PROCEEDINGS OF THE BENCHMARK SOILS PROJECT SYMPOSIUM AT THE INTERNATIONAL CONFERENCE ON SOILS WITH VARIABLE CHARGE

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THE NEED AND PROSPECTS FOR AGROTECHNOLOGY TRANSFER

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ABSTRACT

Many people in the world today do not receive enough food, and the prospects for the future are depressing. The deficits in staple foods in the developing countries are likely to be three to four times as great in 1990 as they are today. There is need for more intensive use of soils, but there is already much concern about the deterioration of soils through excessive and unwise use.

Agricultural research can contribute significantly to the amelioration of these problems, but because research costs are high and increasing, efforts are needed to make agricultural research more efficient. Many small countries will not have the resources to make the magnitude of research effort needed to solve their own problems.

In these dire circumstances, greater efforts need to be made to transfer agricultural technology from place to place and country to country. Presently it is being done mostly by trial and error, but more scientific approaches are being developed. Models that simulate biological processes and regression equations relating crop performance to input and site-factor variables have great potential but only limited success to date, because of the magnitude of environmental site-factor constraints.

Methods of analogous transfer have much greater immediate value. They are widely if casually used. They can be made more useful and more scientific if they are based upon the stratification of resource and environmental constraint variables, particularly of climates and soils.

A methodology for systematic, analogous agrotechnology transfer now exists in the combination of soil survey, Soil Taxonomy, the benchmark soils concept, and the methods of soil survey interpretation. Some useful scientific proofs have been made of the transfer methodology over a global soils network, far exceeding in its geographic coverage the current possibilities of simulation or statistical methods.

It is easy to see how the number of stations in the network can be increased through an International Benchmark Soils Network. The new methodology opens up the real possibility of technical communication and cooperation among the developing countries. It opens up the real possibility of increasing the efficiency of agronomic research. It opens up the need for countries to know their soils better and to strengthen their programs of soil survey interpretation. It opens up the possibilities for much greater and more effective use of soils information in the planning of agricultural development.

An operating network of stations for agrotechnology transfer will not decrease the need for national agricultural research, because there is proof that transfer will not occur in the absence of local research capacity. Research in developed countries and in the international agricultural centers assists the transfer process, but does not replace the need for national research.

THE NEED FOR AGROTECHNOLOGY TRANSFER

There is no fundamental reason why the people of the world should go hungry. The world can feed its people and many more. A recent and optimistic estimate of the carrying capacity of the world is 40 billion people (Revelle, 1976). The worst problems of hunger and the worst problems of poverty can be overcome through concentrated efforts to help small farmers become more productive.

Unfortunately, the performance so far has been less than reassuring. Food production from new arable lands has been sufficient to feed only one-third of the increase in population over the last 20 years. Part of the reason, as Bentley et al. (1980) have pointed out, is that much of the new land being brought into use is of marginal quality with production potentials well below the best that can be expected. The food required to feed the other two-thirds of the increase in population has come from increased use of existing lands mostly in the developed world, and not in the countries where the population increase has mainly occurred.

If present production and consumption trends continue, by 1990 the developing countries will face a deficit in staple food crops of 140 million tons, about three to four times the current deficit. Because such countries, except perhaps those with large oil resources, cannot afford to import so much of their basic foods and feeds, they must reverse the trends by achieving great increases in food production in the future. Most of the increase must come from more intensive use of existing arable lands.

The need to produce more food from existing or new lands means more efficient use of soils. The larger need of economic development within which the production of food must take place also depends on the efficient use of soils: roads, dams, canals, fertilizer plants, distribution centers, and market towns must all be built, and all of these put demands upon the soil. And soils can be destroyed if not wisely used; soil erosion, soil deterioration, deforestation, and watershed damage continue, and in some areas are accelerating. This loss of soils is of serious concern to mankind.

Fortunately, many soils are being used far below their potential so that there is room for improvement. For example, in India, where almost all soils are already in use, the current annual production is 2 billion tons of grain equivalent—but the potential is more than 4 billion tons. In India, and probably elsewhere, the greatest potential for increased production lies in the savanna areas of the semiarid and sub-humid tropics. Although insufficient water is a problem, particularly in rainfed use, new technologies now exist or are being developed through agricultural research for wise and efficient use of these lands.

In other regions, too, agricultural research contributes significantly to increasing production. But research costs are high and increased efforts are needed to make agricultural research more efficient. Many small developing countries do not have the research resources needed to solve their own problems. Greater efforts are needed, therefore, to develop efficient methodologies for agrotechnology transfer from place to place and country to country.

CONCEPTS FOR AGROTECHNOLOGY TRANSFER

The successful transfer of technologies from place to place, even within the semiarid and sub-humid tropics, is not easy. If we critically examine the successful transfer of agrotechnology in the world in recent years, we are struck by the fact that it is seed-based technology that has created the impact. Seed has been the vehicle of change. Furthermore, the technology has moved faster in irrigated areas or areas with assured rainfall. The technology has been based mainly on principles of sole cropping under low risks. The commodities involved are well-known in the world market, and their production is influenced by world market trends.

Soil-based technologies—i.e., technologies to improve the productivity of certain soils—tend to be specific to the soils for which they are developed. They have high site-factor constraints (Swindale, 1980*a*). A soil, unlike a seed, is part of the landscape and cannot be moved physically from place to place. Spatial variability of soils is high, particularly in the tropics where soils are also less well understood. These factors make transfer of technology difficult.

In addition, technology transfer must take other environmental factors and socioeconomic differences into account. Furthermore, agricultural technology cannot be successfully transferred without local adaptive research (Evenson and Binswanger, 1979). The amount and cost of such research is directly related to the magnitude of the site-factor constraints. If the site-factors of the test location and the transfer of location are not too different, the cost of the necessary adaptive research will not be so high.

Besides the most common approach of using trial and error, three scientific approaches exist, in principle, to equate site-factor variables and constraints across locations. They are Simulation Models, Statistical Relationships, and Analogous Reasoning (Nix, 1968, 1980; Keller and Peterson, 1973; Swindale, 1980*a*).

Simulation Models

Simulation models attempt to mimic biological processes through physical laws and relationships, and inherently they should be the best methods for overcoming high site-factor constraints. For a single crop system on similar soils, climate-driven models should be successful because variations in climate essentially determine year-by-year crop yields (*see* for example Lemon et al., 1971).

The incompleteness of scientific knowledge and the complexity of the technologies and of the models themselves are barriers to the use of simulation, and there are few examples of its successful application (*cf.*, Huda, 1980). The successful development of simulation models requires an intensive multidisciplinary effort and this is often difficult to achieve.

Although simulation models cannot yet be said to be usable for agrotechnology transfer, they are important aids to research (Innis, 1975). They codify existing knowledge in highly systematic forms and help in the design of significant experiments. In developing and testing such models, we discern the minimum sets of data required at various levels of prediction. It is worth mentioning that minimum data sets for agrotechnology transfer by simulation invariably require data on climate, soil moisture (which is highly dependent upon the nature of the soil), and crop phenology. It is seldom that these data are collected in scientific experiments.

Empirical Statistical Relationships

Empirically devised statistical relationships are being used for agrotechnology transfer. The biological productivity—and particularly yield—of a crop is empirically related to input and resource variables usually by correlation and multiple linear regression. The data used to derive the statistical relationships are obtained from experiments or production records from a range of environmental conditions over time. The resulting correlations or regression equations, after validation, are used to predict productivity in future years or at new locations. Obviously, statistical predictions can be made with much more confidence at interpolated than at extrapolated sites.

Many examples exist in the research literature, particularly in relating crop responses to applications of fertilizer and/or water. Some examples in which soil-factor variables have been considered are the equations developed by Voss et al. (1970), Culot (1981), and Runge and Benci (1975). Heady (1981), in referring to the many studies of this type with which his name is associated, has pointed out that they are limited in their application to several adjoining countries or states and cannot be used, except in principle, for intercountry transfer. Parametric methods of measuring soil potential productivity belong in this category. They are generally based on easily measured properties of the soil and tend to be rather site-specific (Beek, 1978).

Analogous Transfer

In methods of analogous transfer, an attempt is made to stratify the environment sufficiently precisely to ensure successful transfer of technology (Swindale, 1980*a*). Areas analogous to the experimental site are identified by climate or soil classification.

Although climatic networks are very extensive throughout the world, they have hardly been used for the purposes of transferring technology. The data gathered and hence the classifications are not sufficiently related to agriculture. Partial exceptions are the classifications made by Papadakis (1965, 1970). More recent efforts to use pattern analysis (Russel and Moore, 1976) and reference climatic sites around the world (Shaw and Hill, 1975) suggest that the usefulness of climatic classification for agrotechnology transfer is now being actively explored. No attempts have yet been made to validate climate classifications experimentally.

The development of soil classifications suited to agrotechnology transfer has been far more successful. The prime examples of general soil classification useful for such purposes are Soil Taxonomy (Soil Survey Staff, 1975) and its partial derivative, the Legend for the Soil Map of the World (FAO/UNESCO, 1974). Specific soil classifications for transferring a limited range of agricultural knowledge, such as probable crop responses to fertilizer, have also been developed—for example, the soil-fertility capability classification by Buol et al. (1975).

The usefulness of the benchmark soils concept, which much predates Soil Taxonomy, is based on the idea of transfer by analogy. As currently defined, a benchmark soil is one occupying a key interpretative position in a soil classification framework and/or covering a large area (Miller and Nichols, 1980). It is considered to be a representative reference site from which research results can be transferred or extrapolated to other sites with similar properties.

PROSPECTS FOR AGROTECHNOLOGY TRANSFER

The combined use of soil survey, Soil Taxonomy, the benchmark soils concept, and soil survey interpretation currently provide the elements of a systematic methodology for analogous agrotechnology transfer in the developing world. The usefulness and limitations of this methodology are being determined by the Benchmark Soils Project of the universities of Hawaii and Puerto Rico carried out in cooperation with national soil research institutes in Latin America, Asia, and Africa and supported by the United States Agency for International Development.

Soil survey is proceeding satisfactorily in the developing world. About one-fifth of the world's soils have been surveyed, with the highest percentage in Europe and the lowest in Africa (Wolff, 1980). There is need for greater emphasis on first- and second-order surveys and, concomitantly, greater use of remote-sensing techniques for rapid, higher-order surveys useful for broad planning purposes.

Methods for soil survey are well known and essentially standardized throughout the developing world through the effective assistance of FAO and UNDP. Some international assistance is needed to strengthen national efforts, to train staff, and to assist in improvements in quality. The methods of soil survey need to become more quantitative, following the trend in virtually every other science (Dijkermann, 1974). More quantitative estimates of spatial variability are needed, as are better routine soil characterization methods, for example, of cation-exchange capacities of soils with variable charge, and, most of all, routine measurements of highly significant agriculturally related characteristics, such as soil moisture regimes and soil temperatures.

" 'Soil Taxonomy' was created to support soil surveys and the interpretations of surveys that are required by both developing agriculture and advanced farming" (Johnson, 1980). It appears to be generally satisfactory for its purpose. Improvements are needed, particularly in the classification of tropical soils, and are actively being sought. The heart of Soil Taxonomy is the fifth level of subdivision, the soil family, which is designed to "group the soils within a subgroup having similar physical and chemical properties that affect their responses to management and manipulation for use. The responses of comparable phases of all soils in a family are nearly enough the same to meet most of our needs for practical interpretation of such responses . . . ." (Soil Survey Staff, 1975).

The Benchmark Soils Project is providing a scientific test of Soil Taxonomy by gathering experimental data on soil performance at the family level. In addition, the Project is providing much information about intensive use of certain upland soils in the suborders of Andepts, Udults, and Ustox. Many more such tests are needed. In my view, proposals for changes in Soil Taxonomy should not be considered if they are not supported by empirical data on soil performance. In addition, because the developing world cannot wait, we need to develop agricultural and engineering interpretations at levels of Soil Taxonomy above the family, accepting the higher risk of error that will be involved.

The weakest link in the methodology for transfer is in soil survey interpretation. Although many developing countries now have the capacity to carry out soil surveys at appropriate levels of detail, few appear to be able to convert the surveys into effective interpretations for use and management, such as those described by Chan (1978). Agronomic research designed specifically to help soil survey interpretation, such as that described by Shin (1978), is even less common. Interpretations that are made are often in the form of general land classifications such as the U.S. Land-Capability Classification (Klingebiel and Montgomery, 1961) which is widely used in, but unsuited to, the tropics. It was not designed for use with tropical soils or crops, and it has a conservation orientation—that is, it stresses the limitations of soils rather than their potentials. Planners and development agencies need to be aware of limitations, but they have greater need to know about soil potentials.

Let me cite an example taken from a paper by Murthy (1978). Hoskote sandy loams to clay loams are deep to very deep Oxic Haplustalfs occurring on 1-3 percent slopes on the uplands in the vicinity of Bangalore, India. In the U.S. Land-Capability Classification they are classified as IIe; their sole limitations are erosion susceptibility and the moderately adverse effects of past erosion. Under current dryland farming practices, average farmers using local varieties and almost no manufactured inputs produce less than 900 kg/ha of finger millet, a major local cereal grain. Better than average farmers use improved varieties and some manufactured inputs to produce 2,000 kg/ha. This figure may be the current economic optimum. The potential production as determined by the University of Agricultural Sci ences at Bangalore, using improved varieties and fertilizers, and irrigation, is 4,000 kg/ha—that is, more than four times the current average and twice what the better than average farmers can do. Surely the planner or developer who wants to produce more cereal grain for the people of India will gain much more from knowing what can be produced on this soil at various levels of management than from knowing only that the soil is limited by erosion.

Three levels of management are recommended for soil survey interpretations for agriculture (Soil Survey Staff, in press). These are:

> *Level 1*—The combinations of management practices used commonly by successful farmers for the soil being considered.
>
> *Level 2*—A combination of superior management practices followed by farmers who obtain yields of crops well above the average. This group may be 5 percent of farmers in some areas and as much as 30 percent in others.
>
> *Level 3*—The optimum combinations of management that can be defined for full application of the current state of knowledge and techniques for crop production.

A statement of the agronomic practices relating to each level of management must also be explicitly defined. With this information for several important commodities, a planner will be able to determine the alternatives with considerable accuracy and to decide what levels of plan inputs and what combinations of commodities will best achieve the objectives of this plan.

Information for management levels 1 and 2 is determined from the surveys of farmer practices that the soil surveyor should make as part of his survey project. The information for level 2 gained from these surveys should be supplemented by agronomic research on farmers' fields. Data for level 3 are obtained from soil fertility, soil management, and agronomic research. Research to determine comprehensive crop-production functions (Heady and Dillon, 1961) and research on yield gap analysis (De Datta et al., 1978) produce data at all three levels of management.

Interpretations of soil performance at several levels of management for specific crops on defined kinds of soil can be transferred analogously through Soil Taxonomy to other soils in the same family—or to phases of higher taxa where applicable—within the same country or to other countries. The testing and utilization of this methodology in the developing world is the basic purpose of the Benchmark Soils Project, but the Project has also found that much additional research and technological information can be transmitted through the same pedological pipelines (Uehara and Ikawa, 1979; Benchmark Soils Project, 1979). Not the least benefits, as Gill (1980) has pointed out, are the satisfaction, excitement, and inspiration gained by participating scientists through this system of shared experiences and experiments conducted with the high purpose of improving food and fiber production in the developing world.

AN INTERNATIONAL BENCHMARK SOILS NETWORK

The value of existing efforts at analogous agrotechnology transfer through Soil Taxonomy and the benchmark soils concept can be greatly enhanced and the benefits extended to many more countries through the creation of an International Benchmark Soils Network. This proposal has been supported at international soils conferences and consultations at ICRISAT in 1976 and 1978, IRRI in 1979, Bonn in 1979, and FAO in 1980, and by the Advisory Panel of the USDA/USAID program of Soil Management Support Services.

An obvious first step is to link together existing agricultural research stations in the developing world. FAO and the Benchmark Soils Project have recently embarked upon a project to classify the soils of several such stations to provide a beginning network of about 20 stations. ICRISAT, with its isohyperthermic Typic Pellusterts and Udic Rhodustalfs at ICRISAT Center in India and isohyperthermic Psammentic Haplustalfs at its Sahelian Center in Niger, will participate.

The data available from previous experiments will have obvious limitations in agrotechnology transfer. A coordinated and systematic program for collection of minimum sets of soil performance data and their translation into interpretations is a likely early product from the network. A logical framework for the network and its functions, taken from Swindale (1980*b*), is given in Fig. 1

Some coordination and international funding of the network will be necessary to expand it to other soils; to encourage uniform agronomic research projects to obtain production functions from minimum data sets for important tropical crops; to set up

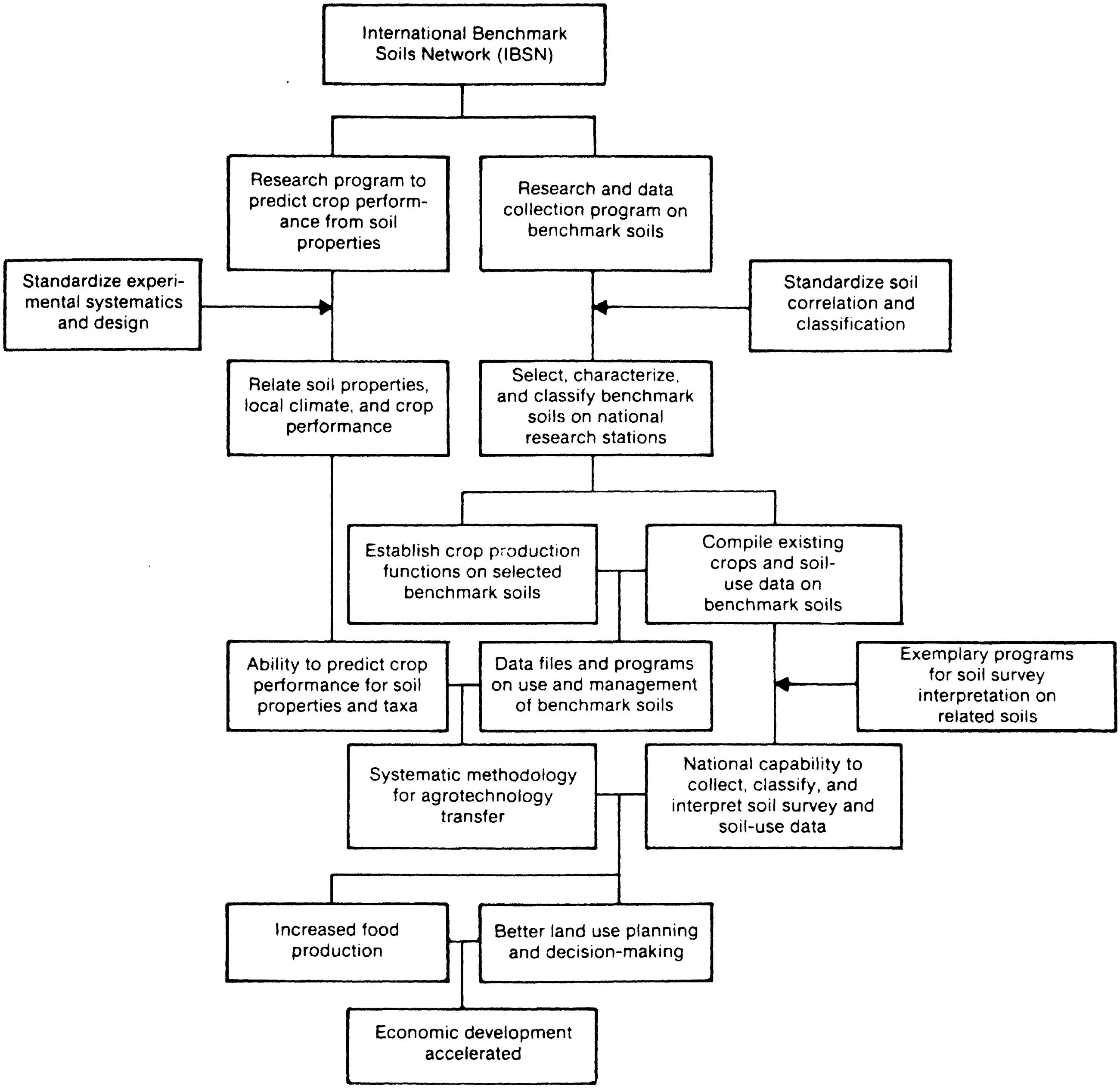

Fig. 1. Logical framework for the International Benchmark Soils Network (Swindale, 1980*b*).

the necessary data banks containing soil distribution, soil characteristics, soil classification, and soil-use files; to communicate with and provide feedback to participating research centers; and to assist with training activities. Current efforts to internationalize Soil Taxonomy through international cooperation need assistance and support. A similar effort in international soil correlation is needed to accompany the efforts to internationalize Soil Taxonomy and to assist in improving the quality of soil surveys (Johnson, 1980), and much greater stimulus needs to be given to the development and use of soil surve interpretations. If the International Board for So Resources and Management that has been su gested at several recent international conferenc becomes a reality, it could provide the coordinatic for the International Benchmark Soils Network.

When this network is established and functionin a lot of research information should become ava able for wider use, and the cost of site-specific tri will be greatly reduced. The transfer of informati on soil-management practices, crops and croppi systems, water-management practices, erosion-control measures, suitability of new crops, economics of crop production, uses and problems of irrigation, and regional and national planning, and priorities for agricultural development will be enhanced (Miranda, 1977).

Most of the soil survey classification, agronomic research and interpretations for benchmark sites must be undertaken by national research institutions. They must also be responsible for the adaptive research necessary to make full use of the benchmark information available from other lands. They provide the essential link between research and development (Swaminathan, 1980).

Based on the experience achieved so far in the Benchmark Soils Project, the contributions that national programs make to an international network will increase their awareness of the value of the agrotechnology transfer methodology. Similar, within-country benchmark soils networks will come into being and enlarge the international network.

Several of the International Agricultural Research centers undertake soils research. The work is necessarily of an international character. It will be easy for these centers to participate in the International Benchmark Soils Network, and, within the framework of their farming or cropping systems programs, they will be able to assume some leadership in improving the methodologies involved. The centers alone, however, cannot provide the entire network, and because of their strong commodity orientations, they are not the best institutions to focus international attention on the wise use of soils.

This symposium emphasizes the transfer of technology for agricultural purposes, a subject much neglected in the developed world. It is important to stress, however, that land throughout the world is used in many, often competing, ways—all of which need to be taken into account in planning. The multiple objectives of modern land-use planning include land uses for cultivated crops, range lands, forests, woodlands, and recreation lands; use of metropolitan land; land use in major engineering projects, such as dams; land uses for transportation and utility corridors; planning for waste disposal on land and for control of non-point source pollution; and the reclamation of disturbed or deteriorated lands (Beatty et al., 1980). Planning is also necessary for specialized lands such as watersheds, wetlands, and coastal zones. No country in the world can afford to plan the use of its entire land surface so comprehensively, but no country can afford to neglect each of these uses, when and where the need arises. And in every country it is essential to designate and protect prime and unique agricultural lands.

In conclusion, I wish to congratulate the organizers of this Conference on Soils with Variable Charge and the Symposium on Agrotechnology Transfer. Many soils of the tropics have variable charge, and the conference will increase our understanding of them. With this understanding and a more systematic approach to obtaining and communicating soils knowledge, it will be possible for soil scientists to contribute more significantly to the solutions of the serious problems faced by the developing world in ensuring adequate food supplies for the future.

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