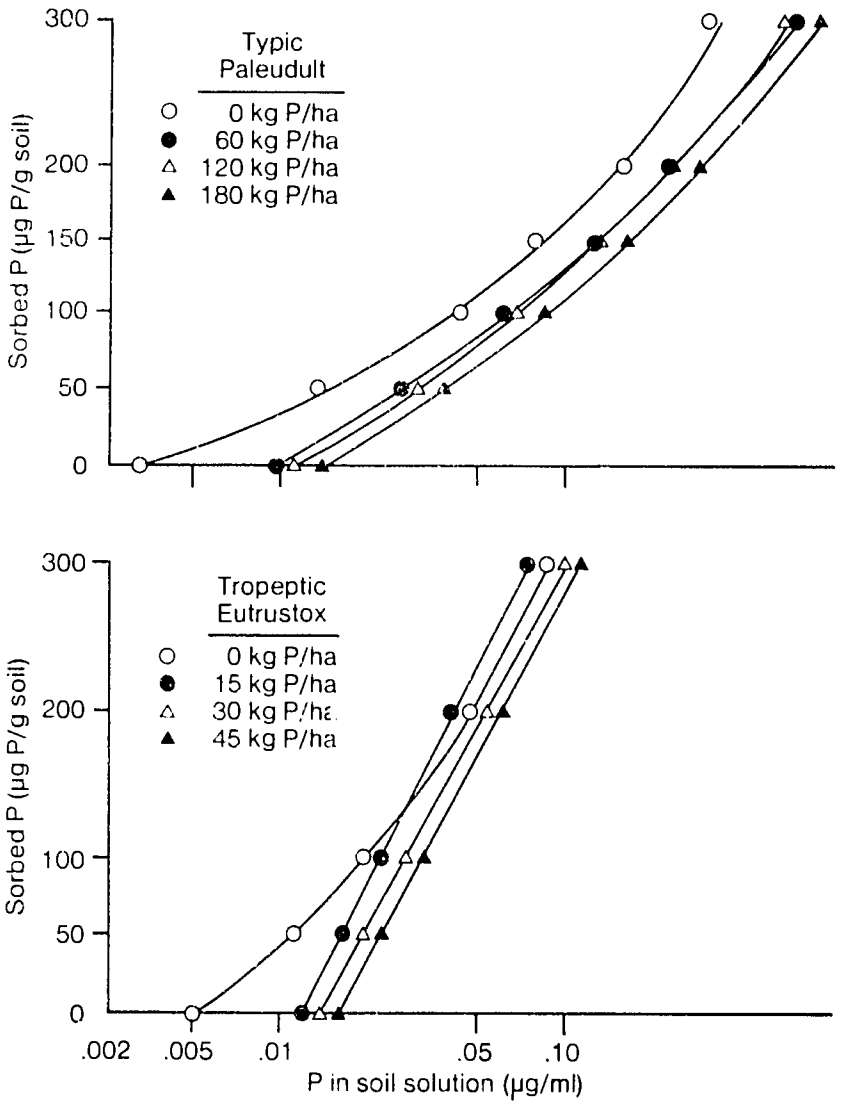


**Fig. 4.** P-sorption curves.

for additional fertility experiments on plots of several transfer experiments (see Chapter 4 for a description of a transfer experiment). The reapplication rate procedure attempted to reestablish the P levels so that the same P response curve would be expected for a transfer experiment and subsequent management (reapplication) experiments. No strong evidence for rejecting the hypothesis of equal P response curves was interpreted as confidence in the soil test calibration procedure to reestablish the P reapplication rates of the original transfer experiment.

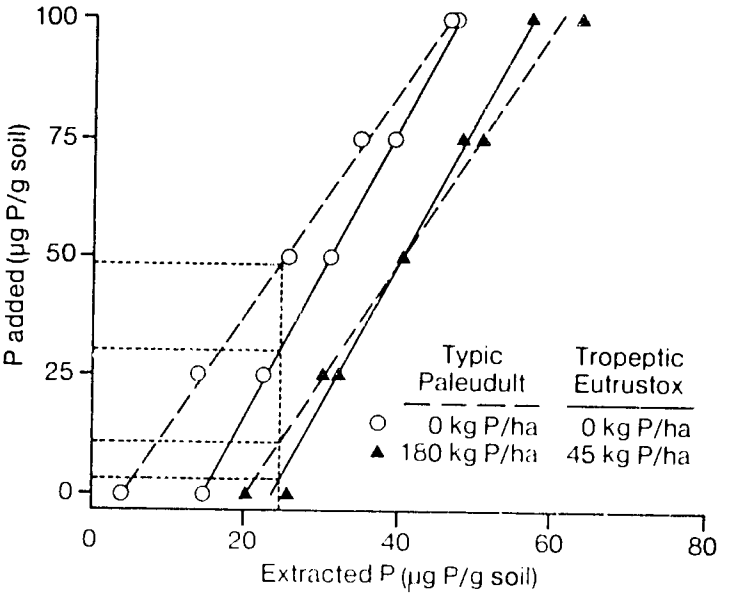


**Fig. 5.** Modified Truog extraction curves of the Typic Paleudult (dashed) and Tropeptic Eutrustox (solid).

*Methodology*: After harvest of a transfer experiment, post-harvest soil samples from each plot were analyzed for soil P by the modified Truog method. These Truog data were used to estimate the intercept and slope of a line between Y (the applied P levels of the transfer experiment using a 0 to 2 coded scale rather than −1 to +1 as in Chapter 4) and the square root of X (the post-harvest Truog values). The equation was solved for X by setting Y equal to the middle value of the applied P scale. This estimate of P remaining in the soil was substituted into the equation of the original extraction curve (used to establish the P applied rates of the transfer experiment), and the equation solved for Y (P added). The difference between the residual soil P (expressed on the P added scale) and half the value of Y (when the square root of 25 was substituted in the original extraction curve [Chapter 4]) was the amount of P required to reestablish the original applied P level at the middle point of the applied P rates. The other four applied levels were established as shown in Chapter 4.

Data from an experiment are used as an example of the calculation of the amount of P required to reestablish original soil P levels. Post-harvest soil samples taken from each plot were analyzed for soil P by the modified Truog method described in Appendix E. The square roots (SQRT) of the modified Truog extractable P values were plotted on the X axis and the coded applied P levels plotted on the Y axis using a 0 to 2

coded scale rather than the −1 to +1 scale. The equation describing this relationship is

$$Y = -2.75 + 1.05\,[\,SQRT(X)\,]$$

This equation was solved for X when Y was set equal to one which gives X = 12.6, the amount of modified Truog P remaining in the soil at the middle treatment level. This estimate of soil P was then substituted into the original extraction curve (used to establish the P applied rates of the transfer experiment) for the relationship between P added and modified Truog extractable P.

$$Y = -60.8 + 23.2\,[\,SQRT(12.6)\,]$$

$$= 21.6\ \mu g\ P/g\ soil$$

This equation was also solved for Y with modified Truog P set equal to the desired soil P level of 25 ppm to give Y = 55.2 μg P/g. Dividing this value by 2 gave an applied P of 27.6 μg P/g at the middle level. The difference between the residual soil P expressed as P added, 21.6, and applied P at the middle level, 27.6, was 6.0 μg P/g which is the P required to reestablish the original applied P level at the mid-point of the P rates. The other four applied P rates were established as described in Chapter 4. The rates for the five coded levels of P are 0.9, 3.6, 6.0, 8.4, and 11.1 μg/g soil.

This procedure was utilized during the last phase of the Benchmark Soils Project. In the earlier reapplication experiments the rates were established using a procedure which was similar but different in that the lower limit of the Truog P range corresponding to the coded applied range of −1 to +1 was adjusted, and the reapplication rate was established independently for each of the five applied rates.

Reapplication experiments were carried out in the three soil families of the Benchmark Soils Project network. Emphasized here is the Typic Paleudult family. Twelve transfer experiments were utilized, including sites at BAK and CAM in Cameroon; BPM, BUK, and NAK in Indonesia; and SOR in the Philippines. These sites are described in Chapters 3 and 7. In addition to the first reapplication experiment with each of the 12 transfer experiments, a second reapplication was established on seven of the 12, and a third reapplication of P levels on two of the seven. In total, there were 33 experiments, including the original 12 transfer and 21 reapplication experiments.

*Phosphorus response curves.* The hypothesis of equal P response curves was statistically evaluated by comparing the P response curves for each set of the 12 transfer and reapplication experiments using methodology described in Chapter 19 of Allen and Cady (1982). Briefly, the quadratic polynomial model, $\bar{y}_i + b_{1i}P + b_{2i}P^2$, described in Chapter 5 is

compared with the model $y_i + b_1P + b_2P^2$ where i is the index for the P response curves of each set of transfer and reapplication experiments. The F statistic showed that the P response curves were different for the majority of the 12 sets.

Examination of the yield data and the data analyses for those transfer experiments with preplant Truog values less than 5 ppm (Table 2) showed that the $b_1$ value of the response curve in the first reapplication experiment was sensitive to the applied rate at the lowest level of applied P (PCODE = -0.85). One reason for the sensitivity at the lowest applied level was that the preplant Truog value for most of the 12 transfer experiments was less than 5. When soil P is low, the estimates of the response curve will reflect small differences in applied P at the low rate.

A data-analytic procedure was then formulated with a focus on adjusting the PCODE value at the lowest applied level of the reapplication experiment. The steps included (1) calculation of the P response curve using all yield data except the lowest applied P rate for the reapplication experiments, (2) calculation of new PCODE values for the lowest applied rate of the reapplication experiments based on the esti-

**Table 2. Experimental results for nine pairs of transfer (listed first within each pair) and first reapplication experiments.**

| Experiment | Preplant Truog (ppm) | Applied P at low rate (kg/ha) | P linear response ($b_1$) (kg/ha) |
|---|---|---|---|
| BPMA | 4.1 | 13 | 1529 |
| | | 22 | 975 |
| BPMC | 4.1 | 13 | 1123 |
| | | 13 | 2719 |
| BPMD | 3.1 | 9 | 1944 |
| | | 22 | 1049 |
| BUKD | 4.6 | 8 | 1591 |
| | | 13 | 830 |
| BUKE | 4.9 | 8 | 1480 |
| | | 10 | 1056 |
| NAKA | 3.7 | 29 | 1429 |
| | | 11 | 995 |
| NAKD | 4.9 | 12 | 957 |
| | | 8 | 1351 |
| SORA | 2.9 | 11 | 1917 |
| | | 7 | 2344 |
| SORB | 3.4 | 12 | 1624 |
| | | 8 | 2815 |

mated P response curve from the previous step, (3) calculation of P response curves for each transfer experiment and reapplication experiment using the newly calculated PCODE values for the lowest P applied rate, and (4) tests for equality of P response curves. Now, the hypothesis of equal P response curves was not rejected except for BPMC.

The results for BPMD (a transfer and three reapplication experiments) reflect the nature of the adjustment procedure. At the lowest P applied level, the PCODE value was adjusted to -0.66 for the first reapplication experiment, remained at -0.85 for the second, and adjusted to -0.90 for the third. With these adjustments, the F statistic evaluating the equality of the four response curves was small (close to 1), indicating a lack of evidence for rejecting the hypothesis of equal response curves.

## Transfer of Maize Response to P Application

Residual P was found to have a marked effect on P availability and crop response to applied P. With higher levels of residual P there was a larger amount of extractable P, and consequently, reduced quantities of P needed to attain the P requirement or critical level of P for optimum crop growth. A unique yield response curve described the response to applied P for each level of residual P so that the predicted yield response varied with residual P. Evaluation of the P reapplication procedure in management experiments with residual P suggests that the soil test calibration procedure properly reestablished the applied P levels except for the lowest P applied level at sites with very low soil P. Within a soil family, information on maize response to P application is transferable, if and only if the soil fertility change due to soil management can be evaluated. Therefore, a soil P test is an essential component in transferring information on crop response to P application within a soil family.

## References

Allen, D. M., and F. B. Cady. 1982. Analyzing experimental data by regression. Van Nostrand Reinhold, New York.

Barrow, N. J. 1980. Evaluation and utilization of residual phosphorus in soils. *In* The role of phosphorus in agriculture. F. E. Khasawneh, E. C. Sample, and E. J. Kamprath, eds. American Society of Agronomy, Madison, Wisconsin.

Fox, R. L., and E. J. Kamprath. 1970. Phosphate sorption isotherms for evaluating the phosphate requirements of soils. Soil Sci. Soc. Amer. Proc. 34:902–907.

Munns, D. N., and R. L. Fox. 1976. The slow reaction which continues after phosphate adsorption: Kinetics and equilibrium in some tropical soils. Soil Sci. Soc. Am. J. 40:46–51.

Nelson, L. A., and R. L. Anderson. 1977. Partitioning of soil test-crop response probability. *In* Soil testing. Correlating and interpreting the analytica results. T. R. Peck, J. T. Cope, Jr., and D. A. Whitney, eds. Spec. Pub. 29 American Society of Agronomy. Madison, Wisconsin.

Widjaja-Adhi, I P. G. 1983. Predicting maize response to phosphorus application in relation to residual phosphorus in Paleudult and Eutrustox soils. Ph.D. dissertation, Univ. Hawaii.

*Crop Performance in Benchmark Environments*

# 11 Performance of Nitrogen-Fixing Trees in Benchmark Environments

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The future outlook of the millions of people in the tropics dependent on fuelwood for energy requires that a concerted effort be made not only to wisely manage the existing tropical forests, but also to increase the supply of fuelwood through new plantings.

Trees most likely to prove useful for increased fuelwood production are those termed "pioneers," which by nature are aggressive and tolerant of hostile environmental conditions. Many of these "pioneers" are rapid-growing legumes that have been known to tropical foresters for years, but are often neglected because their poor form, soft wood, and other qualities made them inferior for traditional production of timber and pulp. The usefulness of nitrogen-fixing trees, however, can extend beyond their ability to produce biomass, as many of the species can also be used for forage and soil enrichment. It is their multipurpose character that makes these trees attractive as fuelwood species in the developing tropical countries.

Knowledge of tree crops and their environmental requirements is needed to begin effective planning. The National Academy of Sciences (1980) compiled the environmental requirements for 60 fast-growing fuelwood trees and grouped them according to their suitability to the humid tropics, the tropical highlands, and the arid and semiarid regions. The objective of planning for fuelwood production is to select the appropriate environment to match these requirements. This chapter discusses methods to determine suitability of an environment for tree crops, offers a method of identifying soils suitable for nitrogen-fixing leguminous fuelwood trees, and presents experimental results from trials of the Benchmark Soils Project.

## Transfer of Fuelwood Production Technology

In many parts of the world the technology for growing a great number of economic crops has been established through years of testing and experimentation. Anyone desiring to grow any of these crops need not go through the tedious and expensive process of rediscovery. To some degree, historic information of this nature is available for fuelwood trees. Good planning requires careful attention to many factors to max-

imize the likelihood of success in transferring such agrotechnologies. In addition to the proper socioeconomic, political, and administrative conditions, successful agrotechnology transfer depends greatly on the relationship of the crop to the environment where it grows or will be grown.

Both crop and environmental information are needed for effective agrotechnology transfer, as the two aspects must be carefully matched to ensure success. Agronomic information on most of the recommended fast-growing leguminous trees (National Academy of Sciences, 1980) remains limited when compared to information available for more traditional crops. The problem is further aggravated by the long period required to obtain tree-crop performance information from field experiments. Despite these limitations, however, there is sufficient knowledge of the general climatic and soil requirements of leguminous trees that a suitable agroenvironmental niche for optimum growth can be identified.

Soil Taxonomy categorizes the environment in regard to soil properties as well as moisture and temperature regimes. By extracting information from the soil name, the environment can be matched with the crop requirements. For example, optimal growth of a tree species may require a warm environment, adequate calcium, and non-limiting water supply throughout most of the growth period. Using Soil Taxonomy, one can pick out soils having an isohyperthermic temperature regime (>22°C), a udic or humid moisture environment, and a high base saturation. There are two soils in the soil order category that have high base saturation, the Mollisols and Alfisols. In the Mollisols, the Udolls have a udic moisture regime; in the Alfisols, the Udalfs should provide the same moisture conditions. Soil families with isohyperthermic temperature regimes should complete the necessary requirements of these trees. A case example of matching tree requirements to the environment is given by Cagauan et al. (1982).

Unlike annuals that complete their life cycles in a few months, trees take several years. By integrating conditions of soil and weather over several years, trees are effective indicators of the use of soil families as functional determinants of agroproduction niches.

## Nitrogen-Fixing Tree Trials

The Benchmark Soils Project participated in a study of nitrogen-fixing trees in collaboration with Dr. J. L. Brewbaker of the University of Hawaii. In this study experiments were established in various countries to determine the adaptability of species to different environments and to study the genotype by environment interaction of the species. In the Benchmark Soils Project experiments, 16 tree species were planted in four locations in three countries. The purpose of these experiments was

**Table 1. Tree species in the nitrogen-fixing tree trials.**

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

to assess species by soil family (genotype by environment) interactions of perennials in Benchmark environments and to obtain information by which to match specific tree requirements to land characteristics.

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

The 16 selected species, mostly legumes, are listed in Table 1. Additional details on the species can be found elsewhere (National Academy of Sciences, 1989; MacDicken, 1983). Five of these species were replicated four times in 4 by 7 m plots with 4 by 4 m spacing (10,000 trees/ha). The experimental design was a randomized augmented block design with each of the replicated species occurring in each block, while each unreplicated species was randomly allocated to one of the blocks.

The trials were located at four sites representing the following soil families: (1) thixotropic, isothermic Hydric Dystrandept at Niulii (IOLE) in Hawaii (Hawaii), (2) clayey, kaolinitic, isohyperthermic Typic Paleudult at Nakau (NAK) in Indonesia (Sumatra), (3) clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox at Waipio (WAI) in Hawaii (Oahu), and (4) very fine, kaolinitic, isohyperthermic Ultic Tropudalf at Davao (DAV) in the Philippines (Mindanao). (See Chapter 3 for more information on the soil families.) Environmental data for the four soil families are listed in Table 2.

## Nitrogen-Fixing Tree Performance

All sites were planted at nearly the same time during the 1981–82 wet season and supplemental irrigation utilized so that soil moisture would not be limiting during seedling establishment. After five months of growth the seedlings showed visible differences. At the cool highland Hydric Dystrandept site, only two (*Acacia mearnsii* and *Eucalyptus saligna*) of the 16 tree species had shown much growth. In contrast, 14 species at the Tropeptic Eutrustox site (warmer, and with higher base saturation)

**Table 2. Environmental characteristics and mean tree height at sites of the nitrogen-fixing tree trials.**

| Soil | Temperature regime | Moisture regime | Soil surface fertility pH (KCl) | Ca (me/100 g) | BS (%) |
|---|---|---|---|---|---|
| Dystrandept | Isothermic | Udic | 4.6 | 7.0 | 21 |
| Eutrustox | Isohyperthermic | Ustic | 4.8 | 5.1 | 66 |
| Paleudult | Isohyperthermic | Udic | 4.8 | 3.0 | 35 |
| Tropudalf | Isohyperthermic | Udic | 4.9 | 9.3 | 82 |

| Soil | Mean tree height (m) Leu | Div | Ses | Cal | Aur | Std err |
|---|---|---|---|---|---|---|
| Dystrandept | | | | | | |
| one year | 2.0 | 3.1 | 1.5 | 2.3 | 1.0 | 1.1 |
| two years | 2.1 | 5.3 | — | 4.3 | 2.5 | 1.4 |
| Eutrustox | | | | | | |
| one year | 4.4 | 4.9 | 3.2 | 2.1 | 2.1 | 1.1 |
| two years | 6.2 | 5.9 | 3.7 | 2.6 | 3.1 | 1.9 |
| Paleudult | | | | | | |
| one year | 2.9 | 3.1 | 2.0 | 2.3 | 2.5 | 1.2 |
| two years | 4.3 | 5.1 | 2.5 | 3.6 | 5.2 | 2.4 |
| Tropudalf | | | | | | |
| one year | 7.3 | 7.9 | 6.0 | 4.9 | 4.8 | 2.5 |
| two years | 10.6 | 11.7 | 7.5 | 6.3 | 6.8 | 3.2 |

Note: Due to past management, the Paleudult was the only site with low extractable phosphorus in the surface horizon. The standard error (std err) is the standard error of a species mean (four replications for each soil except for the Tropudalf with three replications). Two year measurements at the Paleudult site were taken at 20 months. The five replicated species include *Leucaena leucocephala* (Leu), *Leucaena diversifolia* (Div), *Sesbania grandiflora* (Ses), *Calliandra calothyrsus* (Cal), and *Acacia auriculiformis* (Aur).

had grown vigorously. The other two sites both had favorable climatic environments, isohyperthermic temperature and udic moisture regimes. The Ultic Tropudalf, with overall better fertility, including higher pH, calcium, and base saturation levels, showed the best growth during the early months after seedling establishment.

Plant growth measurements (height, basal diameter, and diameter at breast height) were recorded at various time intervals. MacDicken (1983) gives an extensive analysis and discussion of the data for various ages and characteristics, including wood volume calculations and comparisons among the species. Here the emphasis is on evaluating the usefulness of Soil Taxonomy in categorizing environments for successful matching of nitrogen-fixing tree requirements. Height data on the

replicated species, measured one year after the seedlings were planted, were the least variable of the several measurements and are shown in Table 2.

Overall, tree development was best at the Ultic Tropudalf site, with an average growth rate of 0.5 m/month for the replicated species. The warm and wet weather that prevailed at DAV during the first year, in addition to adequate soil fertility at the site, seemed to be an ideal environment for satisfying crop requirements. Trees at the Typic Paleudult site, with a relatively poor fertility status and an unusually long drought during the second half of the growing year, did not perform well. The trees at the Tropeptic Eutrustox site, which is in the ustic (dry) moisture regime, began to show signs of water stress in the latter part of the dry season (10–11 months after planting). The effect of season on the growth rates of the trees was most pronounced at the Hydric Dystrandept site. The first six months of growth occurred during the wet season, which is marked by cool temperatures, high rainfall, and low solar radiation. Initial development was very slow; some improvement in growth was seen during the second half with seasonal increases in air temperature and solar radiation levels. The data suggest that variations in tree growth rates caused by seasonal changes will be much more pro-

The drought tolerance of *Acacia mangium* was evident with its green leaves and continued growth during a six-month drought in Sumatra, Indonesia, while adjacent trees dropped leaves, ceased growth, and in some cases died in the nitrogen-fixing tree experiment.

nounced for sites in the isothermic temperature regime than in the isohyperthermic regime, assuming that soil moisture or fertility does not become a major factor in limiting growth. While species rankings at two years for the isohyperthermic sites were similar to one year rankings, substantive changes occurred at the isothermic (Dystrandept) site. *Sesbania* died out, *L. leucocephala* remained static, and the other three species showed similar or higher percentage changes in height during the second year.

A statistically significant interaction between soils and species was revealed when the one year data were submitted to a combined analysis of variance. Further examination (Figure 1) showed that the Dystrandept and Paleudult soils were major contributors to the interaction.

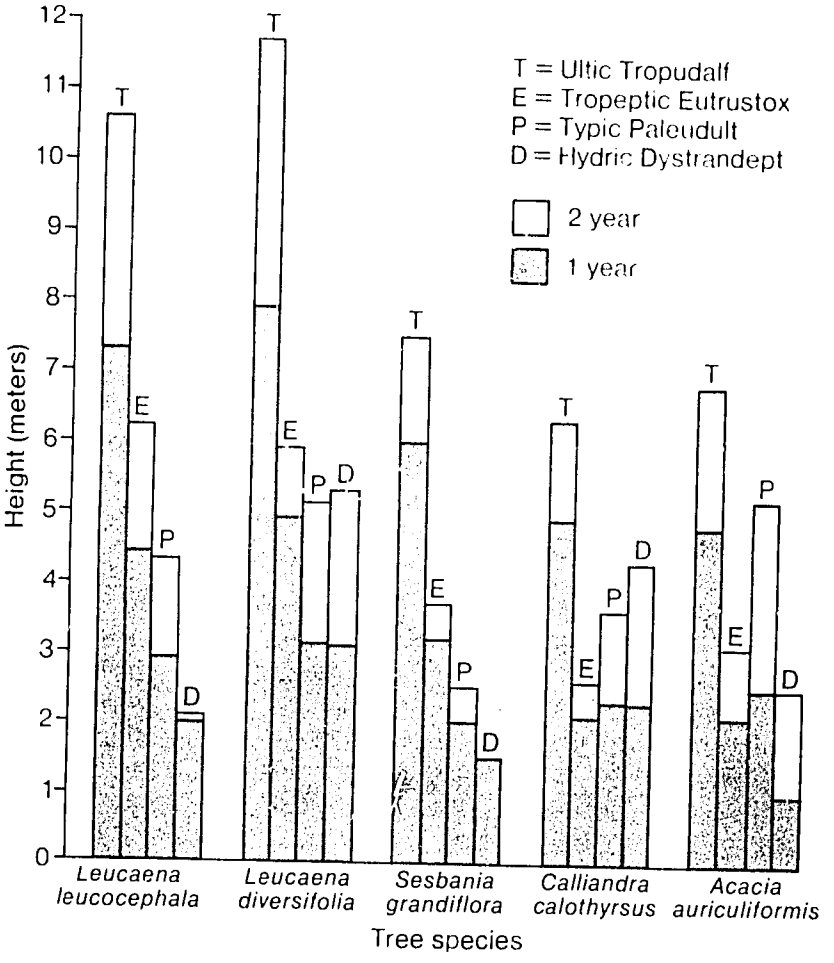


**Fig. 1.** Average height of five nitrogen-fixing tree species at one and two years after planting.

Growth of *Leucaena leucocephala* at 5 months reflects the cool and humid agroenvironment of the Hydric Dystrandepts in Hawaii (top) and the warm and humid agroenvironment of the Typic Paleudults in Cameroon (bottom). Technical problems that occurred during the NFT trial, resulting in insufficient numbers of surviving trees for several species, prevented inclusion of Cameroon data set in the combined analysis.

Whereas the differences between the Tropudalf and Eutrustox remain approximately the same for each of the species, differences involving the other two soils do not. Caution is necessary in interpreting differences among the experiments as being due solely to the soil family. With only one experiment for each family, site and soil family are confounded, and observed differences can also be associated with site characteristics other than those in Table 2. Nevertheless, the tree trials appear to support the concept that the soil family level of Soil Taxonomy achieves a useful stratification of soil characteristics, and temperature and moisture regimes for predicting leguminous tree performance.

## References

Cagauan, B. G. Jr., G. Y. Tsuji, and H. Ikawa. 1982. Planning agroforestry and fuelwood production on the basis of Soil Taxonomy. Dept. Paper 61. Hawaii Inst. of Trop. Agr. and Human Resources. College of Trop. Agr. and Human Resources, Univ. Hawaii.

MacDicken, K. G. 1983. Studies on the early growth rates of selected nitrogen-fixing trees. M.S. thesis, Univ. Hawaii.

National Academy of Sciences. 1980. Firewood crops, shrub and tree species for energy production. Report of an ad hoc panel of the Advisory Committee on Technology and Innovation, Board on Science and Technology for International Development and Commission on International Relations. Washington, D.C.

*Crop Performance in Benchmark Environments*

# 12 Simulation of Maize Response to Nitrogen Application

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Agricultural and environmental research utilizes knowledge of specific processes within a complex system of interacting and interdependent phenomena to attempt a comprehensive understanding of the operation of the system as a whole. In recent years mathematical modeling and simulation techniques, relying on the use of high speed computers, have been developed to provide a comprehensive and quantitative description of the behavior of dynamic crop growth patterns.

A fundamental principle of modeling is that the type of model to be constructed depends on its use (Dent and Blackie, 1979). Simulation models can describe the impact of such phenomena as weather, erosion, soil physical properties, and crop characteristics on agricultural production by utilizing the vast amounts of experimental data that have been collected in many parts of the world (Williams et al., 1983). These models allow testing of assumptions about the value of economic inputs such as water, fertilizers, and pesticides.

## Crop Growth Simulation Modeling for Agrotechnology Transfer

The success of agrotechnology transfer rests, in essence, with the individual farmer. Two of the basic reasons for failures in agrotechnology transfer are mismatches between the environmental requirements of a technology and the environmental characteristics of the land and mismatches between the requirements of a technology and the resource capabilities of the farmer. Traditional methods of agricultural research may not solve the mismatch problem since each farmer and each farm is unique, while results from traditional methods are site-, season-, cultivar-, and management-specific (Nix, 1980).

Currently used methods of agrotechnology transfer are simple observation, trial and error, transfer by analogy, and systems analysis and simulation. When crop research is based on transfer of information by analogy, a network of experimental sites is a necessity. The objective of simulation is not to replace field experimentation. Field experimentation is expensive but essential. Simulation modeling is intended to improve research in terms of efficiency and cost effectiveness. With simulation modeling one can prescribe appropriate technology by predict-

ing the performance of any crop at any location, given a specified set of soil, weather, crop, and management data.

In the present chapter the Crop Environment Resource Synthesis (CERES) maize model is used to predict crop response to nitrogen application on the Hydric Dystrandept and Tropeptic Eutrustox soil families in Hawaii.

## Maize Simulation Model

The Crop Systems Evaluation Unit of the Agricultural Research Service (U.S. Department of Agriculture) at Temple, Texas, has developed a maize growth simulation model—CERES maize. The model incorporates a minimum set of data on management, climate, genotype, and soil (Table 1) and simulates crop growth, phenological stages, and final yield. In the course of the simulation the CERES maize model also calculates water and nitrogen balance and daily root and shoot development of the crop (Jones et al., 1984).

Maize genotypes differ in many ways, including sensitivity to day length, thermal time (growing degree days) needed to complete various

**Table 1. Minimum data set needed to run CERES maize model.**

| Type of data | Data |
|---|---|
| Management | Cultivar name<br>Planting date<br>Plant population<br>Irrigation dates and amounts<br>Fertilizer N: dates, amounts, sources and depth of application |
| Climate | Longitude and latitude<br>Solar radiation (daily)<br>Max and min air temperature (daily)<br>Precipitation (daily) |
| Soil (by layers) | Initial soil water content<br>Initial $NO_3$ and $NH_4$ content<br>Organic carbon<br>Bulk density<br>Drained upper limit of soil water and lower limit of plant extractable soil water; or .33 and 15 bar water contents, soil texture, and CEC. |
| Others | Soil albedo, runoff curve number, C:N ratio, upper limit of stage 1 soil evaporation, profile drainage rate constant, and rooting depth |

stages of growth, and potential kernels per ear. The CERES maize model contains five genotype-specific coefficients that quantify the variability among varieties in phenological development and growth, namely, thermal time from seedling emergence to end of juvenile phase (°C), sensitivity of tassel initiation to photoperiods greater than 12.5 hours (days delay/hour increase in photoperiod), thermal time from end of vegetative growth to physiological maturity (°C), potential kernel number per ear, and potential grain fill rate (mg/kernel/day). These coefficients are determined from phytotron studies and/or adjusted until reasonable agreement between simulated and observed dates of silking and kernel numbers are obtained in optimum fertility experiments.

## Simulating Maize Response to Nitrogen

Nitrogen (N) is a significant component of important plant substances and, in addition, directly influences plant processes such as root development, nutrient uptake, and water use efficiency (Olsen and Kurtz, 1982). Variations in N concentration among plant parts occur with different stages of growth, and also with deficiency or excess of other nutrients in the plant. Nitrogen levels in plant parts also depend on the effect of weather, disease, and pests.

Effective management of nitrogen is complicated by its mobility. Nitrogen is subject to loss via ammonia volatilization, denitrification, and leaching; it may also be augmented by rainfall and biological fixation. Nitrogen has relatively low residual value, so that the N-supplying capacity of the soil cannot be permanently increased by massive application of fertilizer N. Thus, nitrogen fertilizer is applied for a single crop, rather than for a rotation or a crop sequence. Recently, an added concern has been the increase of nitrogen in both surface and ground water bodies. The CERES maize model considers the nitrogen-soil-plant-water-atmosphere system as a whole.

The CERES maize model estimates nitrogen-fertilizer-use efficiency and nitrogen leaching beyond the root zone by taking into consideration the many sources and sinks of nitrogen, and the flow pathways of both water and nitrogen. Under normal conditions nitrogen sources include residual mineral nitrogen in the soil prior to fertilization, fertilizer nitrogen, and organic nitrogen which mineralizes during the growth of the crop. The relative sizes of these sources are affected by the rate and timing of fertilizer application, previous cultural practices, and the rate of mineralization of the stable organic matter of the soil.

No actual measurements of initial mineral nitrogen concentrations throughout the soil profile or rates of mineralization were available for the Hydric Dystrandept experiments. Assumed initial soil nitrate and ammonium concentrations were mathematically adjusted until the

model accurately simulated kernel numbers in the high fertility treatment. Model adjustments were made on one set of experimental data. The remaining runs were made without adjusting the model parameters. In general, initial nitrate and ammonium concentrations between 10 and 30 ppm were required in the top 30 cm of the profile.

Soil properties such as percent organic carbon, total nitrogen, bulk density, and restriction to rooting were assumed to be identical for all experiments at a given site and were taken from Benchmark Soils Project publications and soil survey information. Recorded weather data and actual rates and dates of nitrogen fertilization were used in the simulation. Actual irrigation amounts and dates were used whenever the information was available; however, for most of the experiments irrigation was assumed to occur whenever a soil dried to the lower limit of plant extractable soil water. Chinene (1983) and Singh (1985) give additional information, including plant and soil nitrogen simulation results.

## Maize Response to Nitrogen Treatments

Table 2 shows the actual and simulated grain yields of the highest N (186 kg/ha) and P treatment in Benchmark Soils Project experiments in Hawaii. The first eight experiments presented in Table 2 were conducted on Hydric Dystrandepts and the maize variety was H610. The remaining experiments were carried out on Tropeptic Eutrustox with the X304C maize variety (Chapter 8). Experiments with wind damage (lodging) were not included because this effect is not simulated with the CERES maize model. To illustrate this limitation an experiment that suffered severe lodging (WAI A-11) was simulated. As expected, the model overestimated the grain yield for the high N treatment where lodging of large plants was serious.

Reliable estimates of silking date, yield components, and grain yield in the high fertility treatment in the Tropeptic Eutrustox experiments generally were simulated by the model. On the other hand, the yield predictions in four out of the eight experiments conducted on the Hydric Dystrandepts were not within two standard errors of the actual yield (mean of three replications).

Also presented in Table 2 are the actual and simulated grain yields of the lowest N (29 kg/ha) and high P treatment in the same experiments. Grain yields were reduced by nitrogen deficiency. In HAL B-22 and IOLE 1-10 the model overpredicted the kernel number per ear. This may have been due to barrenness induced by nitrogen deficiency and/or damage to the kernels by corn earworms.

The model predictions again were not satisfactory on the Hydric Dystrandept experiments, whereas the predictions on the Tropeptic Eutrustox sites generally were within two standard errors of the actual

**Table 2. Maize grain yields (kg/ha) of two N levels on Hydric Dystrandepts (HAL, KUK, and IOLE) and Tropeptic Eutrustox (WAI and MOL).**

| Experiment | Standard deviation | 29 kg N/ha | | 186 kg N/ha | |
|---|---|---|---|---|---|
| | | Actual | Simulated | Actual | Simulated |
| HAL B-21 | 610 | 4971 | 5913 | 8169 | 8010 |
| HAL B-22 | 527 | 2967 | 3979 | 8629 | 8516 |
| KUK A-21 | 592 | 6982 | 4926 | 7852 | 7092 |
| KUK C-11 | 686 | 7358 | 6704 | 8768 | 8929 |
| KUK C-12 | 720 | 7249 | 5902 | 9262 | 7587 |
| KUK D-21 | 838 | 5546 | 6976 | 8828 | 8531 |
| IOLE E-10 | 444 | 6263 | 6642 | 7768 | 8463 |
| IOLE I-10 | 519 | 3268 | 4762 | 6600 | 8234 |
| WAI A-10 | 640 | 9456 | 7889 | 10513 | 10676 |
| WAI A-11 | 623 | 5973 | 6049 | 8494 | 10504 |
| WAI B-10 | 575 | 8454 | 7446 | 11530 | 11999 |
| WAI D-10 | 738 | 6661 | 6707 | 9992 | 10841 |
| MOL A-10 | 633 | 7957 | 8571 | 10461 | 10953 |
| MOL B-10 | 825 | 4983 | 5641 | 8773 | 10889 |

values. The minimum data set needed to run the CERES maize model was available or could be determined from available information for the Eutrustox sites. The fact that the model overestimated grain yield in some and underestimated in other cases suggests that initial conditions differed markedly among Hydric Dystrandept sites. More accurate estimates of soil organic matter and total nitrogen might have reduced these discrepancies.

## Yield Response Curves

Figure 1 shows the actual and simulated yield response curves for five levels of N. The P levels varied but were sufficient for optimal P nutrition. The simulated yield responses generally were within two standard errors of the actual values (means of three replications). The consistent overestimation or underestimation by the model in some of the Hydric Dystrandept sites shows the need for accurate input data for the model.

There were cases when the model overestimated or underestimated grain yield, kernel number, and silking dates. These included experiments where values of the minimum data set (Table 1) were estimated. The need for accurate input data (minimum data set) to execute and evaluate the model is very important. The current version of the model does not simulate effects of insect, weed, disease, and wind damage, or phosphorus and potassium deficiencies, or aluminium and manganese toxicities. Thus, anomalies between simulated and observed values would occur if one or more of these factors affected crop performance.

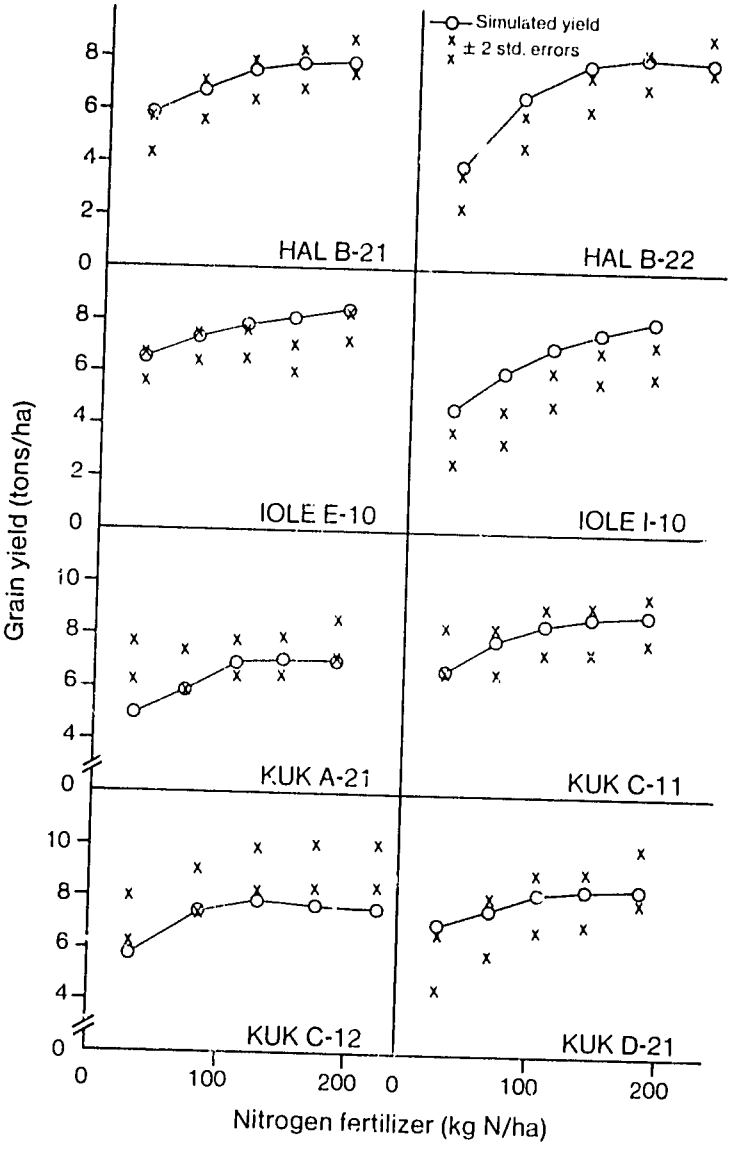


**Fig. 1.** Comparison of simulated yield (open circle) and actual yield ± two standard errors (as marked by the vertical pair of x values) in experiments on Hydric Dystrandepts. The actual yield is the mid-point between the two x values at each level of applied N.

## Nitrogen Management Application

The model was also used to simulate effects of summer (May 1) and winter (December 1) planting dates, cultivars, and applied N on the two soil families in Hawaii. Long-term averaged weather data were used for both the Hydric Dystrandept (IOLE site) and the Tropeptic Eutrustox (WAI site) soil families. Crop growth was not limited by water supply, as the model was programmed to "irrigate" and avoid water stress.

The Tropeptic Eutrustox had higher potential yields than the Hydric Dystrandept for both the summer and winter plantings (Table 3). These simulated results are in accord with the Benchmark Soils Project data (Table 2). Similarly, grain yields were higher for the Tropeptic Eutrustox simulations at all nitrogen rates. In spite of the longer growing seasons associated with the cooler environments, grain yields were lower in the Hydric Dystrandept family because of the limiting solar radiation.

Seasonal differences in yields were more prominent than differences associated with soil families. These simulations show that the N response curve depended on season (Table 3). The optimal N rate, therefore, may vary from one season to another within a soil family. In the cooler months the nitrogen response curve reaches a maximum at a lower N rate because growth is limited by environmental factors (temperature and solar radiation). In the summer plantings potential yields are also determined by the climatic factors if management inputs are optimal.

The maize cultivar X304C was superior to cultivar H610 on both soil families (Table 3). A similar conclusion by the Benchmark Soils Project led to replacing the H610 cultivar in the project's later experiments on

**Table 3. Simulated maize grain yields (kg/ha) as affected by applied nitrogen, soil family (Soil), planting date (Date), and cultivar (Var).**

| | | | Applied nitrogen (kg/ha) | | | | |
|---|---|---|---|---|---|---|---|
| Soil | Date | Var | 0 | 30 | 70 | 108 | 200 |
| TE | May | X304C | 4419 | 6013 | 7496 | 8662 | 10771 |
| | | H610 | 3890 | 5700 | 7164 | 8317 | 9646 |
| HD | May | X304C | 1772 | 4802 | 6659 | 8455 | 9297 |
| | | H610 | 1526 | 4237 | 5934 | 7653 | 8135 |
| TE | Dec | X304C | 1328 | 4398 | 6582 | 7571 | 7635 |
| | | H610 | 1178 | 3910 | 6006 | 6780 | 6780 |
| HD | Dec | X304C | 887 | 1997 | 5302 | 7315 | 7566 |
| | | H610 | 982 | 3323 | 5280 | 6966 | 6966 |

Note: The two soil families are Tropeptic Eutrustox (TE) and Hydric Dystrandepts (HD).

the Hydric Dystrandepts (Chapter 8). The main difference between the two maize cultivars is associated with potential kernel number per ear (G2) and potential grain fill rate (G5). These genetic coefficients give X304C cultivar a higher grain yield potential, primarily because of a higher G2 value. The H610 cultivar has a slightly higher G5 value and may perform better than X304C in cooler environments, e.g., winter plantings in the Hydric Dystrandept family.

As illustrated by this application, simulation modeling can help in such management decisions as selection of variety, planting date, and fertilizer rate. A systems-based research strategy centers on a balanced development of two interactive components: crop models and data bases. Presently, the development of appropriate crop models is limited by inadequate soil, crop, weather, and management data from widely contrasting environments. Thorough validation of simulation models is necessary before they can be fully utilized as a tool for agrotechnology transfer.

## References

Chirene, V. R. N. 1983. Effect of nitrogen and phosphorus on extractable water by maize and simulating maize growth on Tropeptic Eutrustox. Ph.D. dissertation, Univ. Hawaii.

Dent, J. B., and M. J. Blackie. 1979. Systems simulation in agriculture. Applied Science Publishers, London.

Jones, C. A., J. T. Ritchie, J. R. Kiniry, D. C. Godwin, and S. I. Otter. 1984. The CERES wheat and maize models. *In* Minimum data sets for agrotechnology transfer. International symposium proceedings, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, A. P. India, March 21–26, 1983.

Nix, H. A. 1986. Strategies for crop research. Proc. Agron. Soc. of New Zealand 10:107–110.

Olsen, R. A., and L. T. Kurtz. 1982. Crop nitrogen requirements, utilization, and fertilization. *In* Nitrogen in agricultural soils. F. J. Stevenson, ed. Agronomy 22:567–604.

Singh, U. 1985. A crop growth model for predicting corn (*Zea mays* L.) performance in the tropics. Ph.D. dissertation. Univ. Hawaii.

Williams, J. R., P. T. Dyke, and C. A. Jones. 1983. EPIC—A model for assessing the effect of erosion on soil productivity. *In* Analysis of ecological systems: State-of-art in ecological modelling. W. K. Lauenroth, G. V. Skogerboe, and M. Flug, eds. Elsevier Scientific Publishing Co., Amsterdam.

*Utilization of the Benchmark Soils Network*

# 13 Rainfall Erosivity in a Benchmark Soils Network

*A. Lo* and *S. A. El-Swaify*

Erosion is a function of climate, soil, topography, and land use. Predictive erosion models have been formulated to estimate potential hazards and to design control measures. Among them, the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), based on extensive research, is the best known and has been successfully applied in many parts of the United States. Though the equation in principle is transferable, the empirically derived parameters prevent any direct application to other agroenvironments without appropriate adaptation and verification. The objectives of this study are (1) to demonstrate the utility of the Benchmark Soils Project network of experimental sites and accompanying data sets for assessment of potential rainfall erosion, (2) to test the transferability of a currently available erosion prediction and control technology (USLE) to data-deficient areas like the tropics, and (3) to test the soil family "hypothesis" applicability to rainfall erosivity and subsequent inter-transferability among sites.

## The Erosivity Factor

The rainfall factor (R) in the USLE quantifies the potential ability of rain to cause erosion; it is termed the erosivity index or, simply, erosivity. Erosivity has been defined by the $EI_{30}$ index; E refers to the kinetic energy of rainfall (tonne-meters/ha) and $I_{30}$ refers to the maximum 30-minute intensity (cm/hr) of the rainfall (Wischmeier, 1959). The kinetic energy is calculated from the expression

$$\text{Kinetic energy} = 210 + 89 \log_{10} I$$

where kinetic energy is in tonne-meters/ha/cm and the intensity I is in cm/hr. This storm-based index has been successful in quantifying rainfall erosivity in many agroclimatic zones including the tropics (Bols, 1978; Bhatia and Singh, 1976; Lo et al., 1985; Roose, 1977). However, the utility of the $EI_{30}$ as a rainfall erosion index has been questioned by some workers in the tropics. One important basis for this criticism is the requirement of elaborate rainfall records, which usually are not available in many developing countries. Another is the fact that the successful

use of $EI_{30}$ in temperate regions such as its place of origin does not necessarily assure applicability to regions with substantially different climates, such as the tropics. To verify its use, continuous storm records obtained from the network of Benchmark Soils Project sites were analyzed. Erosivity values calculated according to Wischmeier and Smith (1978) were obtained for 17 sites from Hawaii, Indonesia, Philippines, and Cameroon for monitoring periods ranging from 20 to 73 months. Of these, eight sites (IOLE, KUK, and HAL in Hawaii; PUC, PAL, and BUR in the Philippines; ITKA and LPH in Indonesia) belong to the thixotropic, isothermic Hydric Dystrandepts, two sites (MOL and WAI in Hawaii) belong to the clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox, and the other seven sites (DAV and SOR in the Philippines; NAK, BUK, and BPMD in Indonesia; CAM and BAK in Cameroon) belong to the clayey, kaolinitic, isohyperthermic Typic Paleudults. During the project the DAV site was reclassified as a very fine, kaolinitic, isohyperthermic Ultic Tropudalf. This soil family has the same moisture regime (udic) as the Typic Paleudult. The DAV results are discussed here as a Typic Paleudult. Details of the experimental sites and characteristics of the soil families are given in Chapters 3 and 7.

## Monthly Rainfall Distribution

The distribution of mean monthly rainfall amounts averaged over the monitoring period and sites within a country is shown in bar graphs in Figures 1, 2, and 3. Most sites have significantly more rainfall in some months than in others (wet and dry seasons). The Philippine, Cameroon, and Indonesia sites are characterized by a single maximum during or just after the high-sun period. In Hawaii, heavy rainfall occurs in winter months (November to March) when the southerly portions of frontal systems pass over the island chain. For most sites the rainy season begins and ends gradually. The pronounced effect of orography, elevation, and exposure to the prevailing wind is illustrated by some site pairs. For example, the WAI site located on the leeward side of the island of Oahu receives an annual rainfall mean of 1028 mm, versus 2940 mm at the KUK site located on the windward side of the island of Hawaii. The PUC site in the Philippines at 300 m elevation receives 2887 mm per year, as compared to 3853 mm at the BUR site at 425 m elevation.

## Erosive Rain

An erosive rain, according to Wischmeier (1959), is defined as rain showers of greater than 12.5 mm and separated from other rain periods

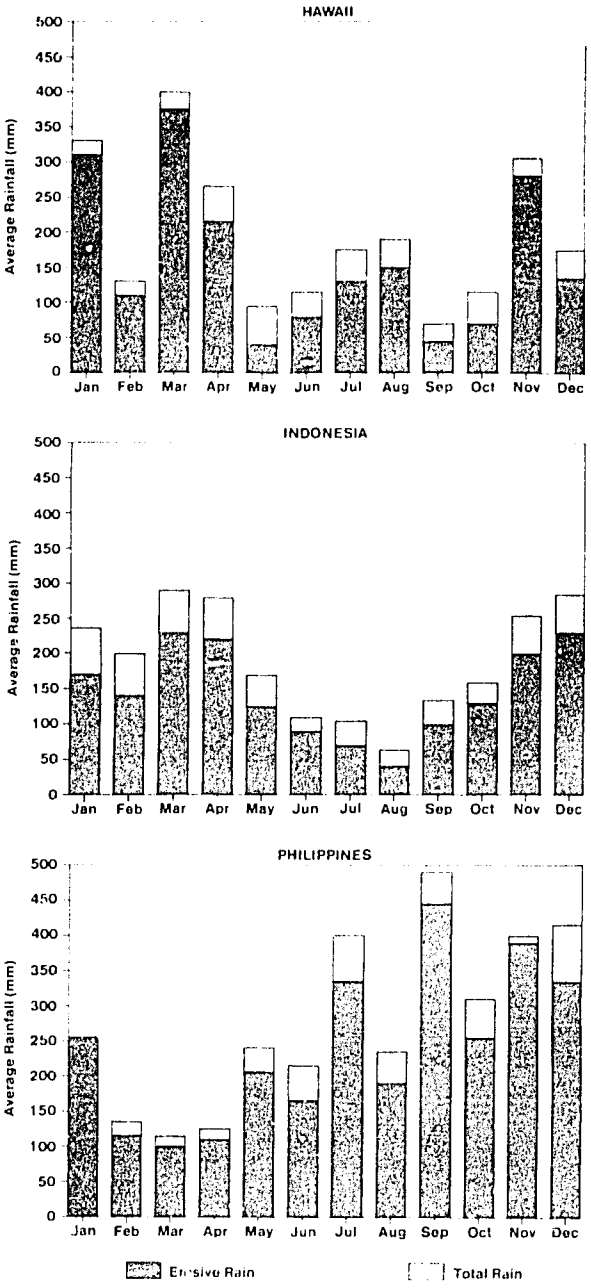


**Fig. 1.** Distribution of total and erosive rain on Hydric Dystrandepts.

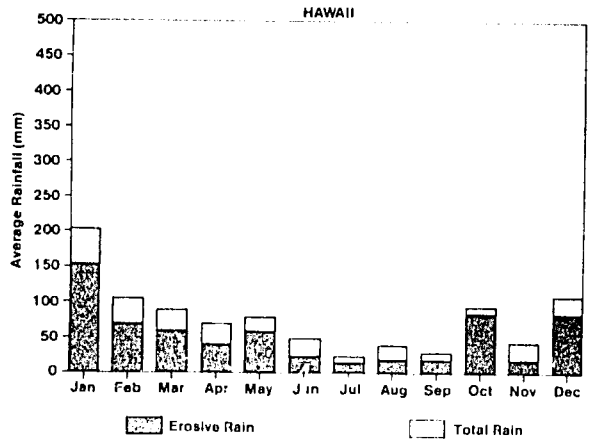


**Fig. 2.** Distribution of total and erosive rain on Tropeptic Eutrustox.

by less than 6 hours, or a minimum of 6.4 mm of rainfall in 15 minutes or less. The amount of erosive rain computed using this definition was compared with the total rainfall amount and is shown in Figures 1, 2, and 3. In general, throughout the year, sites with wetter moisture regimes experienced slightly higher proportions of erosive to total rainfall than sites with drier moisture regimes. It appears from the data that rain received during the wet season is more erosive at all sites except the Dystrandepts in the Philippines. Most (above 70 percent) of the rain which fell during the course of the year at sites other than the Philippine Dystrandepts was erosive. In contrast to this, only about half of the rain received during the dry period between June and September was erosive at both Eutrustox sites in Hawaii.

## Rainfall Intensity

The frequency distribution of the maximum 30-minute rainfall intensity is summarized in Table 1. A significant difference existed between the intensity distribution of rainfall in Hawaii and that obtained in the Philippines, Indonesia, and Cameroon. A large proportion of the erosive storms had maximum 30-minute intensities of less than 12.5 mm/hr. In fact, more than 40 percent of the time for the Eutrustox and 50 percent of the time for the Dystrandept sites, the maximum 30-minute intensity never exceeded 12.5 mm/hr. Intensities greater than 50 mm/hr were recorded less than 5 percent of the time for these sites.

Unlike the Hawaii sites, a significant proportion of the rainfall intensity occurred in the higher intensity classes at all the other sites. On the

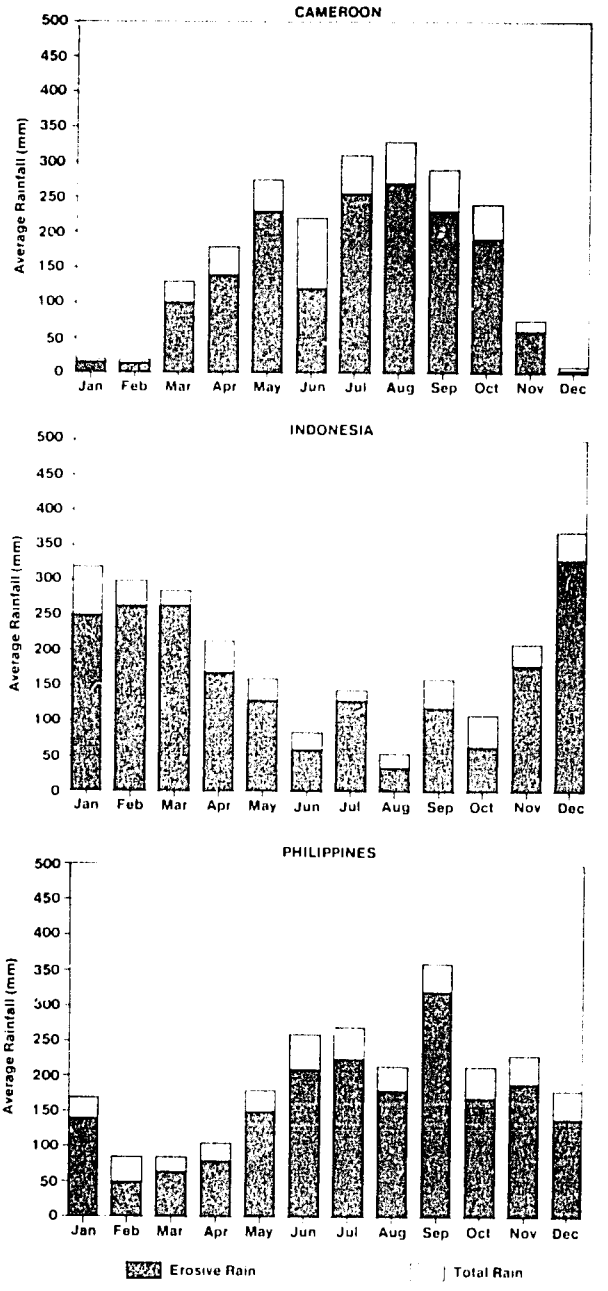


**Fig. 3.** Distribution of total and erosive rain on Typic Paleudults.

**Table 1. Distribution of maximum 30-minute rainfall intensity classes in percent during the monitoring period.**

| | Intensity class (mm/hr) | | | | |
|---|---|---|---|---|---|
| **Site** | 0.0–12.5 | 12.5–25 | 25–50 | 50–75 | >75 |
| **Hydric Dystrandepts** | | | | | |
| *Hawaii* | | | | | |
| IOLE | 71 | 19 | 9 | 1 | |
| KUK | 58 | 26 | 14 | 2 | |
| HAL | 71 | 20 | 7 | 2 | |
| *Philippines* | | | | | |
| PUC | 30 | 38 | 25 | 6 | 1 |
| PAL | 26 | 37 | 28 | 8 | 1 |
| BUR | 27 | 36 | 31 | 6 | |
| *Indonesia* | | | | | |
| ITKA | 27 | 43 | 24 | 5 | 1 |
| LPH | 20 | 35 | 37 | 7 | 1 |
| **Tropeptic Eutrustox** | | | | | |
| *Hawaii* | | | | | |
| MOL | 44 | 26 | 28 | 2 | |
| WAI | 47 | 24 | 24 | 4 | 1 |
| **Typic Paleudults** | | | | | |
| *Philippines* | | | | | |
| DAV | 12 | 34 | 37 | 14 | 3 |
| SOR | 23 | 37 | 31 | 8 | 1 |
| *Indonesia* | | | | | |
| NAK | 14 | 27 | 41 | 13 | 5 |
| BUK | 13 | 29 | 42 | 12 | 4 |
| BPMD | 11 | 33 | 40 | 12 | 4 |
| *Cameroon* | | | | | |
| CAM | 16 | 35 | 40 | 6 | 3 |
| BAK | 16 | 39 | 35 | 8 | 2 |

average, about 10 percent of the time the intensities were greater than 50 mm/hr. Intensities fell below 12.5 mm/hr only about 20 percent of the time. More intense storms occurred at the Paleudult sites in Indonesia, comparatively, than at the other sites. The 30-minute maximum intensity of 56 percent of the rainstorms at these sites was greater than 25 mm/hr. Sixteen percent of the storms had maximum intensities greater than 50 mm/hr. About 4 percent of the rainstorms had intensities greater than 75 mm/hr.

## Mean Annual Erosivity

The average annual erosivity values for each of the sites is listed in Table 2 along with its observed range during the study. Among the

Hydric Dystrandepts, the three Philippine sites yielded higher erosivity values than either the Indonesia or Hawaii sites. For the Tropeptic Eutrustox, both in Hawaii, a slightly higher mean annual erosivity value was obtained for the WAI than for the MOL site. The Indonesia sites were slightly higher than both the Philippine and Cameroon sites among the Typic Paleudults. It is apparent from Table 2 that the magnitude of the erosivity for both the Dystrandepts and Paleudults is about three to four times greater than the Eutrustox. Differences between erosivity values are not significant for the Dystrandepts and the Paleudults. However, the erosivity within the Dystrandept family varied considerably among different agroenvironments. Erosivities for the Hawaii sites (578–1466 tonne-m/ha) were slightly less than the Indonesia sites (871–

**Table 2. Annual rainfall and erosivity values.**

| Site | Duration (months) | Average annual rainfall (mm) | Annual rainfall erosion index mean | range |
|---|---|---|---|---|
| **Hydric Dystrandepts** | | | | |
| *Hawaii* | | | | |
| IOLE | 73 | 2000 | 608 | 187–1017 |
| KUK | 66 | 2940 | 1466 | 465–2502 |
| HAL | 47 | 2112 | 578 | 271–1025 |
| *Philippines* | | | | |
| PUC | 73 | 2887 | 1881 | 932–4103 |
| PAL | 58 | 3300 | 2562 | 895–4822 |
| BUR | 67 | 3853 | 2703 | 1492–3959 |
| *Indonesia* | | | | |
| ITKA | 53 | 1949 | 871 | 673–1079 |
| LPH | 67 | 2630 | 1630 | 869–2202 |
| **Tropeptic Eutrustox** | | | | |
| *Hawaii* | | | | |
| MOL | 61 | 876 | 365 | 186–621 |
| WAI | 57 | 1028 | 524 | 160–1088 |
| **Typic Paleudults** | | | | |
| *Philippines* | | | | |
| DAV | 59 | 2111 | 1852 | 1114–2774 |
| SOR | 36 | 2548 | 1807 | 1457–2147 |
| *Indonesia* | | | | |
| NAK | 45 | 2335 | 2159 | 1594–2880 |
| BUK | 46 | 2668 | 2381 | 1639–3642 |
| BPMD | 51 | 2254 | 2000 | 1164–2696 |
| *Cameroon* | | | | |
| CAM | 32 | 2106 | 1437 | 1069–1771 |
| BAK | 20 | 2074 | 1362 | 1341–138[illegible] |

Note: The erosion index is in hundreds of metric units (tonne-meters/ha); each metric unit = 0.567 English unit (ft-tons/acre). The last month of the monitoring period was December 1982 except for HAL (10/81), ITKA (12/81), and NAK (7/82).

1630 tonne-m/ha), but considerably less than the Philippine sites (1881–2703 tonne-m/ha). The lower value may be partly attributable to the infrequent occurrence of maximum 30-minute rainfall intensities greater than 50 mm/hr, as mentioned earlier. As for the Paleudults, variations among different agroenvironments were minimal.

The range of erosivities at each site was large. The effect was more pronounced at the Hawaii and Philippine sites than at the Indonesia and Cameroon sites. This apparently is due to the extreme variability in annual rainfall, more so for Hawaii and the Philippines than for Indonesia and Cameroon. Therefore, it is clear that long-term rainfall records must be available to establish unbiased estimates of erosion hazards in any given location.

It is instructive in these site comparisons to examine the characteristics of the most erosive storms (storms with the highest erosivity value) observed during the monitoring period at the various sites. A summary of these characteristics is presented in Table 3. Within the Hydric Dystrandepts, the Hawaii sites received the largest storm amount but the Indonesia and the Philippine sites were characterized by the highest short duration intensities. Comparing the ratio of erosion index to rainfall amount (Table 3), the Hawaii sites displayed the least erosive storms. For the Tropeptic Eutrustox, the largest storm at the WAI site was almost twice as erosive as that at the MOL site. The same characteristic, extremely high short duration intensities, was observed at the Philippines and the Indonesia sites belonging to the Typic Paleudult soil family. The only significant difference is that they were of very short duration; most lasted less than 10 hours.

## Seasonal Erosivity Distribution

Cumulative monthly distributions of erosivity values within the year are shown plotted against time in Figure 4. For the Dystrandepts, the Indonesia and Hawaii sites displayed similar erosivity distributions—low values were recorded from May to October and high values from November to April. For the Philippine sites, in contrast, the high erosivity values were observed during the period from May to October. The two Eutrustox sites followed the consistent trend observed at the Dystrandept sites in Hawaii. Among the Paleudults, high erosivity values were confined to May to October for the Philippine and the Cameroon sites, and November to April for the Indonesia sites. It is interesting to note that in all the Philippine and the Cameroon sites more than 75 percent of the total annual erosivity occurred during the period from May to October. This is also true for all the Hawaii sites during the period from November to April. The higher percentages (43 percent and 33 percent, respectively) received by the MOL and the

**Table 3. Characteristics of the most erosive storms recorded during the monitoring period.**

| Site | Duration (hr) | Total rain (cm) | Max 30-min intensity (cm/hr) | Erosion index $EI_{30}$ (metric unit) | Ratio of erosion index to total rain |
|---|---|---|---|---|---|
| **Hydric Dystrandepts** | | | | | |
| *Hawaii* | | | | | |
| IOLE | 107.5 | 60.9 | 3.0 | 383 | 6.3 |
| KUK | 134.0 | 107.6 | 5.0 | 1203 | 11.2 |
| HAL | 52.5 | 28.8 | 5.4 | 339 | 11.8 |
| *Philippines* | | | | | |
| PUC | 61.5 | 73.8 | 9.8 | 1769 | 24.0 |
| PAL | 59.0 | 77.1 | 10.8 | 2035 | 26.4 |
| BUR | 52.0 | 72.4 | 9.0 | 1579 | 21.8 |
| *Indonesia* | | | | | |
| ITKA | 8.5 | 10.6 | 6.4 | 173 | 16.3 |
| LPH | 83.5 | 23.5 | 8.0 | 381 | 16.2 |
| **Tropeptic Eutrustox** | | | | | |
| *Hawaii* | | | | | |
| MOL | 27.5 | 16.9 | 5.0 | 196 | 11.6 |
| WAI | 60.0 | 25.4 | 7.8 | 439 | 17.3 |
| **Typic Paleudults** | | | | | |
| *Philippines* | | | | | |
| DAV | 4.5 | 18.7 | 11.4 | 578 | 30.9 |
| SOR | 48.5 | 54.8 | 7.6 | 973 | 17.8 |
| *Indonesia* | | | | | |
| NAK | 3.5 | 14.8 | 9.8 | 406 | 27.4 |
| BUK | 7.0 | 16.9 | 9.0 | 409 | 24.2 |
| BPMD | 7.0 | 14.4 | 8.8 | 333 | 23.1 |
| *Cameroon* | | | | | |
| CAM | 1.5 | 9.7 | 13.0 | 352 | 36.3 |
| BAK | 6.0 | 9.1 | 8.8 | 205 | 22.6 |

WAI sites were caused by two major storm occurrences in January 1982 (Table 3).

Information given in Figure 4 is useful in determining the period during which the erosion hazard is minimal so that activities which involve high erosion risk, such as land clearing or other disruptive pre-planting or post-harvesting operations, may be confined to these periods.

## Alternative Estimates

To overcome the limitations of short-term observations it would be desirable to extend the data base for rainfall erosivity estimation. To determine which readily available data would be most desirable, linear

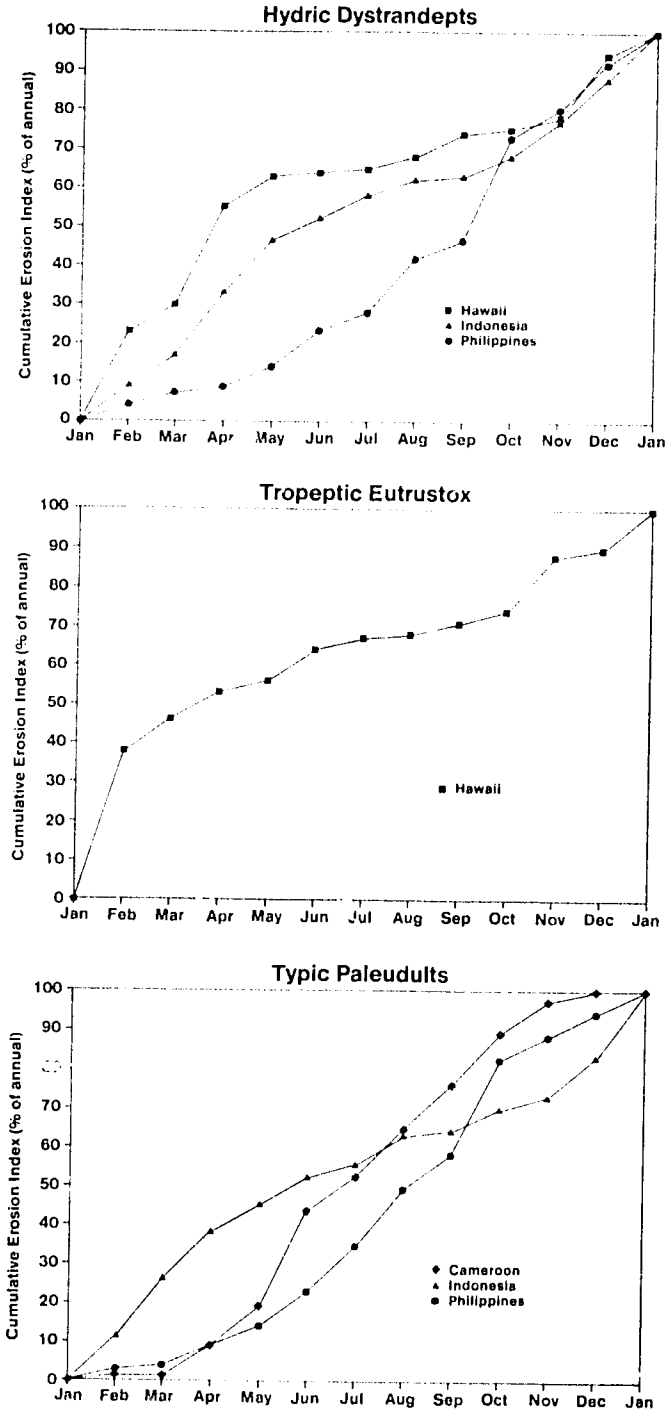


Fig. 4. Monthly erosivity distribution curves.

regression analyses were conducted between the erosion index and the corresponding rainfall amount on daily, monthly, annual, and per storm bases. Various indicators of rainfall amount vary considerably in their success of predicting rainfall erosivity at the various locations. Although the prediction on an annual basis seems slightly better overall, the small sample size rendered the relationship unreliable. In an attempt to improve the monthly correlation, monthly erosivities and rainfall amounts were segregated into two season types. The first type divided the year into two seasons; November to February and March to October. The second type divided the year into June to September and October to May. The season type with the higher correlation coefficient at a particular site was selected for any further estimation purposes at that site.

In some countries, for instance Cameroon and parts of Indonesia, long-term monthly rainfall data are scarce. Using information obtained from published rainfall records and the regression relationships developed above, reliable rainfall erosivity values were computed for 10 sites (Table 4). Most long-term estimates were considerably smaller when compared with the short-term estimates; except for most Hawaii sites, which have experienced some significant droughts during the monitoring periods.

These estimates of rainfall erosivity are valuable tools in assessing the soil loss due to erosion. For a particular location, where the land use and vegetation cover remain unchanged, the soil loss will be directly proportional to the erosivity of the rain in that location. Therefore, the amount of sediment transported will be in direct proportion to the erosivity. With a few measurements of sediment transported in the runoff for different intensity rains it should be possible to estimate, at least approximately, the quantity of soil loss during different periods of the year.

## Predictive Capability of Soil Moisture Regime

The three soil families used in the Benchmark Soils Project included soils with the udic (Typic Paleudults), the slightly drier than udic (Hydric Dystrandepts), and the ustic (Tropeptic Eutrustox) moisture regimes. The udic moisture regime, according to the definition of Soil Taxonomy (Soil Survey Staff, 1975), implies that in most years the soil moisture control section (discussed in detail in Soil Taxonomy) is not dry in any part for as long as 90 days (cumulative). The moisture control section in the ustic moisture regime is dry in some or all parts for 90 or more cumulative days in most years. But the moisture control section is moist in some parts for more than 180 cumulative days, or it is continuously moist in some parts for at least 90 consecutive days. The udic moisture regime will be much wetter than the ustic moisture regime.

**Table 4. Comparison of computed and estimated rainfall erosivity values.**

| Site | Computed | | Estimated | |
|---|---|---|---|---|
| | Mean annual | Data period (yrs) | Mean annual | Data period (yrs) |
| **Hydric Dystrandepts** (slightly drier than udic moisture regime) | | | | |
| *Hawaii* | | | | |
| IOLE | 608 | 6.1 | 863 | 32 |
| KUK | 1466 | 5.5 | 772 | 26 |
| HAL | 578 | 3.9 | 922 | 28 |
| *Philippines* | | | | |
| PUC | 1881 | 6.1 | 1150 | 15 |
| PAL | 2562 | 4.8 | 1547 | 20 |
| BUR | 2703 | 5.6 | 1217 | 20 |
| *Indonesia* | | | | |
| ITKA | 871 | 4.4 | | |
| LPH | 1630 | 5.6 | | |
| **Tropeptic Eutrustox** (ustic moisture regime) | | | | |
| *Hawaii* | | | | |
| MOL | 365 | 5.1 | 248 | 53 |
| WAI | 524 | 4.8 | 587 | 9 |
| **Typic Paleudults** (udic moisture regime) | | | | |
| *Philippines* | | | | |
| DAV | 1852 | 4.9 | 1462 | 20 |
| SOR | 1807 | 3.0 | 1140 | 20 |
| *Indonesia* | | | | |
| NAK | 2159 | 3.8 | | |
| BUK | 2381 | 3.8 | | |
| BPMD | 2000 | 4.3 | | |
| *Cameroon* | | | | |
| CAM | 1437 | 2.7 | | |
| BAK | 1362 | 1.7 | | |

Additionally, the rainfall affecting the udic moisture regime is frequent and intense. This leads to the expected trend of high erosivity values with the udic moisture regime and low erosivity values with the ustic moisture regime. The observed values derived from this study support this hypothesis (Table 4). However, this is far from quantifying rainfall erosivity at a given location and discriminating erosivity within moisture regimes. Specific data on the characteristics of erosive storms and their frequency of occurrence are needed to accurately evaluate reliable rainfall erosivities.

However, rainfall erosivity values were seen to differ only slightly within the same soil family or similar moisture regimes, as seen in Table 4. This provides, if gross assumptions are permitted, a useful tool for estimating the rainfall erosivity at a new location. For example, a new

site belonging to the thixotropic, isothermic soil family of Hydric Dystrandepts located in Indonesia would be expected to have a similar rainfall erosivity as previously obtained for the same soil family in Hawaii or the Philippines. Since the Hydric Dystrandepts experience a similar, if not slightly drier, moisture regime to the Typic Paleudults, the erosivity values observed for the Typic Paleudults in the Philippines, Indonesia, or Cameroon may take the place of the Hydric Dystrandepts in Hawaii or the Philippines in the above example. Obviously, the long-term erosivity values, if such data are available, are preferred for calculation of more reliable estimates.

## Transfer of Rainfall Erosivity

The most successful rainfall erosivity index to date, the $EI_{30}$, was computed at 17 locations using the continuous rainfall records from a network of the Benchmark Soils Project sites. Although the temporal variations were significant, the ratio of erosive to total rainfall was similar and remained within 70 to 85 percent at various sites throughout the year. However, lower rainfall intensities and longer durations dominated the erosive storms in Hawaii; more than 40 percent of the time maximum 30-minute rainfall intensities were 12.5 mm/hr or less. Whereas at the other sites in the Philippines, Indonesia, and Cameroon, erosive storms were of shorter durations. On the average, rainfall intensities of greater than 12.5 mm/hr occurred more than 80 percent of the time.

The magnitude of mean annual erosivity for the Dystrandepts and Paleudults was about three to four times greater than for the Eutrustox. Variations among the sites within the same soil family, and also between soil families for the Dystrandepts and Paleudults, were relatively small. Seasonally, higher erosion hazard or rainfall erosivity coincided with periods of maximum rainfall, which were from November to April for Hawaii and Indonesia, and from May to October for the Philippines and Cameroon.

Varying degrees of success resulted from stepwise linear regression analyses between rainfall erosivities and corresponding rainfall amounts. Relationships developed by segregating monthly rainfall total into two season types were chosen to provide reliable long-term estimates of rainfall erosivity at the Benchmark Soils Project sites.

The predictive capability of the moisture regime classification was limited by the lack of data on the characteristics of erosive storms and their frequency of occurrence. The use of the soil moisture regime alone fell short of quantifying erosivity. However, the closeness of rainfall erosivities within the same soil family and different agroenvironments enables erosivities measured from one location to be transferred to a new location. Aside from the same soil family requirement, this approx-

imation is further justified if their erosive storms are of the similar intensity distribution classes.

## References

Bhatia, K. S., and R. S. Singh. 1976. Evaluation of rainfall intensities and on erosion index values for soil conservation. Indian For. 102:726–734.

Bols, P. L. 1978. The iso-erodent map of Java and Madura. Rept. of the Belgian Technical Assistance Project ATA 105. Soil Research Institute, Bogor, Indonesia.

Lo, A., S. A. El-Swaify, E. W. Dangler, and L. Shinshiro. 1985. Effectiveness of $EI_{30}$ index in Hawaii. *In* Soil erosion and conservation. S. A. El-Swaify, W. C. Moldenhauer, and A. Lo, eds. Soil Conservation Society of America. Ankeny, Iowa.

Roose, E. J. 1977. Use of the universal soil-loss equation to predict erosion in west Africa. *In* Soil erosion: Prediction and control. Spec. Pub. 21. Soil Conservation Society of America, Ankeny, Iowa.

Soil Survey Staff. 1975. Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. Soil Conservation Service. U.S. Dept. Agr. Handbook 436. U.S. Govt. Printing Office, Washington, D.C.

Wischmeier, W. H. 1959. A rainfall erosion index for a universal soil loss equation. Soil Sci. Soc. Am. Proc. 23:246–249.

Wischmeier, W. H., and D. D. Smith. 1978. Predicting rainfall erosion losses. Science and Education Administration. U.S. Dept. Agr. Handbook 537. U.S. Govt. Printing Office, Washington, D.C.

*Utilization of the Benchmark Soils Network*

# 14 Mineral Nutrition of Maize in Benchmark Soils

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Good plant nutrition is a necessary condition for high crop yield. To achieve high yields essential elements must be present in plant tissue in proper amounts. Two general ways to diagnose the nutrient status of plants are (1) an examination of the nutrient concentration in a particular plant part of a given age or stage of development and (2) an examination of the nutrient ratios in the same tissue. In both approaches, the nutrient status of the test sample is compared to the nutrient status of similar samples from a population of nutritionally healthy plants of the same species or cultivar.

Diagnosis based on nutrient concentrations suffers from several inherent weaknesses. Environmental conditions and crop cultivars used in the tropics differ from those in temperate regions. These factors can influence the "adequate range" or "critical" tissue nutrient concentrations at which acceptable crop growth is obtained. The use of incorrect criteria for diagnosis of nutrient deficiencies from plant tissue analyses could result in inaccurate fertilizer recommendations.

In 1973 Beaufils published a system of calculation based on ratios of nutrient concentrations. The ratios obtained from a healthy or high-yielding population of the same crop are used to compute a Diagnosis and Recommendation Integrated System (DRIS) index for each nutrient element. DRIS is fundamentally different from the conventional critical nutrient concentration approach due to its use of nutrient ratios and normalization of indices. Proponents of DRIS claim that this method of nutrient diagnosis is less sensitive to environmental factors, cultivar, age of plant part, and plant part sampled. References to their claims and a comparison of the DRIS methodology with the conventional critical nutrient concentration approach on Hydric Dystrandepts have been given by Escaño et al. (1981b).

Studies were undertaken by the Benchmark Soils Project to evaluate the DRIS system. In addition to the comparative evaluation by Escaño et al. (1981b), del Rosario (1982) established DRIS norms for maize grown in the Benchmark Soils Project network of three tropical soil families and also attempted to determine the influence of environmental factors such as soil and climate and the influence of genotype or variety

on DRIS norms. Data from fertility studies of the Benchmark Soils Project, as described in Chapter 4, were utilized. Here, the data base consisted mainly of grain yields and the corresponding earleaf nutrient analysis at 50 percent tasseling. These experimental data bases, as well as the procedures and methodology employed in these investigations, are described in detail in the dissertations of Escaño (1980) and del Rosario (1982).

## The DRIS Methodology

The DRIS system proposed by Beaufils (1973) is a means of handling the collection, storage, and calibration of large amounts of data and the diagnosis and recommendation required to improve plant production.

*DRIS concepts.* The most important concept in DRIS is nutrient balance. For each pair of nutrient elements there is an optimum ratio. Hence, the optimum concentration of a nutrient is dependent on the concentration of the other nutrients. Optimum ratios are assumed to be equal to the mean values of ratios from desirable or high-yielding populations. These mean values of ratios are referred to as "norms." Nutrient deficiency or toxicity in tissue samples is diagnosed by comparing the test ratios with optimum ratios or norms. Deviations from the optimum or norms are used to calculate DRIS indices for the different nutrients.

Another major concept is the so-called comparability of the calculated DRIS indices. In the critical nutrient concentration approach to nutritional diagnosis, the concentration of one nutrient cannot be directly compared with that of another nutrient because the optimum levels of the various nutrients differ. Also, the relationship between crop yield and the deviation of a nutrient from its optimum concentration is different for each nutrient. DRIS provides a means of normalizing nutrient indices so that all indices can be directly compared. The DRIS approach then consists of two major tasks, namely, the establishment of DRIS norms and the calculation of DRIS indices.

*DRIS calculations.* DRIS norms are mean nutrient ratios derived from a population having desirable characteristics such as high yield, good color, or a desired quality of the crop. The mean value in the desirable population is the norm for a given nutrient ratio.

The DRIS intermediate nutrient ratio measures the deviation of a particular sample nutrient ratio from the particular norm. The simplified formula for calculating the DRIS intermediate nutrient ratio suggested by Jones (1981) is

$$(\text{sample nutrient ratio} - \text{norm})/\text{std. dev. of norm}$$

where the norm and standard deviation of the norm are the mean and standard deviation from the desired population. To illustrate this further, if N, P, and K are the nutrients in question, nutrient ratios are N/P, N/K, and P/K. The three corresponding intermediate nutrient ratios are the standardized deviations of each of these three nutrient ratios from their respective norms. For example, the difference between the N/P sample value and the N/P norm is divided by the N/P standard deviation.

Calculation of DRIS indices involves summing up of DRIS intermediate nutrient ratios containing the particular nutrient in question and dividing by the number of DRIS intermediate nutrient ratios. The sum of DRIS indices is zero. The nutrient ratio carries a positive sign if the nutrient in question is in the numerator and a negative sign if the nutrient in question is the denominator. Hence,

DRIS index for N = (DRIS Intermediate N/P + DRIS Intermediate N/K)/2

DRIS index for P = (DRIS Intermediate P/K - DRIS Intermediate N/P)/2

DRIS index for K = -(DRIS Intermediate N/K + DRIS Intermediate P/K)/2

Plant DRIS indices considered on their own do not give an automatic indication of the nature and amount of a particular element which must be added to the soil. Rather, they simply indicate the nature and degree of nutrient balance in the plant. The most negative index indicates that the element under study is most required by the plant; the most positive index, on the other hand, is the least required. An index equal to zero corresponds to the most balanced situation in the plant.

## Yield-nutrient Relationships

Grain yields were plotted against nutrient composition at 50 percent tasseling for each of 11 nutrients using data from the Benchmark Soils Project. These plots are given by del Rosario (1982), as well as relationships between grain yield and 10 nutrient ratios. Selected plots are discussed here.

In general, at low yield levels the ranges of nutrient concentrations varied widely, but as yields increased, the associated range of tissue concentrations narrowed. Interestingly, the apparent optimum concentration is characteristic (Figure 1) for a soil family for P, K, Mg, S, and Mn while, for other nutrients, a grouping of concentrations by soil family is not apparent. Some nutrient ratios coalesce to a point (Figure 2) or

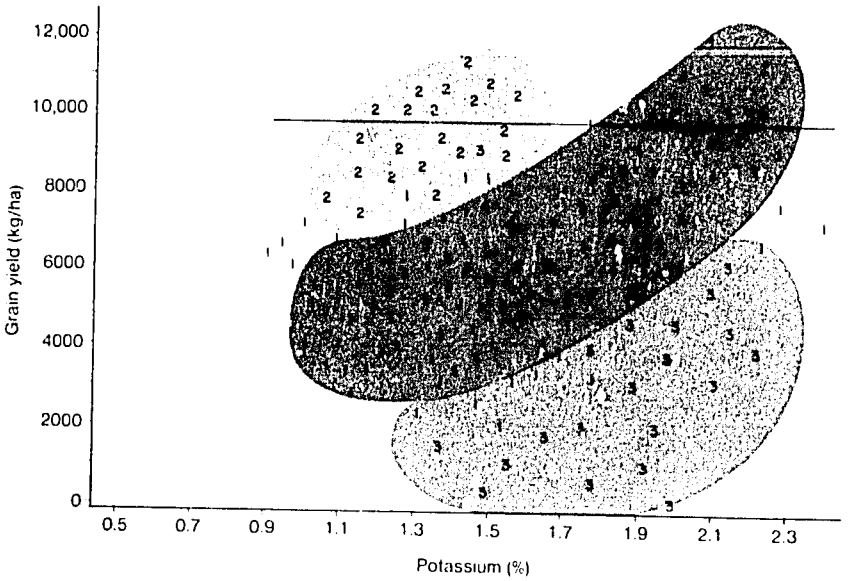


**Fig. 1.** Relationship between grain yield and concentration of potassium in maize earleaves (50% tasseling) in experiments on the Hydric Dystrandepts (1), Tropeptic Eutrustox (2), and Typic Paleudults (3). This is a modification of the original figure from del Rosario (1982).

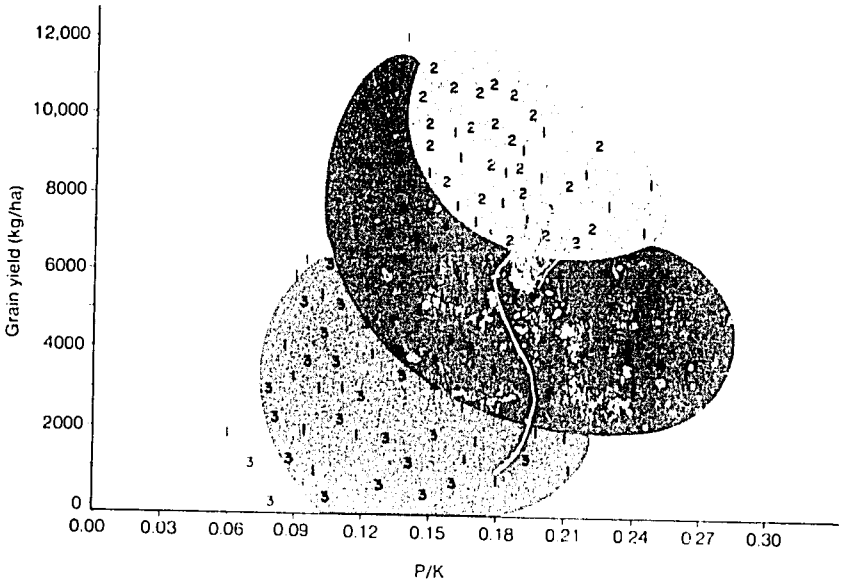


**Fig. 2.** Relationship between grain yield and concentration of P/K nutrient ratio in maize earleaves (50% tasseling) in experiments on the Hydric Dystrandepts (1), Tropeptic Eutrustox (2), and Typic Paleudults (3). This is a modification of the original figure from del Rosario (1982).

remain grouped by family similar to the relationship shown in Figure 1. Consequently, the soil family can contribute to the variance of the nutrient ratio.

## Comparison of Low and High-yielding Populations

One of the assumptions in DRIS is that some nutrient ratios are considered more important than other nutrient ratios (Jones, 1981). The desirable (high-yielding) and undesirable (low-yielding) populations could be compared to determine so-called "important" ratios. "Important" ratios are those nutrient ratios in which either the means are significantly different between the low-yielding and high-yielding populations or the variances in the low-yielding population are significantly higher than the variances in the high-yielding population (Jones, 1981; Escaño et al., 1981b).

In each soil family, the means and variances of 10 nutrient ratios involving N, P, K, Ca, and Mg were compared between the low-yielding and the high-yielding population. The high-yielding population (HYP) and the low-yielding population (LYP) were chosen by taking the two highest yields and two lowest yields from each block of each experiment. A summary of the results is given in Table 1.

The nutrient ratios in the low-yielding population in the Hydric Dystrandepts has significantly higher variances compared to the variances of the same ratios in the high-yielding population. In the case of the Tropeptic Eutrustox, the means of most nutrient ratios were significantly different between the two populations and, in general, were

**Table 1. Summary of "important" (see text for definition) nutrient ratios in the Benchmark Soils Network.**

| Nutrient ratio | Dystrandepts (n = 174) | | Eutrustox (n = 42) | | Paleudults (n = 64) | |
|---|---|---|---|---|---|---|
| | Mean | Variance | Mean | Variance | Mean | Variance |
| N/P | ns | * | ** | * | ns | * |
| N/K | * | * | ** | * | * | * |
| N/Ca | ns | * | ** | ns | * | ns |
| N/Mg | ns | * | ** | ns | ** | * |
| P/K | ns | * | ns | ns | ns | * |
| P/Ca | ns | * | ns | ns | * | * |
| P/Mg | ns | * | ** | ns | ** | * |
| K/Ca | ns | * | * | ns | ns | * |
| K/Mg | ns | * | * | ns | * | * |
| Ca/Mg | ns | * | ns | ns | ** | * |

Note: Statistical significance (* and ** denote significance levels at 0.05 and 0.01, respectively and ns denotes a significance level greater than 0.05) was based on the t-distribution for means and on the F-distribution for variances.

higher for the high-yielding population. On the other hand, the Typic Paleudults showed significant differences in both means and variances of nutrient ratios between the two populations.

Results from the three soil families suggest that two entirely different populations can be isolated and one of the following will be observed.

1. No significant mean difference between two populations but the variances in the LYP may be significantly higher than the variances in the HYP.

2. Means of nutrient ratios may be significantly different between two populations, but the variances in the LYP may not be significantly higher than the variances in the HYP.

3. Means of nutrient ratios may be significantly different between two populations and the variances in the LYP may be significantly higher than the variances in the HYP.

Case (1) may be observed when nutrient elements in both populations are relatively balanced and different yields are produced because of non-nutritional limiting factors; more favorable factors will promote high yield and less favorable ones will restrict yield. One of the basic assumptions in DRIS is that the nutrient ratios in the HYP are considered optimum. It does not necessarily mean, however, that when nutrient ratios are optimum high yields will always be possible, since factors other than nutrition may always be present. In other words, both high and low yields may be possible at so called "optimum" nutrient ratios. Cases (2) and (3) may be observed when nutrition, in fact, is limiting growth; that is, when there is nutrient imbalance in the plant.

## Benchmark DRIS Norms

The first major task in DRIS is the establishment of DRIS norms or optimum values for nutrient ratios coming from a high-yielding population. Since optimum concentration is a necessary but not sufficient condition for high yields, it was necessary to design a method of selecting a high-yielding population which would include samples from lower-yielding varieties and locations where yields were not limited by nutrition. In other words, the desirable population consisted of samples in which the yields were considered high enough for the sub-population being represented. Escaño et al. (1981a) compared methods to determine the optimum concentration or range for each nutrient. Here, the high-yielding population was selected by taking the two highest-yielding treatments from each block of the randomized complete block design with three replicates (six samples per experiment).

Ten nutrient ratios involving N, P, K, Ca, and Mg were generated from each of 10 samples and the means of each of these 10 nutrient ratios were calculated and compared with published norms from Sum-

ner (1977). It was hypothesized that, if in fact the optimum value for nutrient ratios would be the same no matter how the so-called high-yielding population or desirable population is chosen, then the norms generated from the entire Benchmark Soils Project network could reasonably be assumed to be comparable or consistent with published norms for maize.

The method of selecting the high-yielding population in the experimental network gave means or optimum values in most nutrient ratios which were consistently higher than those of the published norms (Table 2). Moreover, the variances of published norms were consistently higher than those of the Benchmark Soils Project norms. This might be attributed to the fact that since both N and P were treatment variables in the experiments, probably the optimum leaf N and P concentrations in the experimental network were higher than the optimum concentrations of the population from which the published norms were generated. Also, the high nutrient ratios with Ca and Mg in the experimental network suggest that optimum Ca and Mg concentrations were lower in the experimental population compared to the published ones.

The overall results suggest that the optimum concentrations of most nutrients in maize from the experimental network might be different from the optimum nutrient concentrations of the population from which the published norms were generated. Furthermore, it is implied that the accuracy of diagnosing nutrient status in maize in terms of the derived indices using either norm might vary. Escaño et al. (1981b) demonstrated the implication of using independent data to generate DRIS norms for each nutrient and correctly diagnosed nutrient status, e.g., N

**Table 2. Means and variance for comparing Benchmark DRIS norms with published norms (Sumner, 1977).**

| Nutrient ratio | Published norms | | Benchmark DRIS norms | |
|---|---|---|---|---|
| | Mean | Variance | Mean | Variance |
| N/P | 10.0 | 2.25 | 10.5 | 3.56 |
| N/K | 1.49 | 0.10 | 1.71 | 0.13 |
| N/Ca | 5.43 | 6.50 | 6.78 | 2.61 |
| N/Mg | 10.3 | 21.4 | 12.9 | 15.4 |
| P/K | 0.15 | 0.00 | 0.16 | 0.00 |
| P/Ca | 0.53 | 0.06 | 0.66 | 0.03 |
| P/Mg | 1.07 | 0.26 | 1.23 | 0.12 |
| K/Ca | 3.13 | 3.38 | 4.10 | 1.37 |
| K/Mg | 7.14 | 22.8 | 7.69 | 5.70 |
| Ca/Mg | 1.90 | 0.46 | 1.94 | 0.39 |

Note: Both P/K variances were 0.001.

and P, in maize in the Hydric Dystrandepts in Hawaii. The locally-calibrated DRIS norms were shown to increase the diagnostic accuracy of DRIS.

## Sources of Variability Among Optimum Nutrient Ratios

For evaluating sources of variability among optimum nutrient ratios, a subset of fertility experiments was selected. The two highest treatment combinations of P and N from each of the three blocks (six plots) were utilized from each experiment. Two experiments were randomly chosen from each site from those experiments with a coefficient of variation less than 20 percent. Then two sites were chosen from each country with experiments on a given soil family. Sites included IOLE, KUK, PUC, PAL, ITKA, and LPH for the Hydric Dystrandepts; MOL and WAI for the Tropeptic Eutrustox; and DAV, SOR, NAK, and BUK for the Typic Paleudults. Chapters 3 and 7 give additional details on the selected sites. This network of 24 experiments was analyzed so that the variability among the 144 observations for each optimum nutrient ratio could be partitioned among various sources of variation. This was done using a hierarchical analysis of variance procedure where each source of variation included the variability of the nested sources of variation.

Across the experimental network, the nutrient ratios were higher in some high-yielding plots in some soil families than in others. For instance, most high-yielding experiments in the Hydric Dystrandepts had lower Mg in the earleaves, hence nutrient ratios with Mg in the denominator were comparatively higher than those of the other two soil families. Similarly, the high-yielding plots in the Tropeptic Eutrustox had lower K content in the earleaves compared to either the Hydric Dystrandept or Typic Paleudult experiments, hence, the nutrient ratios with K in the denominator were higher in the Tropeptic Eutrustox compared to those of the other two soil families. In the case of the Typic Paleudults, most high-yielding experiments had lower Ca content in the earleaves, hence higher nutrient ratios with Ca in the denominator compared to those of the other two soil families. It was not very clear, however, whether the low Mg, K, and Ca concentrations in the earleaves were due to varietal characteristics or to the soil availability of these elements.

The importance of the sources of variation listed in Table 3 is statistically evaluated by comparing a mean square with the mean square immediately below it. The most consistent and obvious source of variability is the term for experiments nested within sites. This variance due to experiments might be associated with different treatments chosen from each experiment, as well as existing seasonal or varietal differences. The variances shown by plots within an experiment might be considered as experimental error but two additional factors must be

**Table 3. Sources of variation, degrees of freedom (df), and optimum nutrient ratio mean squares for a nested model analysis of variance.**

| Source of variation | df | N/P | N/K | N/Ca | N/Mg | P/K |
|---|---|---|---|---|---|---|
| Soil families | 2 | .48 | .69 | 32 | 88 | 61 |
| Sites w/i family | 9 | 17 | .59 | 14 | 62 | 18 |
| Expts w/i site | 12 | 7.7 | .19 | 7.7 | 133 | 16 |
| Plots w/i expt | 119 | 1.2 | .02 | .63 | 3.5 | 2 |
| | df | P/Ca | P/Mg | K/Ca | K/Mg | Ca/Mg |
| Soil families | 2 | .33 | .75 | 35 | 66 | 628 |
| Sites w/i family | 9 | .11 | .69 | 5.9 | 47 | 208 |
| Expts w/i site | 12 | .05 | .95 | 2.9 | 40 | 119 |
| Plots w/i expt | 119 | .01 | .03 | .45 | 1.3 | 7 |

Note: The hierarchial sources of variation include soil families, sites within (w/i) family, experiments (expts) w/i sites and plots w/i experiment. The P/K and Ca/Mg ratios have been multiplied by $10^{-4}$ and $10^{-5}$, respectively.

considered: (1) the plots within an experiment may be associated with different treatments—specifically, the selected treatments associated with the two plots selected from each block can vary from block to block and (2) the optimum nutrient ratios were unadjusted for systematic differences from block to block due to soil heterogeneity.

The soil family mean square generally is not larger than the site within family mean square, which, in turn, might or might not be larger than the experiment within site mean square. Any differences among soil families might have been effectively eliminated by the treatment and blanket fertilizer application.

## References

Beaufils, E. R. 1973. Diagnosis and Recommendation Integrated System (DRIS). A general scheme for experimentation and calibration based on principles developed from research in plant nutrition. Soil Sci. Bull. 1, Univ. Natal, Natal, Republic of South Africa.

del Rosario, B. P. 1982. DRIS norms for maize (*Zea mays* L.) grown in a network of three tropical soil families. Ph.D. dissertation, Univ. Hawaii.

Escaño, C. R. 1980. Comparative evaluation of some diagnostic techniques for determining nutrient requirements of maize grown on Hydric Dystrandepts. Ph.D. dissertation, Univ. Hawaii.

Escaño, C. R., C. A. Jones, and G. Uehara. 1981a. Nutrient diagnosis in corn grown on Hydric Dystrandepts. I. Optimum tissue nutrient concentrations. Soil Sci. Soc. Am. J. 45:1135–1139.

Escaño, C. R., C. A. Jones, and G. Uehara. 1981b. Nutrient diagnosis in corn grown on Hydric Dystrandepts. II. Comparison of two systems of tissue diagnosis. Soil Sci. Soc. Am. J. 45:1140-1144.

Jones, C. A. 1981. Proposed modifications of the Diagnosis and Recommendation Integrated System (DRIS) for interpreting plant analysis. Commun. Soil Sci. Plant Anal. 12(8):785-794.

Sumner, M. E. 1977. Effect of corn leaf sampled on N, P, K, Ca, and Mg content and calculated DRIS indices. Commun. Soil Sci. Plant Anal. 8(3):269-280.

*Matching Crops and Environments by Soil Taxonomy*

# 15 Soil Taxonomy-based Cropping Systems

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and
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The term "cropping systems" can be used to connote different meanings. It may refer to a systems or holistic approach, describe prevailing traditional agricultural systems, designate multiple cropping systems such as intercropping and sequential cropping, or even refer to a monocrop in regions growing only one crop during the year. In the present study the term "cropping systems" refers to year-round sequential cropping patterns, including some intercrops, cultivable in given agroenvironments.

Tropical regions provide a unique opportunity for year-round agricultural production because of the generally consistently favorable temperature and solar radiation conditions. A majority of the small farmers in the tropics take advantage of such conditions through sequential cropping. It is therefore appropriate to evaluate the crop production potential of tropical agroenvironments through year-round cropping.

Conventional cropping systems research may be location specific due to poor and subjective characterization of the research sites. Also, despite substantial progress in identifying physical determinants of cropping patterns, the measurement of these physical determinants in relation to their associated cropping patterns has been overlooked. Consequently, the results of cropping pattern trials generally have not been interpreted based on the environmental characteristics of the site. As pointed out by Zandstra et al. (1981), a thorough description and classification of the environment is required. The validity of the experimental results beyond the experimental area is determined by the quality of climatic and soil classification data. Year-round cropping also integrates the effect of agroenvironment on the crops during the entire growing season and thus is an assessment of the yearly productivity of an agroenvironment.

After consideration of the above concepts it was concluded that cropping systems experimentation on fully characterized sites would be particularly worthwhile. The availability of the Benchmark Soils Project's network of taxonomically classified and (daily) weather-monitored sites presented an ideal opportunity for year-round cropping systems trials.

This chapter describes the performance of year-round cropping pat-

terns conducted on three tropical soil families (clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox; clayey, kaolinitic, isohyperthermic Typic Paleudults; and thixotropic, isothermic Hydric Dystrandepts). The goal was not to develop cropping systems technology, but to relate the concept of a sequence of crop planting to the soil family characterization. Specific objectives included (1) development of soil family-based cropping patterns, (2) determination of the stratification efficiency of the soil family level of Soil Taxonomy for prediction of crop behavior, (3) evaluation of the performance of a particular cropping pattern under different agroenvironments, and (4) assessment of the comparative potential of the three agroenvironments to sustain year-round cropping without irrigation.

## The Experimental Sites

Trials were carried out on nine experimental sites in Hawaii, Indonesia, and the Philippines. Of these, four sites (IOLE, KUK, PAL, LPH) belong to the Hydric Dystrandepts, two sites (WAI, MOL) belong to the Tropeptic Eutrustox, and the other three (DAV, SOR, NAK) to the Typic Paleudults. Details of the experimental sites and characteristics of the soil families are given in Chapters 3 and 7.

## Design of Cropping Patterns

Cropping patterns were designed by matching crop requirements with the characteristics of the agroenviroment. Information about the agroclimate inferred from the soil family nomenclature, coupled with the past weather data and individual crop requirements for moisture and temperature obtained from the literature, were used to select a set of crops. Seasonal variation of rainfall and temperature was considered for fitting crops into a viable cropping sequence. Table 1 presents cropping patterns during the year for the three soil families. Design patterns, in relation to mean monthly temperatures and rainfalls, for the Typic Paleudult, Hydric Dystrandept, and the Tropeptic Eutrustox soil families are depicted in Figures 1, 2, and 3.

*Typic Paleudults.* The cropping pattern consisted of upland rice followed by soybeans (or peanuts) and cowpeas (or mungbeans) in the second and third cycles. Three crops were selected in relation to the isohyperthermic temperature and udic moisture regimes. Rice is the main crop during the first cycle, which starts with the rainy season, and is intercropped with maize (harvested as green corn). The dry season starts during the second cycle but rainfall and residual moisture, along with the higher temperature and solar radiation, are sufficient for a

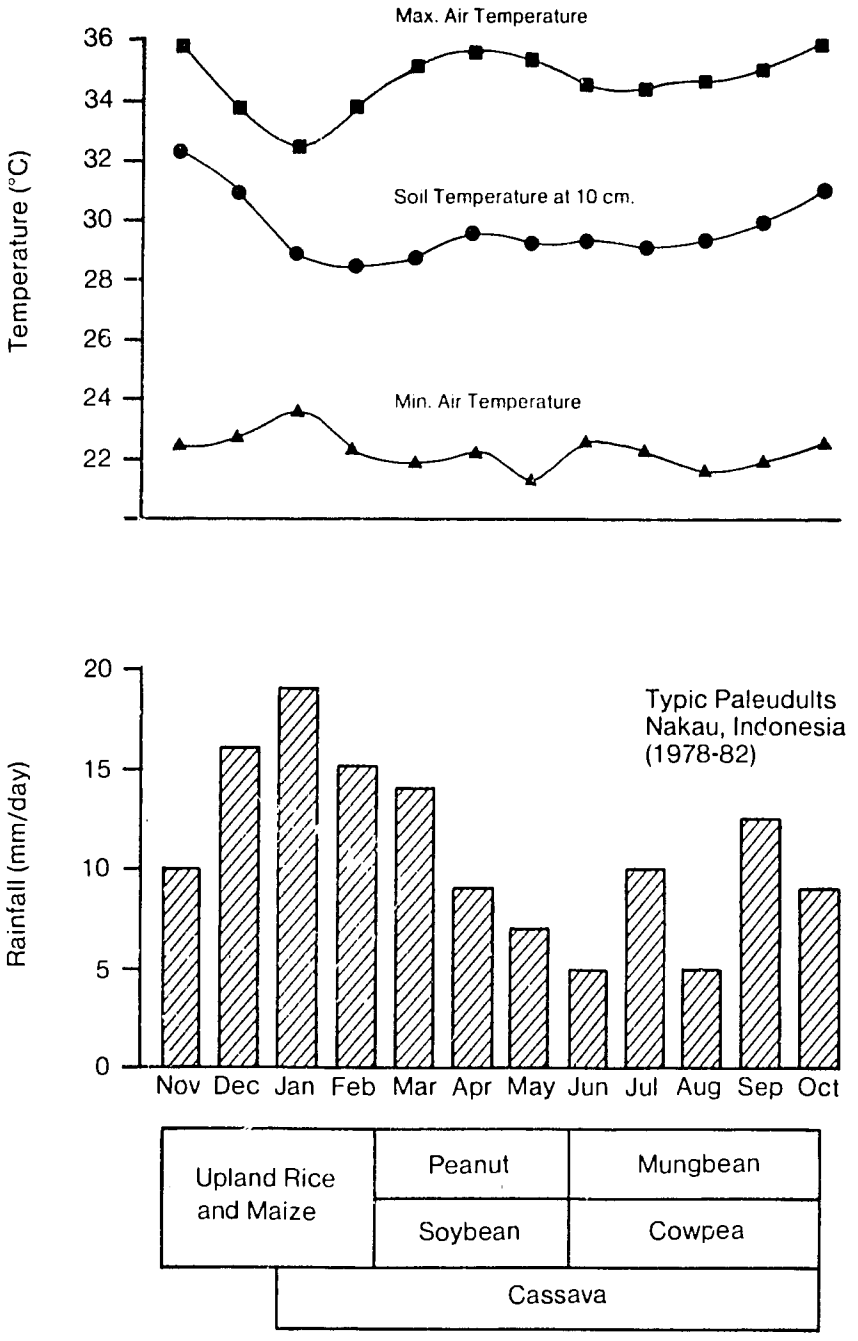



**Fig. 1.** Cropping pattern design for Typic Paleudults in relation to temperature and rainfall.

**Table 1. Cropping system designs for the three soil families of the Benchmark Soils Project.**

| Soil family | Cropping pattern | | |
|---|---|---|---|
| | 1st cycle | 2nd cycle | 3rd cycle |
| Hydric Dystrandepts | Root crop (Irish potato) or vegetable crops (cabbage/carrot/ bush bean) | Vegetable crops (bush bean/green corn or bush bean/ mustard cabbage) | Grain crop (soybean or peanut) |
| Typic Paleudults | Grain crop (upland rice and maize) | Grain crop (soybean or peanut) | Grain crop (cowpea or mung bean) |
| Tropeptic Eutrustox | Root crop (Irish potato) | Grain crop (soybean) | Grain crop (maize) |

Note: The start of the rainy season, which may differ from site to site, is designated as 0, and the end of the third cycle is 12 on a monthly scale. Long-term side crops include taro for the Hydric Dystrandepts, cassava for the Typic Paleudults and cassava, pigeonpea, and taro for the Tropeptic Eutrustox.

grain crop. Cowpeas (or mungbeans) are matched to the hot and dry third cycle.

*Hydric Dystrandepts.* The pattern started with a vegetable crop combination of cabbage, carrot, and bushbeans (or Irish potato as an alternate), followed by alternative vegetable crop combinations of bushbeans and mustard cabbage or bushbeans and green corn. Soybeans (or peanuts) were planted during the warmer and dryer third cycle.

The isothermic environment of the Hydric Dystrandepts matches well with the temperature requirements of the cool-weather vegetable crops and Irish potatoes. These crops were planted during the start of the rainy season, which is also the cool period (November–December for sites in Hawaii and October–November for sites in the Philippines and Indonesia). The udic moisture regime and excellent physical properties of Hydric Dystrandepts are other factors that make these soils ideal for vegetable crops.

*Tropeptic Eutrustox.* The cropping pattern here was Irish potato followed by soybeans and maize. This was considered to be an appropriate match of crop requirements with the isohyperthermic temperature and ustic moisture regimes of the Tropeptic Eutrustox. Manrique (1982) found that the lower temperatures prevalent during the wet season are conducive to good tuberization in Irish potatoes. The soybeans and maize then benefit from the higher temperature and solar radiation of

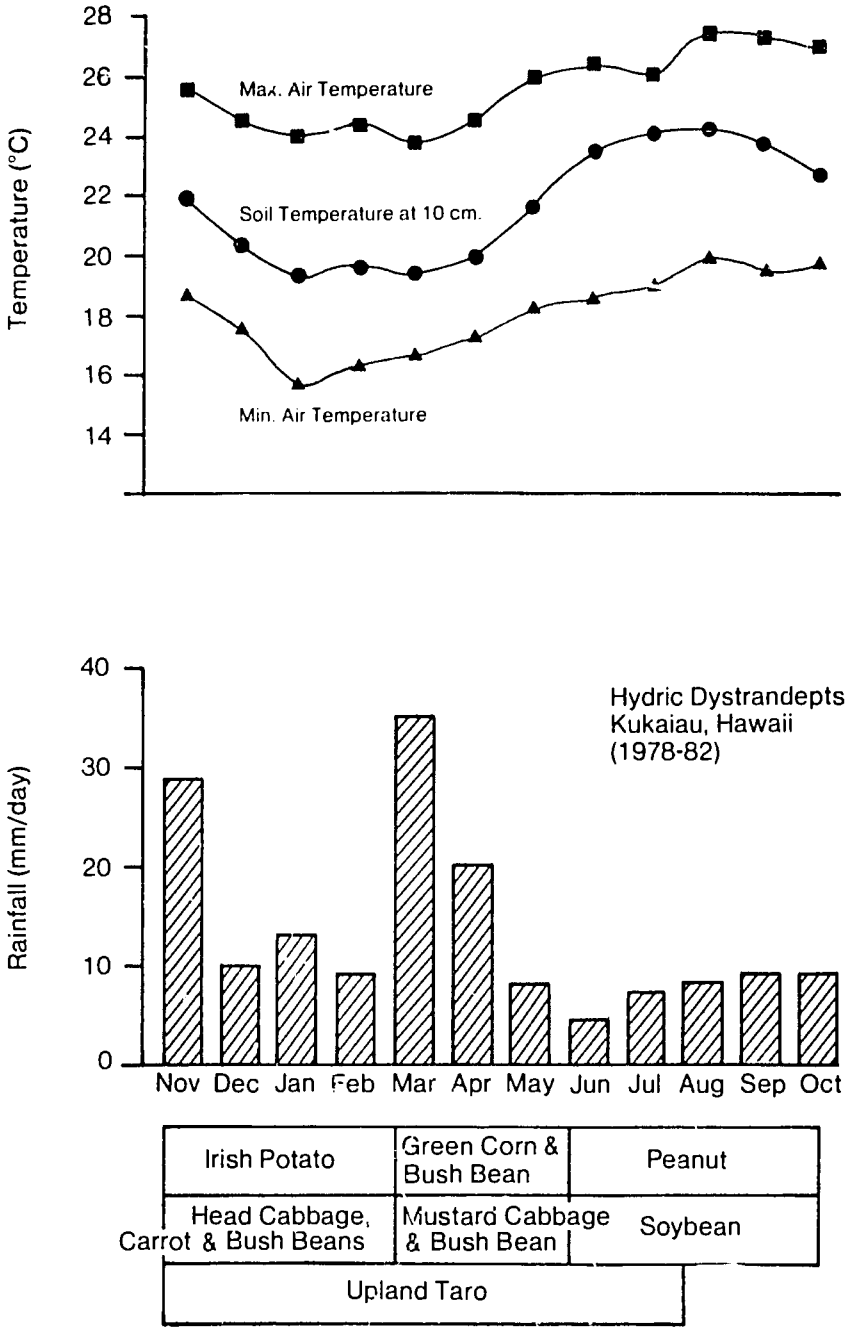



**Fig. 2.** Cropping pattern design for Hydric Dystrandepts in relation to temperature and rainfall.

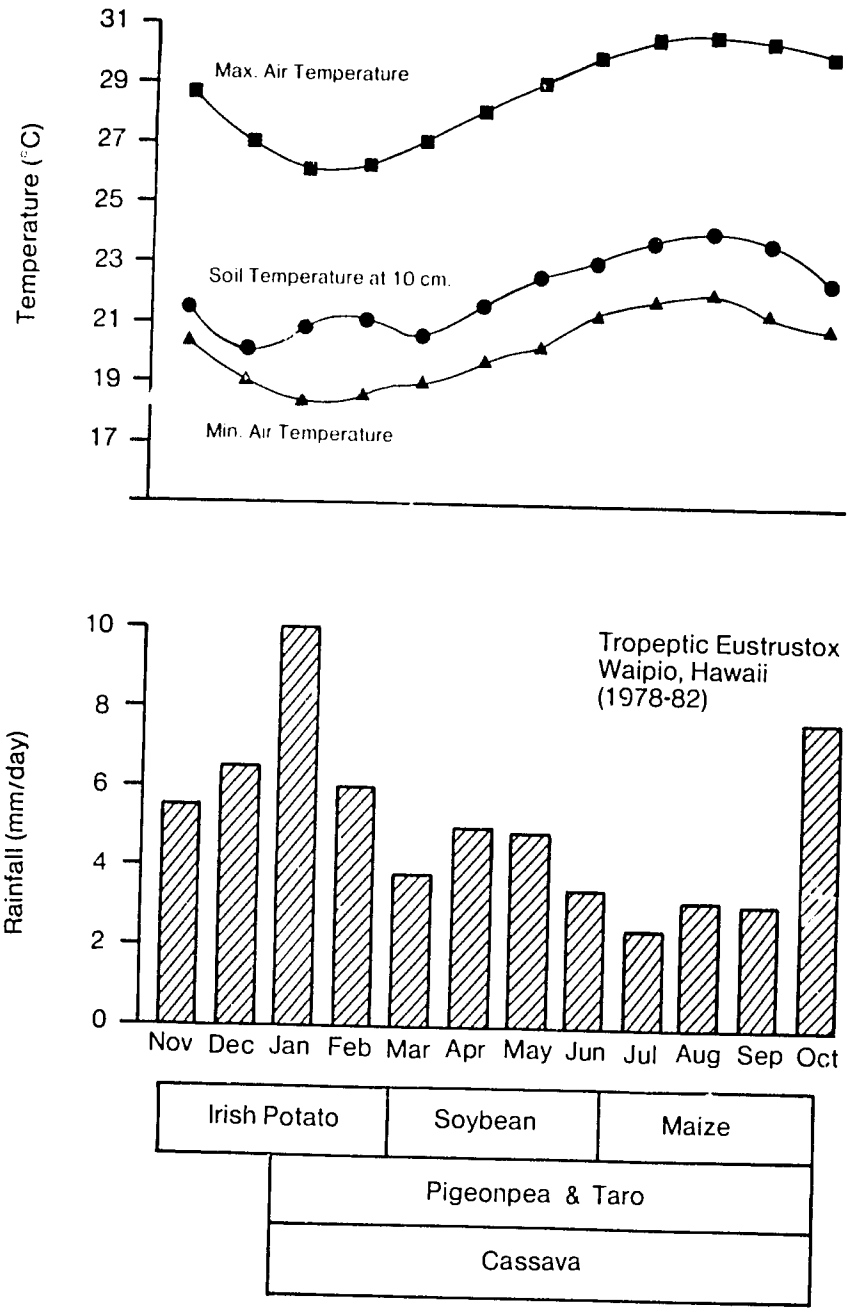



**Fig. 3.** Cropping pattern design for Tropeptic Eutrustox in relation to temperature and rainfall.

the second and third cycles. Irrigation is required except during the first cycle.

## Comparison of Patterns

Soil nutrients were optimized in each experiment while both irrigated and nonirrigated conditions were imposed on crops grown in the udic and ustic moisture regimes. The first crop cycle for each soil family was planted at the start of the rainy season. Cropping patterns designed for one soil family were also planted in one or both of the other soil families for the purpose of rating crop performances under different environments. Each site was continuously monitored for weather variables, as described in Chapter 7. Additional details are given by Varde (1984).

*Evaluation of productivity.* According to Hildebrand (1976) productivity is the output of any product per unit of any particular input or factor of production. Hence, productivity could refer to weight per unit of seed, labor, or water as well as to unit of land. Yield can also be expressed in calories or protein per unit of any input used in the crop production process.

The input or factor of production to which reference is made depends on the importance attached to it. In places where water is limiting, the yield per unit of water assumes importance; where farm labor is scarce, output per hour of labor is relevant. Yield of the economic product per unit of the cultivated land has been widely used as a measure of productivity because of the general assumption that land is the most limiting factor for a farmer. In this study yield (in calories, protein, or weight) per ha has been the measure of productivity.

## Performance of Cropping Systems

Cropping systems experiments, initiated in 1982, were affected by an assortment of start-up problems. Germination and yields were affected by seed troubles, unexpected moisture stresses, and damage due to storms and various pests (including birds and wild pigs). Some of these problems continued through later cycles of the cropping patterns.

Project personnel at the various sites were experienced in maize field plot techniques of the transfer experiments. However, management of cropping systems research is more complex, especially with patterns including various grain, root, and vegetable crops. In the data analysis, uniform management practices at all sites were assumed. The validity of the assumption may be questioned. In fact, it was difficult to maintain uniformity of field plot technique at all sites across the three soil families. Experimenters at each site had varying agronomic backgrounds with the different crops, resulting in varying degrees of creativity in handling the unexpected daily experimental problems. As might

be expected, plot management problems arose with one or more cropping patterns at most sites, thereby creating difficulty in comparing patterns within and across soil families.

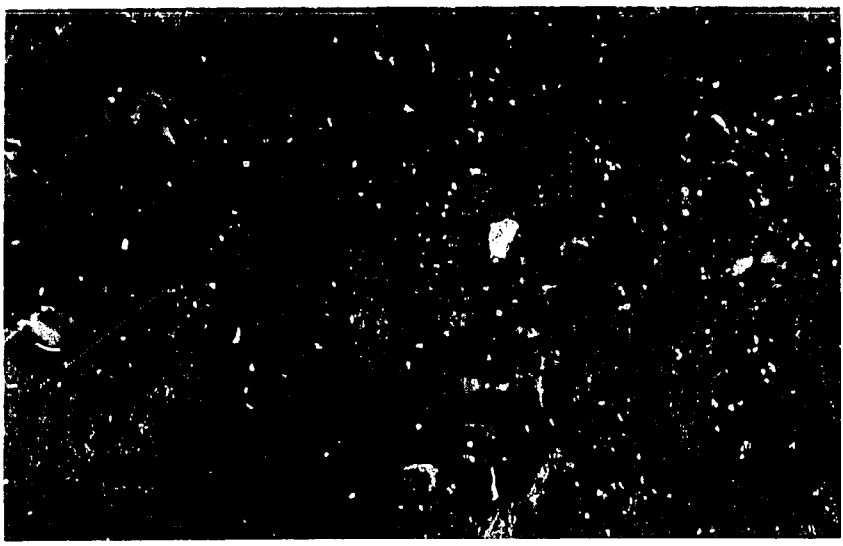
Varde (1984) made an evaluation based on year-round irrigated cropping pattern experiments. Calorie and protein levels were summarized over the crops and cycles within a year for each cropping pattern. Details are given in the Varde dissertation along with the field data. Reported here is a summary of the major results.

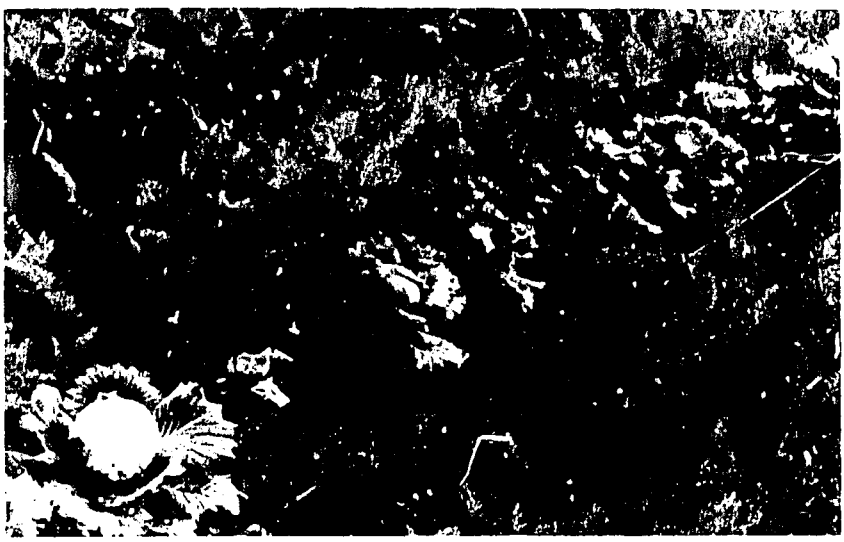
At Tropeptic Eutrustox (TE) sites the TE pattern gave higher calorie and protein yields than all Hydric Dystrandept (HD) pattern combinations. This indicates that the TE pattern was a proper choice for the Tropepric Eutrustox soil family. The project's record calorie (16,580 k cal/ha) and protein (2100 kg/ha) yields were obtained with the TE pattern on the Tropeptic Eutrustox site of WAI during 1981–82. At the KUK site of the Hydric Dystrandept the specifically designed HD pattern combinations produced less calories than the TE pattern due to the high calorie yield of maize (TE pattern) and higher yields of the soybean crop during the second crop cycle (TE pattern) from April to August relative to soybean yield in the third cropping cycle (HD pattern) between September to January.

As expected, the HD pattern performed better than the Typic Paleudult (TP) patterns on most Hydric Dystrandept sites. However, the PAL site behaved differently than other Dystrandept sites. In this case the TP pattern gave higher calorie yields than the HD pattern. This behavior can be attributed to the mismatch between the cool temperature crops of the HD pattern and the high temperature recorded at the PAL site. During the period of this study the mean air and soil temperatures in PAL were consistently over 24°C, and sometimes as high as 27°C. Such temperatures are favorable to warm climate crops such as rice, soybean, peanut, cowpea, and mungbean—which constituted the TP pattern. Chapters 3 and 7 support the premise that the temperature regime of the PAL site is indeed isohyperthermic. The generally higher calorie and protein production of the TP pattern, when compared to the HD pattern, on all Typic Paleudult sites reflects the proper selection of crops for this warm and humid environment. The relatively cool and wet environment of the Hydric Dystrandept soil family is not conducive to good growth of the warmer temperature requirement of TP pattern crops.

## Performance of Individual Crops in Relation to the Agroenvironments

The Benchmark Soils Project matched crop requirements with environmental characteristics to design cropping patterns for three soil families. Primarily, soil temperature, soil moisture regimes, and seasonal weath-





The difference in crop adaptability to environment is reflected in the poor growth of head cabbage (*Brassica olaracea* var *capitata*) and good growth of carrots *(Dacus carota)* in the moist (udic) and warm (isohyperthermic) environment in Mindanao, the Philippines (top), which is in marked contrast to the excellent growth of both crops in the moist (udic) and cool (isothermic) environment on the island of Hawaii (bottom).

er variations were considered in making the choice of crops for a cropping pattern. One of the objectives of cropping systems work is to evaluate the crop/environment matching process and produce conclusions concerning the agroclimatic requirements of various crops under tropical conditions.

Sufficient data were available from seven crops utilized as components of the three cropping systems. Based on their response to the agroenvironment, crops were placed into two groups.

1. Crops highly sensitive to temperature and moisture variation within the tropical range. This group includes the head cabbage, mustard cabbage, Irish potato, carrot, and bushbean of the Hydric Dystrandept cropping pattern (Irish potato is also part of the Tropeptic Eutrustox pattern).

2. Crops with a wide range of adaptability to temperature and moisture conditions (peanuts and soybeans).

Irish potato (Figure 4), mustard cabbage, head cabbage, carrot (Figure 4), and bushbean are cool weather crops and their performance, as expected, was negatively correlated to average soil temperature (correlation coefficients of at least -0.73). Highest yields of these crops were obtained within a soil temperature (at 10 cm depth) range of 18 to 23 °C. Generally, the crops failed beyond an average soil temperature of 24 °C. However, Irish potato and bushbean were less tolerant to high temperature compared to head cabbage and mustard cabbage.

The Figure 4 plots reinforce previous statements concerning the match of crop requirements with temperature environment. High potato yields are associated with sites from both the Hydric Dystrandepts (isothermic) and Tropeptic Eutrustox (isohyperthermic) soil families. However, within the overall isohyperthermic temperature regime of the Tropeptic Eutrustox sites, temperatures are cooler during the first cycle (Figure 3), thereby permitting an Irish potato crop to be part of the TE cropping pattern. The two plots of Figure 4 also show the isohyperthermic temperature regime of the PAL site (identified as "P"). There is also an indication that another Hydric Dystrandept site, LPH (identified as "L") had an average soil temperature greater than 22 °C, at least during the first cycle of both 1981–82 and 1982–83 crop years. However, data from Table 1 of Chapter 7 show that the LPH site should be categorized as isothermic.

## Potential for Rainfed Crop Production

Another objective of the cropping systems research was to evaluate the possibility of rainfed, without supplemental irrigation, crop production in the three soil families. To achieve this objective the cropping patterns designed specifically for each agroenvironment were tested both with and without irrigation.

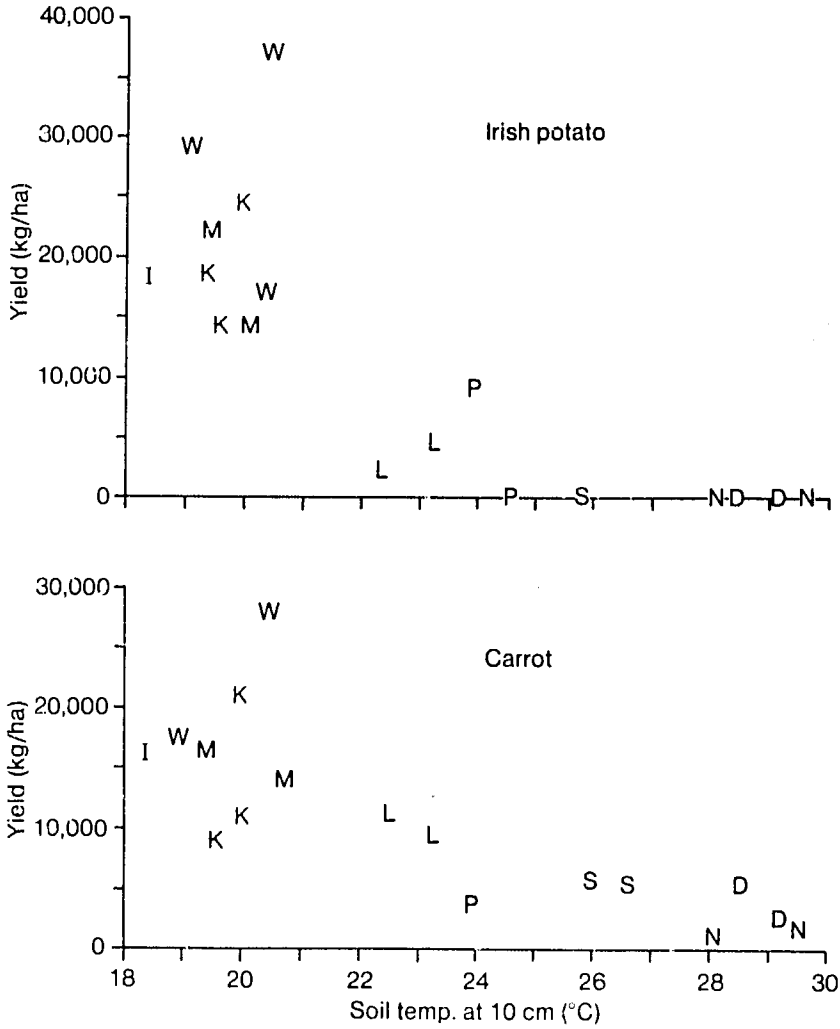



**Fig. 4.** The relationship between soil temperature and crop yields on benchmark sites of Hydric Dystrandepts (I, K, L, P), Tropeptic Eutrustox (M, W), and Typic Paleudults (D, S, N).

The overall trend is illustrated by the performance of the soybean crop in the three soil families (Figure 5). The histogram, calculated by averaging yields over sites within each soil family, is in accordance with the moisture regimes specified by Soil Taxonomy. Differences between irrigated and non-irrigated grain yields were minimal in the Hydric Dystrandepts, followed by the Typic Paleudults (reflecting their udic moisture regime), and at maximum in the ustic Tropeptic Eutrustox agroenvironments.

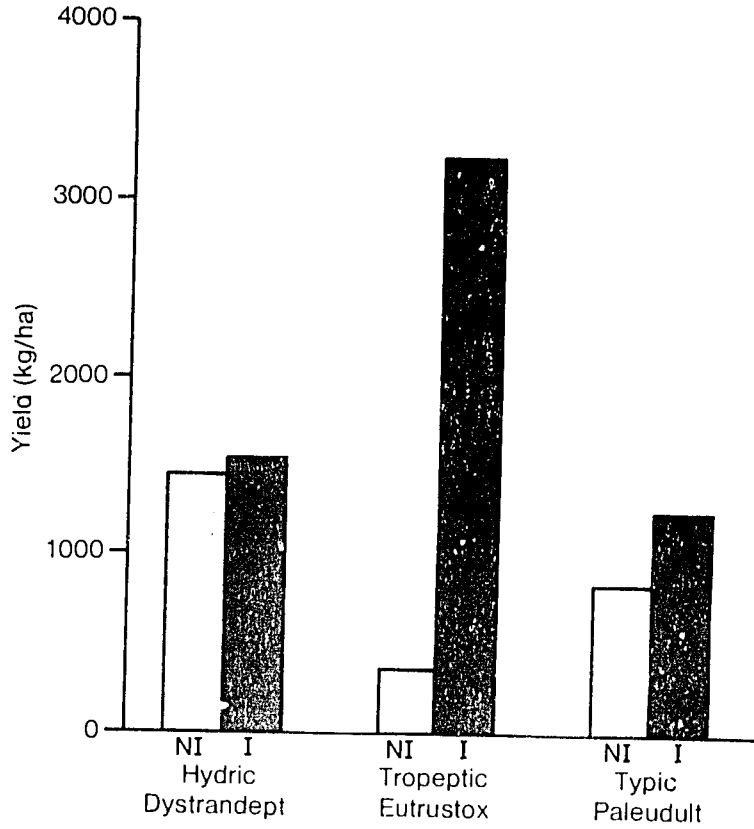



**Fig. 5.** Yields of irrigated (I) and non-irrigated (NI) soybeans on the experimental network of the Benchmark Soils Project.

In the Hydric Dystrandepts the performance of most of the rainfed crops was not statistically significantly different from irrigated ones; and only in very few instances (6 out of 61 test crops) were yields without irrigation less than 60 percent of the irrigated yields. Out of a total of 21 crop trials on the Typic Paleudults irrigated and non-irrigated yields were similar in 11 cases and only in four cases did crops without irrigation produce lower than 60 percent of their yields with irrigation. However, in the ustic moisture regime of Tropeptic Eutrustox soils, 10 out of a total of 12 crops failed when irrigation was not provided.

In summary, the soil family level of Soil Taxonomy achieves a stratification of soil temperature and moisture regimes, and biological, chemical, and physical soil characteristics which is useful for formulating cropping patterns and evaluating their performance. The successful transfer of cropping systems technology depends on matching the requirements of a cropping pattern to the characteristics of a farmer's field.

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

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

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

## References

Hildebrand, P. E. 1976. Multiple cropping systems and dollars and "sense" agronomy. *In* Multiple cropping. R. I. Papendick, P. A. Sanchez, and G. B. Triplett, eds. Spec. Pub. 27, American Society of Agronomy. Madison, Wisconsin.

Manrique, L. A. 1982. Development of a land suitability classification for potatoes *(Solanum tuberosum)*. Ph.D. dissertation, Univ. Hawaii.

Varde, N. P. S. 1984. Performance of year-round cropping systems on three tropical soil families. Ph.D. dissertation, Univ. Hawaii.

Zandstra, H. G., E. C. Price, J. A. Litsinger, and R. A. Morris. 1981. A methodology for on-farm cropping systems research. The International Rice Research Institute (IRRI), Los Baños, Laguna, Philippines.

*Matching Crops and Environments by Soil Taxonomy*

# 16 A Soil Taxonomy-based Land Assessment for Food Crop Production

*L. A. Manrique* and *G. Uehara*

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*Editor's note: The Benchmark Soils Project used analogue transfer to predict yield responses in similar environmental niches, as identified by Soil Taxonomy, throughout the world. Another method of transfer is matching transfer, which, for crops, involves identification of crop requirements—soil and climatic characteristics important to the crop. Various environments are then compared, and an environment that provides most or all of the crop's requirements—one where there is a "good match"—is considered well suited for production of that crop. Where there is a "mismatch," the crop will not grow well or at all—unless the deficiency is correctable by and is corrected by soil management. This paper is reprinted from* Soil Taxonomy News *#19, pp. 3–5, and describes a matching process in which a Soil Taxonomy-based methodology was developed to assess lands for their suitability for producing specific agricultural commodities. It is included to illustrate one of the alternate methods for the transfer of agrotechnology.*

## Introduction

Land assessment is not a new subject; in fact a variety of organizations and individuals pioneered the early efforts to establish the principles of land assessment (FAO, 1976). The principle is based on matching the biological requirements of a crop to the soil and environmental characteristics of the land. The methodology for land assessment described in this article differs from other efforts in the way land characteristics are extracted from the information condensed in the taxa of Soil Taxonomy (Soil Survey Staff, 1975). Soil Taxonomy presents several advantages not offered by other classifications. It is a quantitative, comprehensive, multi-categorical system designed and developed for worldwide application. These advantages were exploited to develop a methodology designed to be applicable to a wide range of crops on a worldwide basis.

## Methodology

The methodology (Manrique and Uehara, 1984a) consists of four steps: (1) compiling data on the characteristics and requirements of the crop under study, (2) ascertaining the soil and climate information needed to assess crop performance and extracting the soil and climatic informa-

tion from taxa of Soil Taxonomy, (3) synthesizing land qualities necessary to assess crop performance from the soil and climatic information extracted from Soil Taxonomy and other available data, and (4) matching the requirements of the crop to the qualities and characteristics of the land in question, and assessing the suitability of a land for crop production with zero, low, and high levels of management input. High levels of input include management practices such as irrigation, fertilizer and soil amendment application, and other agronomic practices which will ensure maximum crop yields. A zero input level describes a situation where no management practices are utilized. The low input level is an intermediate situation between zero and high input levels.

*Crop requirements.* The methodology requires that crop requirements be known in order to select important land characteristics from soil surveys. Crop requirement is the level of a certain soil or climatic characteristic which permits optimum plant growth and yield. Table 1 shows a summary of potato and forage legume requirements.

*Land qualities.* The selection of land qualities relevant to crop production becomes crucial in the matching process. Land characteristics are the attributes of the land that affect crop performance, such as soil physical and chemical properties and environmental characteristics. For example, Soil Taxonomy provides readily available information to characterize a few of the more important land qualities for potato production. Table 2 shows a summary of diagnostic criteria used to define some land qualities relevant to potato production.

*Matching process.* Matching is the confrontation of the crop require-

**Table 1. Selected requirements for potato and forage legumes.**

| Requirement | Potato | Forage legumes |
|---|---|---|
| Air temperature, °C | 15–20 | 25–30 (*C. pubescens*, *S. humilis*, *D. uncinatum*, *D. intortum*) |
| Soil temperature, °C | 15–22 | 25–30 (most species) |
| Soil moisture regime | Udic | Udic-ustic (*C. pubescens*, *S. guianensis*, *D. intortum*) |
| | | Ustic-aridic (*S. humilis*)<br>Udic (*D. uncinatum*) |
| Soil acidity, % Al sat. | <20 | <40 (*S. guianensis*, *S. humilis*, *C. pubescens*, *D. intortum*, *D. uncinatum*) |
| Soil P, mg kg$^{-1}$ (P in soil solution | 0.20 | 0.20 (establishment, *D. aparines*)<br>0.01 (second cut, *D. aparines*) |
| Soil K, cmol (+) kg$^{-1}$ (ammonium acetate) | >0.25 | >0.20 (most species) |

**Table 2. Diagnostic criteria used to define some land qualities relevant to potato production (Manrique and Uehara 1984a).**

| Land quality | Main diagnostic criteria | Alternative diagnostic criteria |
|---|---|---|
| Water availability | Moisture availability index (MAI) | Soil moisture regime |
| Oxygen availability | Percentage clay, soil moisture regime, and mineralogy class | Particle-size class, soil moisture regime, and mineralogy class |
| Soil thermal regime | Soil temperature regime, and mean annual soil temperature | Formative elements and extragrade in taxa |
| Soil acidity | Al saturation | pH in 1M KCl |
| Nutrient availability (Potassium) | Exchangeable K (normal ammonium acetate) | Particle-size class, soil moisture regime, and mineralogy class |
| Nutrient availability (Nitrogen) | Organic matter content, C/N | Soil moisture regime, soil temperature regime, formative elements, and extragrade in taxa |
| Nutrient availability (Phosphorus) | Available P (Olsen method) | Particle-size class, mineralogy class, and soil temperature regime |

Note: MAI = PD/ETP, where PD is dependable precipitation and ETP is potential evapotranspiration.

ments with the land qualities to give an estimate of crop performance. The matching process takes place at two levels: (1) the matching of crop requirements for a particular land quality, and (2) the matching of crop requirements with all land qualities included simultaneously in a quantitative analysis. A simple computing procedure was developed to handle the matching process (Manrique and Uehara, 1984a). The matching process is a critical step of the methodology. The level of matching, as indicated by the land suitability classes (Table 3), is determined by the degree to which the land in question meets the requirements of the crop. A mismatch results when the land qualities fail to meet the requirements of the crop. Because mismatch can be corrected in some cases by soil management, the land suitability varies with input levels (Table 4).

*The system of classification.* The system has three categories: Order, Class, and Subclass (Table 5). Order reflects whether or not a land is suitable for a particular use. Class reflects the degree of suitability

Growth and development of potato *(Tuberosum solanum)* are influenced by environmental constraints. A good match between the potato's requirements and the environment is demonstrated by the excellent stand in the cool (isothermic) Hydric Dystrandept site at Java, Indonesia (top), while a mismatch is evident in the poor growth at the warm (isohyperthermic) Typic Paleudult site in Sumatra, Indonesia (bottom).

within each Order. Subclass reflects the kinds of limitations within Classes. For example, the Typic Paleudult of Malaysia (Table 4) is classified in the Order Unsuitable, Class 5 (Permanently Unsuitable), Subclass $U_5$-TR with limitations in soil temperature for potato growth (Manrique and Uehara, 1984b).

**Table 3. Suitability classes for soil thermal regime. Crop: potatoes (Manrique and Uehara 1984a).**

| Suitability class | | Diagnostic criteria |
|---|---|---|
| 1 | Good | Soils with an isomesic or isothermic temperature regime. |
| 2 | Fair | Soils with a hyperthermic or isohyperthermic temperature regime and MAST of 25 °C or lower, or<br>Soils with a mesic or thermic temperature regime. |
| 3 | Poor | Soils with cryic, frigid, or isofrigid temperature regime, or<br>Soils with a formative element Bor or Cry in their taxonomic names. |
| 4 | Unsuitable | Soils with an isohyperthermic temperature regime and MAST higher than 25 °C, or<br>Soils with a pergelic temperature regime or an extragrade pergelic in their taxonomic names. |

Note: MAST = mean annual soil temperature measured at 50 cm depth

**Table 4. Suitability classes for selected soils at three different levels of input.**

| Soil | Location | Suitability class[a] ZIL | LIL | HIL |
|---|---|---|---|---|
| | **Potatoes**[b] | | | |
| Typic Hydrandepts | Hawaii | 4 | 4 | 1 |
| Ustollic Camborthids | Hawaii | 4 | 4 | 1 |
| Typic Chromusterts | Hawaii | 5 | 5 | 3 |
| Typic Gibbsiorthoxs | Hawaii | 4 | 4 | 1 |
| Typic Hapludults | New Zealand | 4 | 4 | 1 |
| Aquic Dystrochrepts | New Zealand | 4 | 4 | 1 |
| Oxic Haplustalfs | Brazil | 4 | 4 | 1 |
| Rhodic Paleudalfs | Brazil | 4 | 3 | 1 |
| Typic Paleudults | Malaysia | 5 | 5 | 5 |
| Haplic Acrorthoxs | Malaysia | 5 | 5 | 5 |
| | **Forage Legumes** | | | |
| Typic Hydrandepts | Hawaii | 4 | 4 | 2 |
| Ustollic Camborthids | Hawaii | 3 | 3 | 1 |
| Typic Chromusterts | Hawaii | 1 | 1 | 1 |
| Typic Gibbsiorthoxs | Hawaii | 3 | 2 | 1 |

Notes: a) ZIL = zero input level, LIL = low input level, HIL = high input level. Suitable (Class 1, 2, and 3), Partially Unsuitable (Class 4), Permanently Unsuitable (Class 5). All land qualities were included in the matching process.
b) Source: Manrique and Uehara (1984b)

**Table 5. The categories of the land assessment system (Manrique and Uehara 1984a).**

| Order | Class | Subclass |
|---|---|---|
| Suitable (S) | 1 (Good) | — |
| | 2 (Fair) | — |
| | 3 (Poor) | — |
| Unsuitable (U) | 4 (Partially Unsuitable) | U4-WA, U4-NA, U4-A, U4-SS |
| | 5 (Permanently Unsuitable) | U5-OA, U5-ST, U5-TR, U5-RD |

Note: WA = water availability, NA = nutrient availability, A = soil acidity, SS = soil salinity and sodicity, OA = oxygen availability, ST = soil tilth, TR = thermal regime, RD = root development.

## Testing the Methodology

The land assessment for potato was tested using soil survey and Soil Taxonomy information of sixty-two soils from Hawaii, California, Brazil, New Zealand, and Malaysia (Manrique and Uehara, 1984b). Potato experiments conducted in three of the sixty-two soils showed that potato yield response both with and without management inputs as consistent with the land assessment. Land assessment for forage legume production (genera *Stylosanthes*, *Centrosema*, and *Desmodium*) for twenty-one Hawaiian soils were also obtained using the same methodology (Manrique, 1984, unpublished data). Land assessment based on four qualities, nutrient availability, water availability, soil acidity, and soil thermal regime, indicated that nutrient availability was the land quality that most frequently failed to meet the requirements of tropical forage legumes. Utilization of high levels of management input made all twenty-one of the studied Hawaii soils suitable for forage legume production while even low levels of management input significantly reduced the number of unsuitable soils. The land assessment was consistent with published field results on forage legume performance in Hawaii.

## Conclusion

The methodology described in this article provides a systematic computing procedure to use soil survey data based on Soil Taxonomy to assess whether a land is suitable for crop production and to determine the kinds of management input needed to obtain optimum production. Limited field testing of the methodology indicate that reliable estimates

of land use capability can be obtained by using this Soil Taxonomy-based land assessment. The use of this methodology in developing countries could increase the likelihood of success in assessing which adapted crops can be recommended for a specific location, consequently reducing the risk of crop failure.

## References

FAO. 1976. A framework for land evaluation. Soil Bull. 32. Food and Agriculture Organization of the United Nations, Rome.

Manrique, L. A., and G. Uehara. 1984a. A proposed land suitability classification for potato. I. Methodology. Soil Sci. Soc. Am. J. 48:843–847.

Manrique, L. A., and G. Uehara. 1984b. A proposed land suitability classification for potato. II. Experimental. Soil Sci. Soc. Am. J. 48:847–852.

Soil Survey Staff. 1975. Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. Soil Conservation Service, U.S. Dept. Agr. Handbook 436. U.S. Govt. Printing Office, Washington, D.C.

PART III

# EXECUTIVE SUMMARY

# Executive Summary

In May 1974 a contract (AID/Contract No. ta-C-1108) was signed between the U.S. Agency for International Development (USAID) and the University of Hawaii (UH) to initiate a project entitled "Crop Production and Land Capabilities of a Network of Tropical Soil Families." A companion contract (AID/Contract No. ta-C-1158) was signed with the University of Puerto Rico in January 1975. The contract activities have been known more briefly and popularly as the Benchmark Soils Project. The purpose of the project was to test an innovative approach to agrotechnology transfer. The intent was to assist less-developed countries (LDCs) in more efficiently utilizing their land resources to increase yields and improve quality of agricultural production by bypassing three major constraints: insufficient capital; scarcity of qualified research personnel; and, above all, the time needed to close the widening gap between agroproduction and food requirements.

The Benchmark Soils Project's goal of the acceleration and reduction of the cost of agricultural planning and development in LDCs through the process of agrotechnology transfer relates to USAID's objective of expanding the information available on the management of tropical soils to increase food production. The objectives of the project were

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, and
3. to demonstrate the value of soil and land classification in formulating agricultural development plans in selected areas.

The project established experimental sites in three soil families in a network which included Brazil, Cameroon, Indonesia, the Philippines, and the U.S. (Hawaii and Puerto Rico) and conducted a series of parallel-linked experiments with maize to determine the grain yield response to P and N fertilizer applications. Data generated in these experiments were used to test the hypothesis that agrotechnology can be transferred on the basis of information contained in the soil family name. The project received two three-year extensions and continued until 1983 when sites were closed down. All field operations officially ended on May 31, 1983, and closing ceremonies recognizing the contributions of the local

staff were held in each country. The following is a summary of some of the accomplishments of the University of Hawaii Benchmark Soils Project.

## Establishing a Network of Benchmark Soil Families

Three soil families from upland areas having the potential to be productive under appropriate management practices were selected to test the hypothesis of agrotechnology transfer. Soil surveys were conducted in the U.S. and countries in S.E. Asia and Africa to establish a network of 18 sites. The three selected soil families were

1. thixotropic, isothermic Hydric Dystrandepts,
2. clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox, and
3. clayey, kaolinitic, isohyperthermic Typic Paleudults.

Of the 18 sites, three of the Dystrandepts and four of the Paleudults were reclassified after a second site check. Small differences in soil temperature, base saturation, mineralogy, and organic matter content, and strict adherence to the rules of soil classification resulted in the final classification. However, since the sphere of transferability of agrotechnology is not restricted only to similar-named kinds of soils, but is valid for any soils possessing a common set of characteristics fulfilling the requirements of the technology in question, it was expected that the transfer of agrotechnology based on the soil family would take place as the soils had appropriately similar characteristics.

Establishing the network of soils required a combination of negotiations for land and technical cooperation, soil surveys of potential sites, classification of soils at these sites according to Soil Taxonomy, and the appointment of a project leader. Each project leader assigned to head a project on location in the cooperating country was trained in Hawaii in the agronomic techniques to be followed in the conduct of the transfer experiments.

## Successful Test of a Model for Agrotechnology Transfer

An important result of the project was the development of a methodology for the statistical evaluation of the hypothesis of the transfer of agrotechnology—including a summary statistic, a transfer or prediction statistic.

The statistical test of the transfer hypothesis was completed for the Hydric Dystrandepts and Typic Paleudults. As anticipated, the *intra-family* transfer predictions of maize grain yield response to applied P and N were judged to be the same as the site-specific predictions (within

random variability), if a measure of soil P and N was included in the transfer equation.

Also as expected, due to the greater number of variable factors, the evaluation of *inter-family* transfer of agrotechnology indicated that yield response to applied P and N could not be accurately predicted for the Typic Paleudults using the transfer equation of the Hydric Dystrandepts and vice versa, according to the inter-family prediction statistic. Similarly, the yield response to P and N could not be predicted for the Tropeptic Eutrustox with the transfer equations of the Hydric Dystrandepts or Typic Paleudults.

## Upland Areas Shown to Have Potential for Intensive Cropping

Maize production was highest in the Tropeptic Eutrustox (provided moisture was adequate), next highest in the Typic Paleudults (provided soil acidity and plant nutrients were not limiting factors), and lowest in the Hydric Dystrandepts (even when soil acidity and phosphorus were not constraints).

The maturity date of maize reflected the soil temperature regimes of the soil families. Maize grown in the warm agroenvironment of the Typic Paleudults matured earlier than that grown in the warm Tropeptic Eutrustox or cool Hydric Dystrandepts. Although both the Typic Paleudults and Tropeptic Eutrustox have isohyperthermic temperature regimes, the mean annual temperature of the Tropeptic Eutrustox was nearly 5 °C lower than that of the Typic Paleudults. This suggests that another temperature regime may be needed to further divide sites with mean annual temperatures in excess of 22 °C.

Cropping system experiments evaluating the performance of year-round cropping patterns designed to match agroenvironments described by the soil family were conducted at selected sites. Cropping patterns designed for one soil family were also planted in one or two other soil families for the purpose of evaluating crop performances in different environments. The highest caloric (46,580 k cal/ha) and protein (2100 kg/ha) yields were obtained with the Tropeptic Eutrustox cropping pattern on the Tropeptic Eutrustox site. The pattern specifically designed for a particular soil family generally performed best at sites of that family. Crops found to be highly sensitive to temperature and moisture variation included head cabbage, mustard cabbage, Irish potato, carrot, and bushbean; while peanut and soybean had a wide range of adaptability to temperature and moisture conditions. The Hydric Dystrandepts and Typic Paleudults, with their udic moisture regimes, were well suited for year-round rainfed crop production (except in years with prolonged droughts for the latter). The Tropeptic

Eutrustox was able to support rainfed crop production only during the short wet season. Stratification of the temperature and moisture regimes by the soil family of Soil Taxonomy proved useful in formulating cropping patterns and evaluating their performance.

## Soil and Land Classification Demonstrated to be of Value in Agricultural Planning

The amount of applied P required to reach the critical level of modified Truog extractable P was found to be higher for the Hydric Dystrandepts, with their non-crystalline mineralogy (thixotropic property), than for the other two families with crystalline, clay mineralogy. Residual soil P was shown to have a marked effect on P availability and crop response to applied P. With higher levels of residual P there was a larger amount of extractable P, greater relative effectiveness of residual P, and, consequently, reduced quantities of P needed to attain the P requirement for optimum crop growth.

The Typic Paleudult sites in Indonesia were found to be well suited for the direct application of phosphate rock of high and intermediate reactivity, and results suggest that low reactivity phosphate rocks may also be suitable amendments for use on these acid soils. In contrast, the Hydric Dystrandept sites in the Philippines required highly reactive phosphate rock to produce yields comparable to those with superphosphate.

Mean annual erosivity for the Dystrandepts and Paleudults was found to range from 578 to 2703 tonne-m/ha and 1362 to 2381 tonne-m/ha, respectively, which, on the whole, is three-to-four times greater than that of the Eutrustox, which ranges from 365 to 524 tonne-m/ha. A large proportion of erosive storms in Hawaii had low intensity rainfall, while storms in the Philippines, Indonesia, and Cameroon were of high intensity. The soil moisture regime of Soil Taxonomy alone was not able to quantify erosivity. By analogy, however, the closeness of rainfall erosivities within the same soil family in the allowable range of agroenvironments would seem to enable erosivities measured from one location to be transferred to a new location in the same family.

Manual or mechanical workability of the Typic Paleudults and Tropeptic Eutrustox was a function of their clayey texture, kaolinitic mineralogy, and soil moisture content. Both soils were characteristically very hard when dry and very sticky and plastic when wet. Power requirements to work these soils were lower when they were moderately dry. The Hydric Dystrandepts, with their thixotropic properties and low bulk density, on the other hand, had a lower power requirement over a wide range of soil moisture conditions.

The soil family stratified the occurrence of maize pests within a coun-

try, although not over all countries because of the region-specific occurrence of many of the pests. For example, downy mildew (*Peronosclerospora* spp.) commonly occurs in Indonesia and the Philippines, but not in Cameroon or Hawaii. Downy mildew was most severe in the warm, moist environment of the Typic Paleudults and relatively minor in the cool, moist Hydric Dystrandepts.

Nitrogen-fixing tree species, mostly legumes, planted in each of the soil families reflected the differences in soil moisture and temperature regimes of the soil family in their growth as early as six months after planting in the field and differences were still apparent two years after planting. Of the replicated species, *Leucaena diversifolia* and *Calliandra calothyrsus* were best adapted to the cool, moist environment of the Hydric Dystrandept site, while *L. leucocephala* and *L. diversifolia* exhibited a wide range of adaptability by their performance in the warm, moist conditions of the Typic Paleudult and Ultic Tropudalf sites as well as in the warm, dry conditions of the Tropeptic Eutrustox site. *Acacia auriculiformis* and also *A. mangium* exhibited tolerance to soil acidity and severe drought at the Typic Paleudult site.

## 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. These data have been used by project personnel, as well as researchers from other institutions, for basic agronomic studies, erosivity studies, investigation of weather relationships, and testing of growth simulation models. These data are unique in that they were obtained from sites with fully characterized soils, continuous weather data, and carefully conducted experiments located in widely separated geographic areas in the tropics. These data sets may be one of the most important contributions of the Benchmark Soils Project to researchers and are available upon request.

## A Network of Cooperating Countries and Agencies

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

The "Workshop on Experimental Designs for Predicting Crop Productivity with Environmental and Economic Inputs" was held at the University of Hawaii in 1974 and attended by 38 participants from the United States and abroad. This initial workshop of the Benchmark Soils Project was devoted to discussions relevant to the research methodology and the experimental designs to be employed by the project.

Project personnel participated in the organization and conduct of the "Second International Soil Classification Workshop" in Malaysia and Thailand in 1978 and in the "Third" and "Fourth International Soil Classification Workshop(s)" in Syria and Rwanda, respectively, in April 1980 and June 1981, under a special grant from USAID through the Soil Management Support Services (SMSS).

Advisory Committees convened by the Philippine Council for Agriculture and Resources Research and Development (PCARRD), Center for Soil Research (CSR), and Institut de la Recherche Agronomique (IRA) included cooperating agencies in the Philippines, Indonesia, and Cameroon to provide guidance in the conduct of regional programs by the project and to serve as a bridge between host-country scientists and planners.

Project personnel have collaborated with SMSS scientists in presenting forums on "Soil Taxonomy and Agrotechnology Transfer" in Fiji, the Philippines, Cameroon, Thailand, and Papua New Guinea.

The New Zealand Soil Bureau and the International Society of Soil Science (ISSS) invited the Benchmark Soils Project to participate in an informative one-day symposium on project accomplishments and impact during the international conference on "Soils with Variable Charge" in February 1981.

## Training on Soil Taxonomy and Agrotechnology Transfer

Awareness of project goals was generated through the development of a training program on "Soil Taxonomy and Agrotechnology Transfer."

The project conducted five training workshops. The first was a workshop on "Soil Resources and Utilization of Agrotechnology Transfer for Country Development" held in the Philippines in 1977. It was conducted jointly with Cornell University and included 42 participants from Brazil, Indonesia, Malaysia, the Philippines, Thailand, and the U.S. (including representation from Puerto Rico). The next was a workshop on "Soil Taxonomy" held in the Philippines with 10 participants in 1979. This was followed by a workshop on "Soil Taxonomy and Agrotechnology Transfer" conducted in Indonesia with 25 participants in 1980, and another on "Agrotechnology Transfer" held in the Philippines with 24 participants in 1980. The fifth workshop was on "Soil Classification and Agrotechnology Transfer," held in Cameroon with 35 participants in 1983.

Nine graduate students have received advanced degrees from the University of Hawaii with Benchmark Soils Project support. These include one from Cameroon, with an M.S.; three from Indonesia, one M.S. and two Ph.D. degrees; three from the Philippines, all with Ph.D. degrees; and one from the U.S. with a Ph.D. degree. Seven additional

graduate students supported from other sources collaborated on research problems related to project concepts and objectives. Their contributions are reported, in part, in the Final Report of the Benchmark Soils Project.

## International Awareness and Utilization of Project Concepts

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

The mailing list for Benchmark Soils Project publications grew to over 2000 people from more than 80 countries. Expressions of interest in the project were received from countries throughout the world. The mailing list was eventually used jointly by both the project and SMSS.

The project published the *Benchmark Soils News* as the primary means of disseminating information related to project concepts, activities, and accomplishments. In addition, a total of 10 Technical Reports and three conference/seminar proceedings have been published. Numerous papers have been presented at conferences and workshops to both local and international audiences.

A seminar entitled "Uses of Soil Survey and Classification in Planning and Implementing Agricultural Development in the Tropics" was organized by the Benchmark Soils Project and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) under the sponsorship of USAID. It was held at ICRISAT in Hyderabad, India, in 1976. The purpose of the seminar was to establish communication on uses of soil survey data in relation to land use planning and agricultural development for crop production. Proceedings of the seminar were published in *Soil-Resource Data for Agricultural Development*, edited by L. D. Swindale.

The Benchmark Soils Project concepts formed the core of the discussion at a workshop entitled "Operational Implications of Agrotechnology Transference Research" held at ICRISAT, Hyderabad, India, in 1978. At the workshop the Soil Conservation Service of the U.S. Department of Agriculture agreed to "internationalize" Soil Taxonomy and 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.

A joint proposal prepared in the Philippines by the Benchmark Soils Project Advisory Committee (consisting of personnel from the Bureau of Soils, PCARRD, the University of the Philippines at Los Baños, and the Benchmark Soils Project) resulted in the funding of a 6 million-peso

(U.S. $600,000) project titled "Classification of Philippine Soils Using the Soil Taxonomy Framework for Agrotechnology Transfer."

Both Indonesia and the Philippines decided to adopt Soil Taxonomy as a supplementary soil classification system along with their own local systems. Participants at the Benchmark Soils Project-sponsored workshop on "Soil Classification and Agrotechnology Transfer" in Cameroon in 1983 endorsed the formation of a proposed National Soils Center. This body, eventually established in April 1983, proposed to encourage the simultaneous use of three soil classification systems—the French, FAO, and Soil Taxonomy; to develop correlations between these systems; and to develop the facility to conduct standard soil surveys and use agrotechnology transfer in the country.

In an effort to pave the way for effective utilization of the principles and concepts of the Benchmark Soils Project, a "Panel Consultation on Strategy for Land Evaluation and Agrotechnology Transfer in the Tropics and Subtropics" was held in March 1980 in Rome, Italy. The meeting, a follow-up to that held at ICRISAT in 1978, was organized and conducted jointly by the Benchmark Soils Project and the Food and Agriculture Organization (FAO) of the United Nations, and held at FAO headquarters. The intent was to develop an international strategy for land evaluation research and soil-based agrotechnology transfer in the tropics and subtropics. The "Panel" recommended that an International Network of Benchmark Sites for Agrotechnology Transfer (IBSNAT) be established for the tropics and subtropics. The main objective would be to elucidate the fundamental relationships between land characteristics and crop requirements to facilitate the exchange of agrotechnological production methodologies. This project was funded by USAID and is the successor of the Benchmark Soils Project.

# APPENDICES

*Appendix A*

# History of the Benchmark Soils Project

1973

A project statement to fund the Benchmark Soils Project was submitted to the Technical Assistance Bureau/United States Agency for International Development (TAB/USAID) for consideration.

1974

A workshop on Experimental Designs for Predicting Crop Productivity with Environmental and Economic Inputs was held at the University of Hawaii (UH) to develop strategy on experimentation and to determine the number of sites per soil family.

A contract implementing the Benchmark Soils Project was signed on May 31, 1974, by the United States Agency for International Development (USAID) and UH.

The thixotropic, isothermic Hydric Dystrandepts, and the clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox soil families were selected to test the agrotechnology transfer hypothesis, based on the important role these soil families play in agriculture in Hawaii and by the fact that they possibly would be identified in Asia and Africa.

Soil survey for sites on Hydric Dystrandepts in Hawaii was initiated.

1975

A contract to implement the Benchmark Soils Project in Puerto Rico was signed by USAID and the University of Puerto Rico (UPR). UH and UPR would work cooperatively using the Tropeptic Eutrustox soil family as the common basis for research. UPR would identify the Tropeptic Eutrustox soil family in Puerto Rico and establish sites in Central and/or South America.

Hydric Dystrandept sites in Hawaii were established and the first transfer experiment was planted. Hydric Dystrandept sites were identified in the Philippines and Indonesia.

## 1976

An agreement was signed by the Philippine Council for Agriculture and Resources Research (PCARR) and UH to implement the Benchmark Soils Project in the Philippines. Three Hydric Dystrandept sites were established in the Bicol region of Camarines Sur.

A workshop on Uses of Soil Survey and Classification in Planning and Implementing Agricultural Development was held at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, India.

Soil surveys for Hydric Dystrandepts, Tropeptic Eutrustox, or an Ultisol soil family in Ghana, Nigeria, Cameroon, Kenya, and Tanzania were initiated.

The first on-site Benchmark Soils Project review was conducted by an AID-appointed review team. A recommendation was made to continue the project for three years and to include a third soil family belonging to the order Ultisols as requested by the Agency for Agricultural Research and Development (AARD) in Indonesia and PCARR in the Philippines.

The first coordination meeting of the UH and UPR Benchmark Soils Project was held in Mayaguez, Puerto Rico.

An agreement was signed by the Agency for Agricultural Research and Development/Soil Research Institute (AARD/SRI) and the Benchmark Soils Project to implement the Benchmark Soils Project activities in Indonesia.

Three Hydric Dystrandept sites in Java, Indonesia, were established.

## 1977

A training course on Soil Resources Inventory and Utilization of Agrotechnology Transfer for Agricultural Development was held at the University of the Philippines at Los Baños (UPLB), College, Laguna, Philippines.

The second Benchmark Soils Project coordination meeting was held in the Philippines on common methodologies and management practices used in the conduct of transfer experiments.

Soil survey and study for a common Ultisol family was initiated in the areas of tropical Africa, Indonesia, and the Philippines.

First *Benchmark Soils News* newsletter was published.

Participation in the International Workshop on Hilly Land Development in the Philippines and the International Soil Classification Workshop and Correlation Tour in Brazil.

1978

Tropeptic Eutrustox sites were established on the islands of Molokai and Oahu, Hawaii.

Typic Paleudult sites established in Indonesia and the Philippines.

A workshop on the Operational Implication of Agrotechnology Transference Research was held at ICRISAT, Hyderabad, India, to plan long-range activities in the utilization phase of the Benchmark Soils Project.

First approximation on the transfer analysis using experimental data from the Hydric Dystrandepts sites was completed.

1979

The second on-site Benchmark Soils Project review was completed with a recommendation for a second three-year extension to complete testing of the transfer hypothesis.

The first instructional workshop on Soil Taxonomy was conducted at UPLB, Laguna, Philippines. The participants included government planners and soil specialists from the government agencies, agricultural colleges, and universities.

A memorandum of understanding was signed by the Benchmark Soils Project and the Office National de la Recherche Scientifique et Technique (ONAREST) to implement the Benchmark Soils Project in Cameroon.

1980

The Benchmark Soils Project and the Food and Agriculture Organization of the United Nations (FAO) invited international agricultural scientists to Rome to discuss strategies for soil-based agrotechnology transfer in land evaluation for the tropics and subtropics. Plans to establish the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) were discussed.

Soil Taxonomy and Agrotechnology Transfer workshops in Indonesia and the Philippines were organized for planners and soil/crop scientists.

The Benchmark Soils Project organized an in-house workshop at the University of Hawaii that was an interdisciplinary session on agrotechnology transfer. Technical papers were presented from various agricultural sciences including resource economics, geography, food, and nutritional sciences.

Typic Paleudult sites were established in Cameroon.

Brazil and Puerto Rico field operations were completed.

1981

Accomplishments of the Benchmark Soils Project were presented to the congress of the International Society of Soil Science (ISSS) at its Conference on Soils with Variable Charge at Massey University, Palmerston North, New Zealand.

On request of the International Soil Museum in the Netherlands, soil monoliths representing the three soil family networks were presented for use as an international reference and display.

Management experiments on cropping systems and nitrogen-fixing trees (NFT) were implemented to demonstrate the effects of soils and environments on crop performance.

1982

A workshop on Soil Taxonomy and Agrotechnology Transfer was held in Yaounde and Buea, Cameroon, in cooperation with the Soil Management Support Services (SMSS), the Institut de la Recherche Agronomique (IRA), and FAO.

1983

Final on-site review completed. A non-funded extension was granted to May 1984 to complete compilation of data sets and report writing.

All field operations of the Benchmark Soils Project three soil family network were completed in May 1983. The NFT experiments with the Philippines, Indonesia, and Hawaii were maintained until the second quarter of 1984.

Final meeting of the UH project leaders was held in Hawaii to discuss the final project report, liquidation of project funds, and turnover of equipment and supplies after the termination of the Benchmark Soils Project in each country.

Schedule for publication of the final project report was outlined.

1984

Second non-funded extension was granted to December 1984.

# *Appendix B*

# Puerto Rico
# Executive Summary

*Editor's note: This Executive Summary is reprinted from* Research on the Transfer of Agrotechnology Transfer. Final Report of the Puerto Rico Benchmark Soils Project 1975–1981. *Beinroth, F. H. 1982. Mayaguez, Puerto Rico, University of Puerto Rico. Pp. 7–11.*

## Reference Background

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

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

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

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

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

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

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

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

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

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

## Test of the Transfer Hypothesis

The field data of the transfer experiments were statistically evaluated with three different techniques developed under the auspices of the BSP. They were the P-statistic, the confidence interval procedure, and a graphical method. The results with the confidence interval procedure and the graphical method provided strong positive evidence for transferability. The results with the P-statistic were less conclusive but not negative. Attention is drawn to Figure 61 in the text which allows an instant visual appraisal of the transferability of management practices.

1. See editor's note.

The graphs show that, if certain site variables are considered, fertilizer response at a new site can be predicted on the basis of experiments conducted at other sites with the same soil family essentially as well as by an experiment conducted at the new site.

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

## Agronomic Accomplishments

The results of the agronomic research demonstrate the high productivity of Eutrustox with moderate fertilizer inputs. Highest mean maize yields of over 9000 kg/ha were obtained in Puerto Rico and Brazil with about 40 kg/ha of phosphorus and 175 kg/ha of nitrogen. Soybean yields were as high as 5000 kg/ha. These are excellent yields for the tropics and underline the high crop production potential of Eutrustox, particularly if one considers that with irrigation at least two crops can be grown in the same year.

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

A maize plant population of 55,000 to 60,000 plants/ha can be recommended for Eutrustox on the basis of studies in Puerto Rico and Brazil. For unirrigated maize production in the Jaiba area, mid-November was determined as the optimal time for planting. With planting dates later in the wet season yields dropped off sharply from 6300 to 2000 kg/ha.

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

Tillage experiments indicated that for maize production in Eutrustox

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

An intensive multicropping experiment using a 20 × 20 m area of Eutrustox yielded produce valued at U.S. $1160 over a 27 month period. The study showed how small plots of land can be intensively utilized with modest inputs to effectively improve the quantity and quality of the diet of resource-poor farm families.

## Dissemination and Impact

The Benchmark Soils Project was prominently exposed and discussed at many international conferences and workshops. Project rationales and findings were further disseminated through a sizeable and effective public relations and publication program implemented and sustained by the University of Hawaii BSP. More than 1200 individuals and institutions in 89 countries are routinely informed about BSP developments.

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

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

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

## Conclusions

With the overall success of the University of Puerto Rico project, the BSP has begun to scientifically establish the validity of a soil family-based model for agrotechnology transfer. The encouraging results of the present project are expected to be reinforced by the findings of the ongo-

ing project of the University of Hawaii which will be based on larger data sets from three different soil families.

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

# *Appendix C*

## Key to Site Designations

| Site | Location |
|---|---|
| Kukaiau (KUK) | Honokaa, Island of Hawaii, Hawaii, U.S.A. |
| Niulii (IOLE) | North Kohala, Island of Hawaii, Hawaii, U.S.A. |
| Niuli'i (Halawa, HAL) | North Kohala, Island of Hawaii, Hawaii, U.S.A. |
| PUC | Philippine Union College, Panicuason, Naga City, Island of Luzon, Philippines |
| PAL | Palestina, Pili, Naga City, Camarines Sur Province, Island of Luzon, Philippines |
| BUR | Burabod, Calabanga, Naga City, Camarines Sur Province, Island of Luzon, Philippines |
| LPH | Lembaga Penelitian Hortikultura (Horticultural Research Institute), Segunung, Cipanas, West Java Province, Island of Java, Indonesia |
| ITKA | Institut Theologia Keguruan Advent (Seventh-Day Adventist Theological Church School) Cisarua, Bandung Province, Island of Java, Indonesia |
| PLP | Pusat Latihan Pertanian (Agricultural Training Center), Lembang, Bandung Province, Island of Java, Indonesia |
| Wahiawa (Waipio, WAI) | Waipio, Island of Oahu, Hawaii, U.S.A. |
| Lahaina taxadjunct (Maunaloa, MOL) | Maunaloa, Island of Molokai, Hawaii, U.S.A. |
| DAV | Bureau of Plant Industry, Bago Oshiro, Davao City, Island of Mindanao, Philippines |
| SOR | Sorsogon, Camarines Sur Province, Island of Luzon, Philippines |
| BPMD | Balai Pendidikan Masyarakat Desa (Community Educational Center), Kotabumi, Lampung Province, Island of Sumatra, Indonesia |
| NAK | Nakau Estate, Kotabumi, Lampung Province, Island of Sumatra, Indonesia |
| BUK | Bukit Kemuning, Sukanegeri, Lampung Province, Island of Sumatra, Indonesia |
| CAM | Barombi-Kang, Kumba, Cameroon |
| BAK | Barombi-Kang, Kumba, Cameroon |

Note: The names of Hawaii sites are soil series names.

# *Appendix D*

# Ranges of Characteristics for the Benchmark Soils Project Network

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

## Typic Paleudults

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

## Tropeptic Eutrustox

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

# *Appendix E*

# Procedure for Developing Phosphorus Extraction Curves

The general procedure involves the equilibration of a series of soil samples with incremental amounts of standard phosphorus solution for 24 hours. The P adsorbed on the soil is extracted with the modified Truog extractant (Ayres and Hagihara, 1952) and P in the extract is determined by the phosphorus analysis procedure of Murphy and Riley (1962) with ascorbic acid as the reducing agent (Watanabe and Olsen, 1965). A curve of best fit is calculated by regression techniques and the resulting equation is used in calculations to determine the amount of P to be applied (Chapter 4).

## P Equilibration and Extraction

*Reagents.* The two reagents are:

1. Modified Truog solution (concentrated): 0.025N $H_2SO_4$ + 0.038% $(NH_4)_2SO_4$, and

2. Phosphorus standard: $Ca(H_2PO_4)_2 \cdot H_2O$ in distilled water to give standard P solutions of 25 ppm to 200 ppm.

*Procedure.* Thoroughly mix soil sample and pass through 2 mm sieve. Weigh four 1 g samples of soil (oven-dry basis) into 100 ml plastic bottles and add 0 to 600 μg P/g soil using standard P solutions. The quantity of standard P added should give solution concentrations after equilibration varying between 10 and 40 μg and will depend on P adsorption characteristics of the soil. Make final volume to 20 ml with distilled water, adjusting for soil moisture content. Close bottles and shake on a reciprocating shaker for 24 hours at 126 oscillations/min. At the end of this time, add 80 ml of the modified Truog solution, which when added to the 20 ml already in the bottle, gives a solution of the desired concentration (0.02N $H_2SO_4$ + 0.03%$(NH_4)_2SO_4$) with a soil:extractant ratio of 1:100. Shake on the reciprocating shaker for 1/2 hour, then filter and determine P in the extract.

## P Determination in Soil Extract

*Reagents.* The two reagents are:

1. Reagent A: Dissolve 12 g of ammonium paramolybdate $[(NH_4)_6Mo_7O_{24} \cdot 4H_2O]$ in 250 ml of distilled water and dissolve 0.29 g

of antimony potassium tartrate [$KSbO \cdot C_4H_4O_6$] in 100 ml of distilled water. Add both solutions to 1000 ml of 5N sulfuric acid [$H_2SO_4$], mix thoroughly, and make to 2000 ml volume. Store in a pyrex bottle in a cool, dark place.

2. Reagent B: Dissolve 1.056 g of ascorbic acid [$C_6H_8O_6$] in 200 ml of Reagent A and mix thoroughly. Prepare a fresh solution daily.

*Procedure.* Pipette aliquot containing 10 to 40 $\mu$g of P into a 25 ml volumetric flask, dilute to 20 ml with distilled water, add 5 ml of Reagent B, dilute to volume, and mix thoroughly. Read optical density after 10 minutes at 850 nm (color is stable for 24 hours). Prepare a standard curve of 10 to 40 $\mu$g P by additions of $Ca(H_2PO_4)_2$ standards to the diluted modified Truog extracting solution.

*Comments.* The amounts of P to be added are not known in advance so they must be determined by making a preliminary determination of P adsorbed on the soil after equilibration. The initial soil P level is determined by the above procedure, without the addition of standard P solution to the sample. Dystrandept soil samples should not be air dried because they dry irreversibly with changes in their chemical and physical characteristics.

## References

Ayres, A. A., and H. H. Hagihara. 1952. Available phosphorus in Hawaiian soil profiles. Hawaiian Planters' Record 11:81–99.

Murphy, J., and J. P. Riley. 1962. A modified single solution method for determination of phosphate in natural waters. Anal. Chim. Acta. 27:31–36.

Watanabe, F. S., and S. R. Olsen. 1965. Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soil. Soil Sci. So. Am. Proc. 29:677–678.

# *Appendix F*

## Cultivars and Pesticides Utilized by the Benchmark Soils Project

Maize Cultivars

| Country | Cultivar | Description | Source |
|---|---|---|---|
| *Hydric Dystrandepts* | | | |
| USA (Hawaii) | H610 | Single cross hybrid | Department of Horticulture, University of Hawaii, Honolulu, Hawaii, USA |
| Indonesia | Harapan, H6 | Open pollinated varieties | Central Research Institute for Food Crops, Bogor, Indonesia |
| Philippines | UPCA-1 | Open pollinated variety | College of Agriculture, University of the Philippines at Los Baños, Philippines |
| *Tropeptic Eutrustox* | | | |
| USA (Hawaii) | X304C | Single cross hybrid | Pioneer Hi-Bred International, Des Moines, Iowa, USA |
| USA (Puerto Rico) | X304C | Single cross hybrid | Pioneer Hi-Bred International, Des Moines, Iowa, USA |
| Brazil | X304C | Single cross hybrid | Pioneer Hi-Bred International, Des Moines, Iowa, USA |
| *Typic Paleudults* | | | |
| Philippines | Tiniguib | Open pollinated variety | Bureau of Plant Industry, Davao, Philippines |
| Indonesia | H6 | Open pollinated variety | Central Research Institute for Food Crops, Bogor, Indonesia |
| Cameroon | X304C | Single cross hybrid | Pioneer Hi-Bred International, Des Moines, Iowa, USA |

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## Pesticides

| Chemical name (ISO) | Method of application | Target pests |
|---|---|---|
| *Insecticides* | | |
| carbaryl | Foliar spray | planthoppers, rosebeetles, armyworms, earworms, cutworms, borers |
| carbofuran | Banded with seed or top dress over plant | planthoppers, cutworms, seedling maggot, earworms, borers |
| chlorpyrifos | Foliar spray | planthoppers, aphids, borers, grasshoppers, cutworms |
| diazinon | Foliar spray | planthoppers, aphids, borers, earworms, spider mites |
| *Fungicides* | | |
| mancozeb | Foliar spray | northern and southern leaf blights, common rust |
| metalaxyl | Seed treatment | downy mildew |
| zineb | Foliar spray | northern and southern leaf blights, common rust |
| *Herbicides* | | |
| alachlor | Pre-emerge | annual grasses |
| atrazine | Pre-emerge | broadleaves and annual grasses |
| glyphosate | Directed spray | weeds in fallow areas prior to field preparation |

Note: ISO is the International Standardization Organization.

# *Appendix G*

# Model Estimates and Site Variable Data for the Transfer Experiments

Typic Paleudults

| SITE | SOILPH | B1 | SOILP | B3 | B5 | SOILN | B2 | B4 | VARIETY | SEASON |
|---|---|---|---|---|---|---|---|---|---|---|
| BAKA | 4.7 | 1022 | 5.4 | -1419 | 137 | 21.0 | 27 | -661 | 0 | 0 |
| BAKC | 4.5 | 1223 | 5.3 | -1014 | 106 | 21.0 | -33 | 296 | 0 | 0 |
| BAKE | 5.1 | 447 | 10.6 | 219 | -101 | 15.3 | 373 | -457 | 0 | 0 |
| BAKF | 5.0 | 609 | 9.0 | -246 | 27 | 21.0 | -288 | -1059 | 0 | 0 |
| BPMA | 4.5 | 1529 | 4.1 | -1329 | 948 | 5.6 | 872 | -635 | -1 | 1 |
| BPMC | 4.2 | 1123 | 4.1 | -1248 | 470 | 4.3 | 923 | -221 | -1 | -1 |
| BPMD | 4.1 | 1944 | 3.1 | -1766 | 943 | 4.8 | 887 | -998 | -1 | 1 |
| BUKC | 3.9 | 1256 | 5.1 | -1313 | 290 | 21.0 | -27 | -130 | -1 | 1 |
| BUKD | 4.0 | 1591 | 4.6 | -1580 | 321 | 21.0 | 145 | -454 | -1 | -1 |
| BUKE | 4.3 | 1480 | 4.9 | -2066 | 262 | 13.1 | 593 | -688 | 1 | 1 |
| BUKF | 4.6 | 1108 | 4.7 | -944 | 405 | 13.5 | 242 | -190 | 1 | -1 |
| BUKG | 4.6 | 1738 | 5.7 | -1661 | 304 | 21.0 | 243 | -336 | 1 | 1 |
| BUKH | 4.3 | 2188 | 5.2 | -2282 | 51 | 21.0 | 140 | -116 | 1 | 1 |
| CAMA | 4.8 | 128 | 19.0 | 37 | 85 | 12.2 | 545 | -396 | 0 | 0 |
| CAMB | 5.1 | 299 | 17.0 | -90 | -129 | 13.2 | 530 | -196 | 0 | 0 |
| CAMC | 5.0 | 422 | 19.0 | -335 | -347 | 21.0 | -14 | 421 | 0 | 0 |
| NAKA | 4.6 | 1429 | 3.7 | -1975 | 404 | 8.0 | 718 | -432 | -1 | 1 |
| NAKD | 4.1 | 957 | 4.9 | -1593 | 393 | 5.7 | 899 | -351 | -1 | -1 |
| NAKJ | 4.2 | 1853 | 3.2 | -1866 | 368 | 10.7 | 510 | -576 | -1 | 1 |
| NAKN | 4.6 | 903 | 4.7 | -980 | 83 | 21.0 | -262 | -114 | 1 | -1 |
| NAKO | 4.4 | 2248 | 3.6 | -1718 | 167 | 7.9 | 880 | -210 | 1 | 1 |
| NAKP | 4.3 | 2193 | 4.0 | -2550 | 771 | 9.3 | 781 | -989 | 1 | 1 |
| SORA | 4.2 | 1917 | 2.9 | -2354 | 1156 | 4.7 | 863 | -594 | 0 | 0 |
| SORB | 4.3 | 1624 | 3.4 | -2039 | 1028 | 3.3 | 1592 | -709 | 0 | 0 |

## Hydric Dystrandepts

| SITE | SOILPH | B1 | SOILP | B3 | B5 | SOILN | B2 | B4 |
|---|---|---|---|---|---|---|---|---|
| BURB | 4.6 | 1430 | 4.9 | -2276 | 693 | 8.7 | 625 | -81 |
| BURD | 4.5 | 1142 | 6.9 | -1275 | 405 | 3.1 | 1114 | -639 |
| IOLE | 4.2 | 409 | 42.0 | -189 | 46 | 8.1 | 819 | -758 |
| IOLK | 4.4 | 633 | 15.0 | -170 | 88 | 8.5 | 820 | -83 |
| ITKC | 4.2 | 122 | 109.0 | -566 | -138 | 6.5 | 493 | -425 |
| ITKD | 4.1 | 37 | 75.0 | -101 | 6 | 17.4 | 360 | -445 |
| ITKE | 4.2 | 181 | 79.0 | -436 | -250 | 18.6 | 518 | -386 |
| LPHE | 4.4 | 554 | 22.0 | -416 | 453 | 15.2 | 239 | -534 |
| LPHG | 4.4 | 109 | 36.0 | -380 | 315 | 14.3 | 317 | -225 |
| PALE | 4.5 | 2432 | 3.7 | -2156 | 268 | 21.0 | 115 | -46 |
| PALF | 4.4 | 1647 | 5.3 | -1341 | -196 | 21.0 | 47 | -184 |
| PALG | 4.0 | 1855 | 5.4 | -2057 | 312 | 12.2 | 453 | -95 |
| PLPG | 4.5 | 131 | 36.0 | -194 | -352 | 5.3 | 1114 | -1060 |
| PUCK | 4.4 | 1107 | 6.7 | -1818 | 157 | 16.3 | 296 | -62 |
| PUCR | 4.4 | 1737 | 5.8 | -2069 | 968 | 5.6 | 932 | -770 |
| PUCS | 4.2 | 2228 | 4.7 | -1506 | 216 | 16.8 | 194 | 237 |

Note: Site variable information includes preplant 1N KCl pH (SOILPH), ppm preplant extractable Truog (SOILP), ppm preplant extractable nitrogen (SOILN), and site-specific estimates of the second order response surface model (B1 and B3 are P linear and quadratic responses, B2 and B4 are N linear and quadratic responses, and B5 is the PN interaction response in kg/ha).

# *Appendix H*

# Bibliography of Project Publications

## Technical Reports

Beinroth, F. H. 1979. Laboratory data and descriptions of soils of the Benchmark Soils Project: Vol. 2—Puerto Rico project. BSP Tech. Rept. 5. Dept. Agron. and Soils, College of Agr. Sci., Univ. Puerto Rico, and Dept. Agron. and Soil Sci., College of Trop. Agr. and Human Resources, Univ. Hawaii. 8 pp.

Beinroth, F. H., H. Ikawa, and G. Uehara. 1979. Classification of the soil series of Hawaii in four systems: A guide to correlating tropical soils (Tech. Series Bull. 10, Hawaii Agr. Exp. Sta. revised and edited). BSP Tech. Rept. 2. Dept. Agron. and Soil Sci., College of Trop. Agr. and Human Resources, Univ. Hawaii, and Dept. Agron. and Soils, College of Agr. Sci., Univ. Puerto Rico. 56 pp.

Benchmark Soils Project. 1982. Procedures and guidelines for agrotechnology transfer experiments with maize in a network of benchmark soils. HITAHR Res. Ext. Series 015 (BSP Tech. Rept. 3). Hawaii Inst. of Trop. Agr. and Human Resources, College of Trop. Agr. and Human Resources, Univ. Hawaii. 64 pp.

Cady, F. B., C. P. Y. Chan, C. L. Garver, J. A. Silva, and C. L. Wood. 1982. Quantitative evaluation of agrotechnology transfer: A methodology using maize response to phosphorus on Hydric Dystrandepts in the Benchmark Soils Project. HITAHR Res. Series 015 (BSP Tech. Rept. 6). Hawaii Inst. of Trop. Agr. and Human Resources, College of Trop. Agr. and Human Resources, Univ. Hawaii. 31 pp.

Cagauan, B. G., Jr., G. Y. Tsuji, and L. W. Peterson, eds. 1983. Agrotechnology transfer in Indonesia and the Philippines. HITAHR Res. Ext. Series 027 (BSP Tech. Rept. 9). Hawaii Inst. of Trop. Agr. and Human Resources, College of Trop. Agr. and Human Resources, Univ. Hawaii. 120 pp.

Ikawa, H. 1979. Laboratory data and descriptions of soils of the Benchmark Soils Project: Vol. 1—Hawaii project. Misc. Pub. 165 (BSP Tech. Rept. 1). Hawaii Agr. Exp. Sta., College of Trop. Agr., Univ. Hawaii. 37 pp.

Uehara, G., ed. 1984. A multidisciplinary approach to agrotechnology transfer: Proceedings of a Benchmark Soils Project/Hawaii Institute of Tropical Agriculture and Human Resources Workshop. HITAHR Res. Ext. Series 026 (BSP Tech. Rept. 7). Hawaii Inst. of Trop. Agr. and Human Resources, College of Trop. Agr. and Human Resources, Univ. Hawaii. 164 pp.

## Proceedings and Edited Books

Briones, A. A., and B. G. Cagauan, Jr. 1977. The soil family as a basis for extension of agrotechnology in hilly lands. *In* Proceedings international workshop on hilly land development, Legaspi City, Philippines. Pp. 166-179.

Ikawa, H. 1978. Occurrence and significance of climatic parameters in the Soil Taxonomy. *In* Soil-resource data for agricultural development. L. D. Swindale, ed. Hawaii Agr. Exp. Sta., College of Trop. Agr., Univ. Hawaii. Pp. 20-27.

Ikawa, H. 1980. The Benchmark Soils Project of Hawaii and Puerto Rico: Researching a method for agrotechnology transfer in the tropics. *In* Land evaluation guidelines for ranked agriculture. World Soil Resources Rept. 52. Food and Agriculture Organization of the United Nations (FAO), Rome. Pp. 108-113.

Ikawa, H., ed. 1984. Proceedings of the Benchmark Soils Project symposium at the international conference on soils with variable charge. HITAHR Res. Ext. Series 042 (BSP Tech. Rept. 8). Hawaii Inst. of Trop. Agr. and Human Resources, College of Trop. Agr. and Human Resources, Univ. Hawaii. 62 pp.

Silva, J. A. 1979. The Benchmark Soils Project and its impact on Hawaii. *In* 11th Proceedings Hawaii fertilizer conference, Kauai, Hawaii. Misc. Pub. 164. Hawaii Coop. Ext. Serv., College of Trop. Agr. and Human Resources, Univ. Hawaii. Pp. 5-14.

Silva, J. A., and L. D. Swindale. 1975. A project to determine crop production and land capabilities of a network of tropical soil families. *In* Proceedings fertilizer INPUTS (Increasing Productivity Under Tight Supplies) Project, planning and organization meetings. East-West Center, Univ. Hawaii. Pp. 153-161.

Swindale, L. D., ed. 1978. Soil-resource data for agricultural development. *In* Proceedings of seminar on uses of soil survey and classification in planning and implementing agricultural development in the tropics. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, India, and Hawaii Agr. Exp. Sta., College of Trop. Agr., Univ. Hawaii. 316 pp.

Swindale, L. D. 1978. A soil research network through tropical soil families. *In* Soil-resource data for agricultural development. L. D. Swindale, ed. Hawaii Agr. Exp. Sta., College of Trop. Agr., Univ. Hawaii. Pp. 210-218.

Swindale, L. D., H. Ikawa, and G. Y. Tsuji. 1975. Systems of soil classification and their relation to water management. *In* Proceedings of the international symposium on research needs for on-farm water management. United States Agency for International Development (USAID), Washington D.C. Park City, Utah. Pp. 96-100.

Uehara, G. 1978. Agrotechnology transfer and the soil family. *In* Soil-resource data for agricultural development. L. D. Swindale, ed. Hawaii Agr. Exp. Sta., College of Trop. Agr., Univ. Hawaii. Pp. 204-209.

Uehara, G. 1981. Tropical soils management and its transfer. *In* Food and climate review 1980–81. L. E. Slater, ed. Aspen Inst. for Humanistic Studies, Queenstown, Maryland. Pp. 47–51.

Uehara, G. 1981. Agricultural engineering. *In* McGraw-Hill yearbook of science and technology. McGraw-Hill Book Co., New York. Pp. 80–82.

## Departmental Papers

Caganan, B. G., Jr., G. Y. Tsuji, and H. Ikawa. 1982. Planning agroforestry and fuelwood production on the basis of Soil Taxonomy. Dept. Paper 61. Hawaii Inst. of Trop. Agr. and Human Resources, College of Trop. Agr. and Human Resources, Univ. Hawaii. 16 pp.

Silva, J. A., ed. 1981. Experimental designs for predicting crop productivity with environmental and economic inputs for agrotechnology transfer. Dept. Paper 49. Hawaii Inst. of Trop. Agr. and Human Resources, College of Trop. Agr. and Human Resources, Univ. Hawaii. 184 pp.

Silva, J. A., and F. H. Beinroth. 1975. Report of the workshop on experimental designs for predicting crop productivity with environmental and economic inputs. Dept. Paper 26. Hawaii Agr. Exp. Sta., College of Trop. Agr., Univ. Hawaii. 50 pp.

## Journal Papers

Beinroth, F. H., G. Uehara, J. A. Silva, R. W. Arnold, and F. B. Cady. 1980. Agrotechnology transfer in the tropics based on Soil Taxonomy. Adv. in Agron. 33:303–339.

Escaño, C. R., C. A. Jones, and G. Uehara. 1981. Nutrient diagnosis in corn grown on Hydric Dystrandepts. I. Optimum tissue nutrient concentrations. Soil Sci. Soc. Am. J. 45:1135–1139.

Escaño, C. R., C. A. Jones, and G. Uehara. 1981. Nutrient diagnosis in corn grown on Hydric Dystrandepts. II. Comparison of two systems of tissue diagnosis. Soil. Sci. Soc. Am. J. 45:1140–1144.

Manrique, L. A. 1984. Feasibility of potato production in Hawaii. HITAHR Res. Series 026. Hawaii Inst. of Trop. Agr. and Human Resources, College of Trop. Agr. and Human Resources, Univ. Hawaii. 44 pp.

Manrique, L. A. 1985. Performance of potato (*Solanum tuberosum* L.) in three tropical soil families as influenced by their temperature regimes. Am. Potato J. 62:101–110.

Manrique, L. A., and G. Uehara. 1984a. A proposed land suitability classification for potato (*Solanum tuberosum* L.). I. Metholodgy. Soil Sci. Soc. Am. J. 48:843–847.

Manrique, L. A., and G. Uehara. 1984b. A proposed land suitability classifi-

cation for potato (*Solanum tuberosum* L.). II. Experimental. Soil Sci. Soc. Am. J. 48:847–852.

Manrique, L. A., G. Y. Tsuji, G. Uehara, and R. L. Fox. 1984. Winter and summer performance of potato (*Solanum tuberosum*) in isohyperthermic temperature regimes. Am. Potato J. 61:41–56.

Manuelpillai, R. G., M. Sudjadi, M. Supartini, and J. A. Silva. 1982. Influence of P applications on maize yields in the Typic Paleudults in South Sumatra. Trop. Agr. (Trinidad) 59(2):173–178.

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

## Dissertations and Theses

Awemo, J. N. 1983. Assessing Mycorrhizal Inoculum potential of soil and response of cowpea to inoculation on a Tropeptic Eutrustox. M.S. thesis, Univ. Hawaii. 128 pp.

del Rosario, B. P. 1982. DRIS norms for maize (*Zea mays* L.) grown in a network of three tropical soil families. Ph.D. dissertation, Univ. Hawaii. 229 pp.

Escaño, C. R. 1980. Comparative evaluation of some diagnostic techniques for determining the nutrient requirement of maize grown on Hydric Dystrandepts. Ph.D. dissertation, Univ. of Hawaii. 216 pp.

Harris, D. J. 1983. Evaluation of phosphorus fertilizer materials on two benchmark soils of the tropics. Ph.D. dissertation, Univ. Hawaii. 136 pp.

Reeel, M. R. 1980. Reclassification of Andepts of the state of Hawaii in the proposed order Andisols. M.S. thesis, Univ. Hawaii. 101 pp.

Reeel, M. R. 1983. Revision of Soil Taxonomy in the classification of low activity clay soils. Ph.D. dissertation, Univ. Hawaii. 245 pp.

Santoso, D. 1981. Performance of maize varieties in three tropical soil families and their response to N and P fertilization. M.S. thesis, Univ. Hawaii. 224 pp.

Soekardi, M. 1985. Soil interpretation for non-agricultural and agricultural uses in the soils of the Benchmark Soils Project. Ph.D. dissertation, Univ. Hawaii. 187 pp.

Widjaja-Adhi, I. P. G. 1983. Predicting maize response to phosphorus application in relation to residual phosphorus in Paleudult and Eutrustox soils. Ph.D. dissertation, Univ. Hawaii. 230 pp.

## Progress Reports and Newsletters

Benchmark Soils Project. 1978. Research on agrotechnology transfer in the tropics based on the soil family. Progress Report 1 (through Dec. 1977). Dept. Agron. and Soil Sci., College of Trop. Agr., Univ. Hawaii, and Dept. Agron. and Soils, College of Agr. Sci., Univ. Puerto Rico. 64 pp.

Benchmark Soils Project. 1979. Development of transfer model and soil taxonomic interpretations on a network of three soil families. Progress Report 2 (Jan. 1978–June 1979). Dept. Agron. and Soil Sci., College of Trop. Agr. and Human Resources, Univ. Hawaii, and Dept. Agron. and Soils, College of Agr. Sci., Univ. Puerto Rico. 30 pp.

Benchmark Soils Project. 1982. Assessment of agrotechnology transfer in a network of tropical soil families. Progress Report 3 (July 1979–Sept. 1982). Dept. Agron. and Soil Sci., College of Trop. Agr. and Human Resources, Univ. Hawaii, and Dept. Agron. and Soils, College of Agr. Sci., Univ. Puerto Rico. 104 pp.

Benchmark Soils News. 1977–1982. Quarterly newsletter, vols. 1–5, nos. 1–4; vol. 6, nos. 1–2. Benchmark Soils Project, Dept. Agron. and Soil Sci., College of Trop. Agr. and Human Resources, Univ. Hawaii.

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