Minimum Data Sets for Agrotechnology Transfer

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International Crops Research Institute for the Semi-Arid Tropics

Proceedings of the

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Foreword

Successful transfer of agrotechnology from research station to farmers' fields or from one country to another depends on matching the requirements of a crop to the characteristics of its environment and the resources of the farmer. The International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) was established to increase both the speed and the success rate of technology transfer, using systems analysis and computer simulation models to eliminate the guesswork of trial-and-error transfer methods.

The minimum data set needed to simulate crop requirements in relation to soil, climate, and management, so as to predict crop performance, was discussed at an international symposium in March 1983. Fifty-six scientists from regional, national, and international research centers chose ten crops for study across a worldwide network of experimental sites. As a result of the symposium a minimum data set applicable to several crops has been circulated to IBSNAT cooperators. Agronomists and crop modelers are jointly designing field experiments to test the adequacy of this data set and to determine more precisely the additional data needed for each crop and for its adaptation to different environments.

The proceedings make available much current information about crop models and simulation models of climate, crops, and soils and should be of interest to many agricultural and biological scientists.

ICRISAT is pleased to accept responsibility for publishing the proceedings of this symposium.

L.D. Swindale
Director General

Purposes of the Symposium:

- Identify the number and nature of research stations in the network.
- Agree on the number of crops to be researched.
- Agree on the design of experiments.
- Identify the minimum data set to collect from each experiment.
- Formulate plans for data-base management and analysis.
- Assign responsibilities for data collection, data-base management, and data analysis.

Keynote Address

Keynote Address

L D. Swindale*

Our symposium today is jointly sponsored by ICRISAT, the University of Hawaii, the Soil Conservation Service of the United States Department of Agriculture (SCS), and the U.S. Agency for International Development (USAID). Among these agencies there are three research programs involved, ICRISAT's Farming Systems Research Program; the Soil Management Support Service (SMSS), which is a joint endeavor of the SCS and USAID; and the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT), which is a new initiative of the University of Hawaii and USAID and several governments. I have already spoken elsewhere of the ICRISAT Farming Systems Program. The Soil Management Support Services Program is a U.S. Government program designed to encourage and assist wise and productive soil management by (a) providing short-term technical assistance in soil survey, land-use planning and conservation, and (b) helping to increase the transfer of improved soil management technology by revising Soil Taxonomy to make it internationally applicable.

As Goro Uehara has said, IBSNAT is an outgrowth of the Benchmark Soils project that was established in 1974 by the Universities of Hawaii and Puerto Rico and the Governments of the USA, the Philippines, Indonesia, Brazil, and later, the Government of the Republic of Cameroon.

The basic purpose of the Benchmark Soils Project was to correlate food-crop yields with soil properties and soil-use practices on a network of benchmark soils—mostly deep upland soils—to determine scientifically the transferability of agroproduction technology among tropical countries, to develop methodologies, and to create the required infrastructure for successful agrotechnology transfer.

The benchmark soils of the network belonged to three common soil families, as defined in the U.S. Soil Taxonomy. The family groups soils within a subgroup having similar physical and chemical properties that affect their response 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—I repeat, practical-interpretations of such responses.

The use of similar soil families provides the technological base to increase the transfer of improved soil management technology, which is a major objective of both the SMSS and IBSNAT,

The types of experiments that the Benchmark Soils Projects conducted were established at a workshop on Experimental Design for Predicting Crop Performance, held in Hawaii in 1974. Two main types of experiments were developed: one set, the transfer experiments, for testing the hypothesis of agrotechnology transferability; the second, the management experiments, to provide information on economic and efficient practices that local farmers might utilize and also to provide information for subsequent soil survey interpretation and land classification.

The transfer experiments were tightly controlled, to provide a statistical test of transferability. Early in the life of the project it was suggested that experiments of the required standard and quality were best conducted within the USA on state or federal agricultural experiment stations and on fairly homogeneous landscapes. The Benchmark Soils Projects chose not to follow that advice, and proceeded to conduct the experiments over a far-flung network of stations, some newly carved out of the bush, in five countries, on three continents. That the projects were successful is a great tribute to the scientists and staff. Not only did they succeed in their primary objectives, they also demonstrated good experimental methodologies and the communications value of the benchmark soil concept around the developing world in a way that no set of precise experiments conducted, say, in the U.S. midwest, could ever have hoped to do.

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The management experiments were intended to provide information for immediate practical use. I have the impression that the huge effort needed to successfully conduct the transfer experiments and to develop the statistical tests prevented the conduct of an adequate number and variety of management experiments. This may therefore become the responsibility of IBSNAT.

One early product of the Benchmark Soils Projects was the book *Soil Resources Data for Agricultural Development,* the proceedings of a seminar entitled "Uses of Soil Survey and Classification in Planning and Implementing Agricultural Development,'' jointly sponsored by the Benchmark Soils Projects and ICRISAT and held in Hyderabad in early 1976. The seminar and the excellent papers presented helped to define what soils information was best suited to the needs of agricultural development planners. Might I repeat the main conclusions:

The planners need data on the extent, location, and quality of the soil resource. They need to know its alternative and potential uses and the conservation needs. They need information on how to correct soil problems or deficiencies and the likely cost of managing soils at different levels of production. Most of all, they need single-factor interpretation of soil units for several important crops, either quantitatively in tables or spatially arranged on maps. Yield predictions at several defined levels of management are the most useful form of management data. These are the conclusions that the soil scientists and planners arrived at during that seminar.

The book also has some excellent case studies of soil survey interpretations. Two in particular are worthy of mention. The first, by H. Y. Chan of the Rubber Research Institute of Malaysia, gave quantitative and practical examples of the interpretations of surveyed and classified soils for rubber; the second, by Shin Hong Hwa of Korea, describes how soil survey interpretation was used to determine what lands should be selected for the production of a new high-yielding rice. Both papers are impressive examples of the value of soil survey interpretation in agriculture and of how to combine agronomic experimentation with soil survey data. It has been done before.

In addition to successfully carrying out the field experiments and testing the main hypothesis, the Benchmark Soils Projects demonstrated the value of setting up a network of agricultural experiment stations on named kinds of soils around the world. The projects also showed that much additional research and technological information could be based upon benchmark soils. One of the major benefits has been the satisfaction—even excitement—gained by the participating scientists through the system of shared experiences and experiments on a common and understandable soil network.

The Benchmark Soils Projects suggested quite early that existing agricultural research stations could be linked together through Soil Taxonomy and the classification of station soils at the family level. Attempts were made in the Benchmark Soils Projects to do this and in a subsequent University of Hawaii project to make the required soil classification and to collect soils and soil-use data into a central computerized storage system. It is my impression that those early projects did not make a great deal of headway.

The idea was discussed again, as Dr. Uehara has said, at ICRISAT in 1978 at a workshop entitled 'The Operational Implications of Agrotechnology Transfer Research." The workshop proposed the establishment of an international benchmark soils network based on the national and international research centers and on the collection of minimum sets of performance data. It was proposed that the network have responsibilities in soil characterization, including the standardization of methods, international soil correlation, classification of research station soils, extension of Soil Taxonomy to international use, and establishment of related data banks and communications networks.

Additional responsibility was suggested to expand agrotechnology transfer by helping national programs set up their own internal benchmark soils networks. It was suggested that IBSNAT would be responsible for developing a coordinated program of research on the relationships between soil characteristics, climatic parameters, and crop performance.

Figure 1, showing the logical framework proposed for IBSNAT, helps to place our present symposium in context. The network as it was envisaged at that time, 1978, had two parallel linked arms: one to predict crop performance from soil properties, which is the major theme of our present symposium; the other to develop and exploit benchmark soil networks.

The international network of benchmark soils exists already in the Benchmark Soils Projects. It

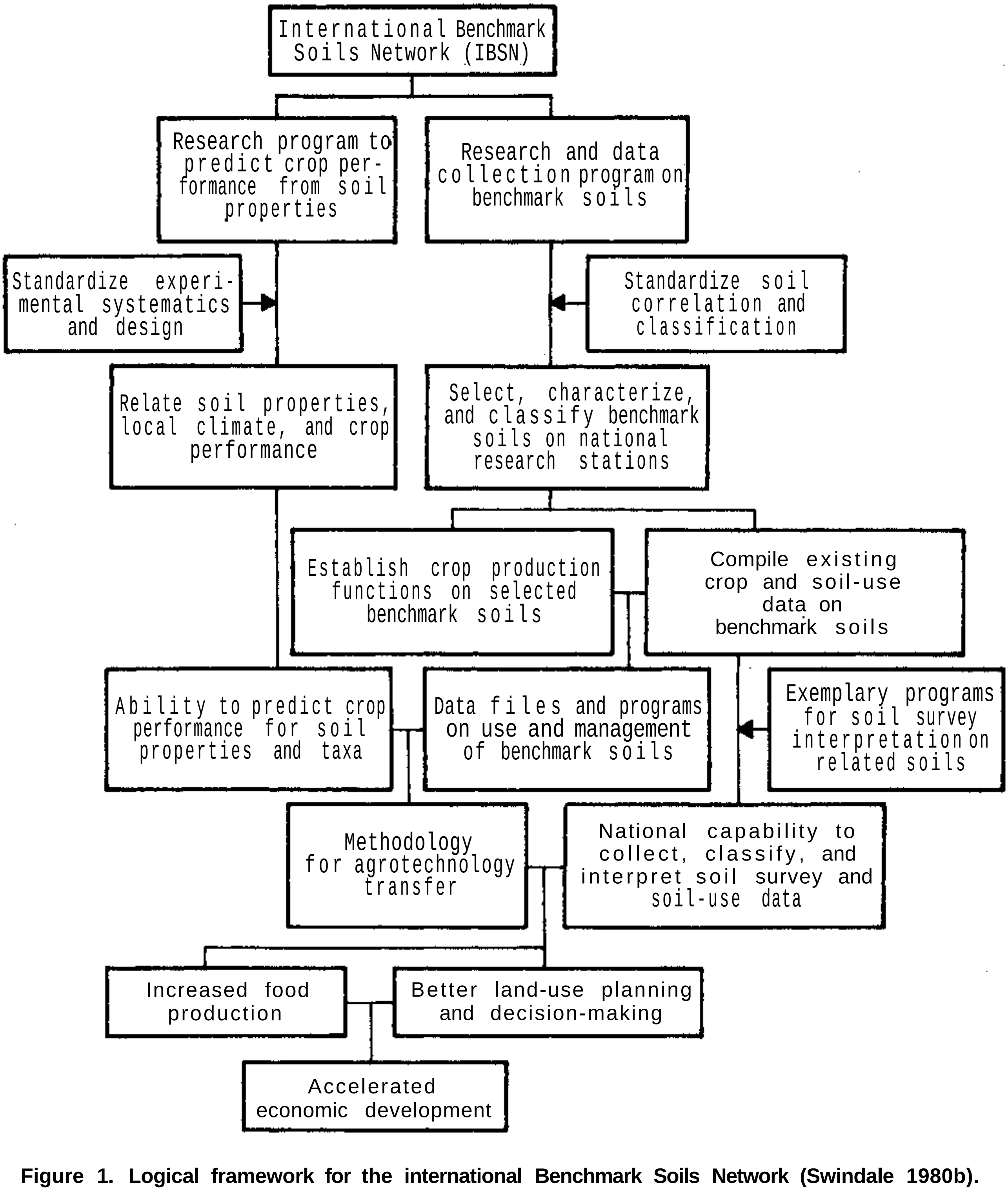

Figure 1. Logical framework for the international Benchmark Soils Network (Swindale 1980b).

needs supplementation. Several national networks already exist. Clearly, they will provide additional sites for inclusion in the international network. Other sites will come from the international agricultural research centers such as ICRISAT and CIAT, and cooperating countries that are not presently part of the network may also wish to be included. I would like now to describe an in-country network that the National Bureau for Soil Survey and Land Use Planning (NBSS & LUP) and ICRISAT have been investigating, to give you an example of what such a benchmark soil network can do,

This project takes in only a portion of India, specifically the Deccan Plateau of Central India with its Vertisols and associated—mainly black-soils. The research area is bounded approximately by Hyderabad and Sholapur in the south; indore, Bhopal, Jabalpur in the north; and it includes Nagpur, where the NBS is located. The purposes are to determine the value that a benchmark soils network in this area has for planning agricultural research and land use and for predicting the suitability of better technologies, particularly an improved technology developed at ICRISAT for management of deep Vertisols; to do some studies on the taxa for Vertisols in Soil Taxonomy, and to strengthen soil survey interpretation and land-use planning in the NBBS.

The methodology includes compiling data on all benchmark soils in the area, including their characterization and classification, and then reviewing the network to see if we have too many or too few soils in it. As part of that process we hope to develop criteria that are useful for choosing benchmark soils in a network. Then we will compile soil-use data for sorghum production on five of the most extensive benchmark soils, several of which are more than 100 000 ha in extent, all in different families of the Vertisols.

Although we know that the farmers' yields vary a great deal, we will still be able to determine, by getting enough data, what is the average yield and the average level of management; what yields are obtained by the best 20% farmers, at what level of management; and what maximum yields are obtained by research workers at the highest—though not necessarily the most economic—levels of management. We will see how these three levels of yield at different levels of management differ from one another across the set of soils. We will also make observations on yield gaps and production potentials on these soils. We should be able to point out where more research and where more extension work are needed.

We will be able to determine if (a) the benchmark soil network already selected in this area adequately represents the soil pattern, (b) soils in the same soil families appear to have similar current agricultural land uses or potentials, and (c) what changes are needed to make the taxonomy of Vertisols better suited for agrotechnology transfer. We will produce interpretative suitability maps (well suited, moderately suited, poorly suited) for the improved Vertisol management technology and we will produce some training course materials in soil survey interpretation and land-use planning for use in the NBSS.

Our project exemplifies many of the stages shown in the right half of Figure 1, the framework for an International Benchmark Soils Network, The work can all be done within a national soil survey organization. We have received some assistance from the SMSS, particularly in standardizing soil correlation and classification, and I expect we would need their further assistance in developing the training materials in soil suvey interpretation. This is not very sophisticated research. But it is important work. The technology for deep Vertisol management is spreading rapidly around this country. It started in a small way on farmers' fields 2 years ago. Last year it increased tenfold, this year 30- to 40-fold over that increase. That is 400-fold in 2 years.

We soil scientists have some responsibility to help to steer this in the right direction on to the right soils, just as IBSNAT funded by USAID has a duty not only to do good research but to do good.

We are aware that we are not utilizing in our project the methodology that was developed by the Benchmark Soils Project and is so well laid out in a recent publication, *Procedures and Guidelines for Agrotechnology Transfer Experiments.* They are excellent methods and I hope they will be well used. But soil scientists have been transferring technology for a long time now and we do intend to stratify our environment down to a few soil families in the most homogeneous soil order.

This quite complicated technology is being transferred to similar soils already, with economic success. It is proving less suited on some shallow black soils—mostly Vertic Ustochrepts and Vertic Ustropepts—and less suited also to the Alfisols that start here at ICRISAT and extend south, right to the end of the country.

Soil surveys are properly concerned about the transfer of information for practical purposes. Let me quote from a paper by David Slusher, who was the Assistant Director of Soil Survey Interpretations in the SCS.

> If soils are to be evaluated for purposes for which they are now not used or are used in

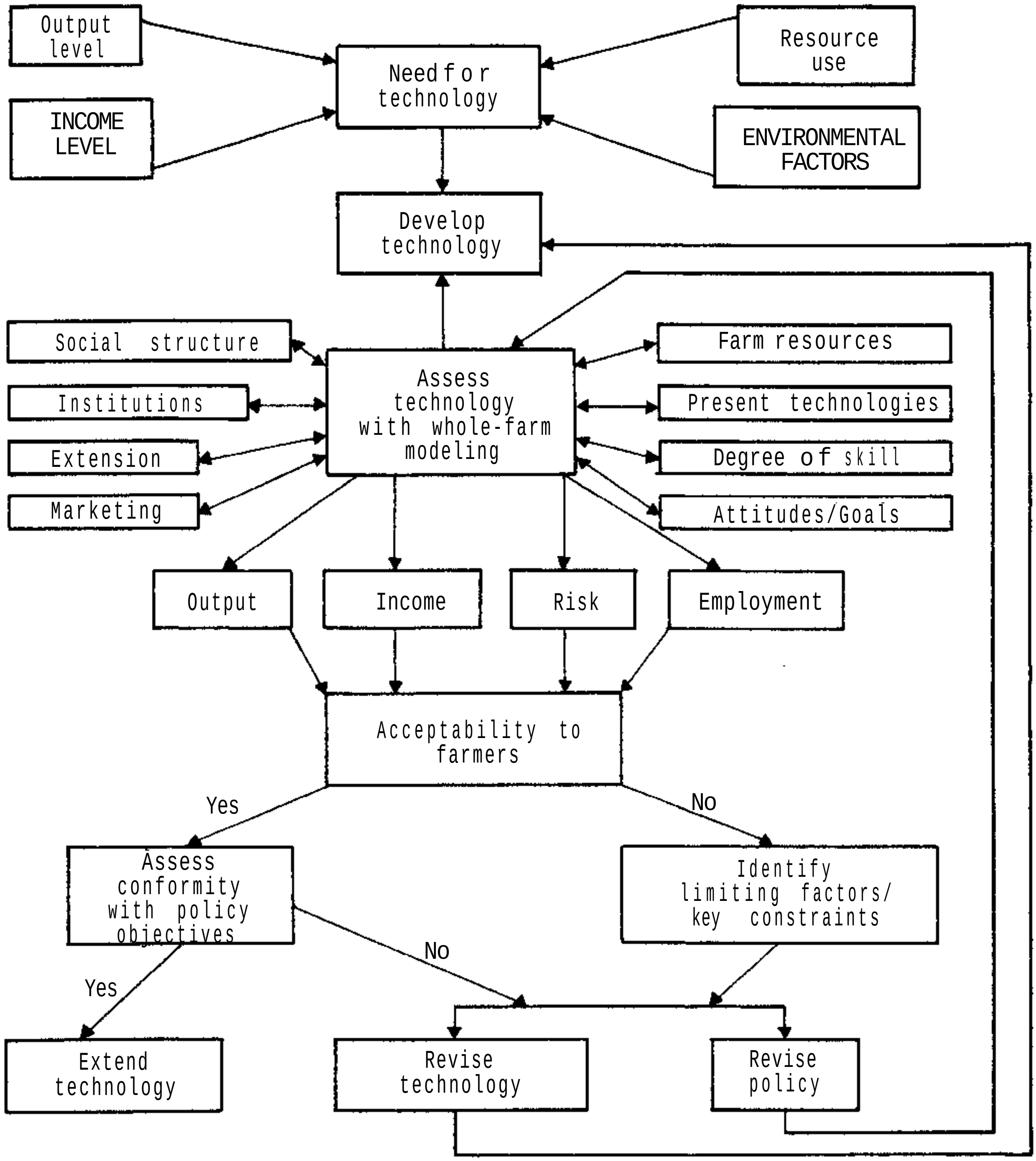

Figure 2. Technology assessment with whole-farm modeling.

> only a few places, then it is necessary to infer corrective measures and other indices of soil potentials that are needed.
>
> If similar soils are used for the purpose being evaluated/these evaluations can be based on the performance of similar soils, with adjustments made to slightly raise or lower the performance level or to modify the measures to account for properties more or less favorable than those of similar soils.

This is transfer of technology. It is also arguing by analogy. Henry Nix first called this process transfer by analogy. We do it all the time in soil science.

An alternative method of transfer is to use the simulation models that we will study in our symposium. The left half of Figure 1 shows a research program to predict crop performance from soil properties and standardized experimental systematics and design. In this symposium our purpose is to develop a scientifically sound ability to predict crop performance from soil properties and taxa, so that we can combine this ability with information on use and management of benchmark soils to provide a systematic methodology for agrotechnology transfer and to make better land-use planning decisions.

Simulation models attempt to mimic biological processes through physical laws and relationships. For a single-crop system on similar soils, climate-driven simulation models are probably the most successful because variations in climate essentially determine year-by-year crop yields. They are not, however, the most useful for our work. They will clarify for us existing knowledge in a highly systematic form and they will help us design significant experiments. From these models we should be able to determine what are the minimum sets of data required for various levels of prediction.

We will consider in this symposium evidence from sorghum, wheat, cassava, potato, soybean, and groundnut. We will also consider models that concentrate on the water and nitrogen in soils and on the erosion of soils. Hopefully from all these we will be able to discern not only the minimum data sets required for each of those models but some common elements amongst them all. To be useful, however, IBSNAT, must establish relationships between the response of a crop or crops and easily observable and/or predictable soil properties.

I predict—rather obviously—that soil moisture will be a significant variable in all the crop models. That is not enough. We will only succeed in the use of simulation models if we can find several significant soil variables in each crop model or in our combined model. To predict crop performance from soil taxa we must find variables that allow us to discriminate among soil taxa. And these variables, I remind you, are the inherently stable soil characteristics, not easily changed by man.

If we cannot include several—I would say, at least three or four—such variables in our simulation models, they will not succeed for our immediate purpose and we may have to continue to rely on analogous transfer. Furthermore, we must remember that to utilize several soil variables we must establish experimental sites to cover an adequate range of variation for each. This, perhaps, suggests that we must choose our variables before we choose our network. Willingness and a capacity to cooperate may not be enough. We must have the right soils. Here, I am sure, we will seek much guidance from the EPIC model that will be described in this symposium.

One little problem of our approach in this symposium is that we are dealing with growth models of single crops, whereas in much of the developing world several crops are grown together. However, I do not see this as a serious problem. For several of the soils, we have models for crops that are grown together, and I hope that we will have the ingenuity to combine them or otherwise find our way around that problem.

Somewhat more significant and difficult is that virtually all farmers make decisions affecting their entire enterprise, not just about one or another of their crops. We must therefore have the capacity to model whole farming systems. Figure 2 shows such a whole-farm analysis model, developed at ICRISAT by economist R. D. Ghodake and his colleagues, and some of the early results. I do not believe that we in this symposium can deal with this particular issue of whole-farm modeling, but it is one of which we need to be well aware.

Let me now inaugurate this Symposium on Minimum Data Sets for Agrotechnology Transfer. It is an important subject, with many implications beyond the immediate needs of IBSNAT. We have an excellent set of speakers and topics. So let us go to it.

Collaborators' National Networks

Minimum Data Sets for Agrotechnology Transfer on Vertisols and Associated Soils in India--

J. C. Bhattacharjee and R. J. Landey*

Abstract

In India, about 80% of black soils in general and Vertisols in particular occur in the central peninsular region. The climate is semi-arid to subhumid and is characterized by hot, dry summers and mild winters. About 75 to 90% of the annual rainfall, ranging from 500 to 1500 mm, is received during the monsoon season, from June to September. The high shrinking and swelling with changes of moisture limit the use and management of Vertisols and associated soils. Workability in these soils is poor because of their stickiness during the rainy period, while suitable tillage operations are difficult because of wide open cracks during the dry period. Thus these soils are workable under only a narrow range of moisture conditions.

National and international organizations are trying to evolve a viable soil-based agrotechnology on Vertisols and associated soils for transfer to farmers' fields. In April 1982 the Indian Council of Agricultural Research and ICRISAT began collaborative efforts to develop possible transfer models of practical viability. The project findings would also serve to bring out the interpretative specificity of criteria to establish taxa for Vertisols in Soil Taxonomy.

In the first phase of this project, data on benchmark soil series already reported by the NBSS & LUP were compiled and detailed soil surveys were conducted in a few adopted villages to test the transferability of the improved agrotechnology. Data on 15 soil series representing 12 soil families occurring in semi-arid to subhumid parts of central peninsular India were compiled and reviewed. Of these 12 soil families, 8 represented Vertisols and 4 represented the Vertic subgroup of Inceptisols.

Areal extent, climate, and salient characteristics of these soils are discussed in this paper. Minimum data sets have also been outlined for evolving soil-based site-specific agrotechnology to promote food and fiber production on Vertisols and associated soils under the dryland farming system.

Since the early 1900s, major cultivated soils of India have been grouped as alluvial, black, red, lateritic, and laterite soils occurring in a wide range of climates. About 90% of the black soils occur in semi-arid parts of India. Also large areas of black soils have been reported to occur in the semi-arid tropics in Chad, Sudan, Ethiopia, and other African countries and in Australia, covering 180 million ha (Swindale and Miranda 1981) or 70% of the total world area (257 million ha) that lies between 45°N and 45°S latitudes (Dudal 1965).

The unique morphological features and physical and chemical properties of the black soils attracted Indian soil scientists and agronomists to expand use of these soils for the benefit of farmers. Many fertilizer trials on crop response to different doses of nutrient levels were conducted, but without any fruitful dialogue among soil scientists, agronomists, and farmers. Moreover,

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short-term problem-oriented projects were undertaken without rational follow-up activities.

The first requirement, therefore, was to develop soil maps in different scales and soil information at different levels for transfer of technology at different levels. This task has been entrusted to the national organizations and state agencies. Simultaneously, concerted attempts have been made to intensify research on dryland farming by national and international organizations in India-such as the All India Coordinated Research project for Dryland Agriculture (AICRPDA), ICRISAT, and various Indian agricultural universities—to develop a viable agrotechnology on black soils in general and on Vertisols in particular.

However, the technology evolved for Vertisols could not perform uniformly at different geographical locations in India. This limitation may possibly be due to differential behavior of soils in different environments. Thus the characteristics and behavior of all Vertisols are not identical, although they show a considerable degree of uniformity in Soil Taxonomy. On the question of transfer of agrotechnology, Smith (1965) contended that "High categories are essential for comparisons of the soils of large area, but are of limited value for the transfer of experience."

The order is the level of generalization with the smallest number of taxa with a set of key properties indicating pedogenic processes in soil development. It appears that management requirements need interpretation of the set of data abstracted from a larger population of basic taxonomic units, since improved agrotechnology is based on soil and site specificity. Thus the soil family, at the critical position between the heterogeneity of the subgroup and the homogeneity of the series, indicating similar use potential and directly related to the interpretation of soil survey, would be a suitable medium for transfer of agrotechnology.

Distribution, Climate, and Physiography

Spatial Distribution

Soilscapes of Vertisols and associated soils occur extensively in peninsular India, extending from 8°45' to 26°0'N latitude and 68°8' to 83°45'E longitude, covering 72.9 milion ha and accounting for 22.2% of the total area of the country, 28% of the world's black soils, and 40% of black soils in the semi-arid tropics.

About 80% of this 72.9 million ha area of black soils occurs in the states of Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh, and Karnataka.

The common soilscapes associated with black soils are those of shallow to very shallow Typic Ustorthents with rock outcrops on residual plateau, hill ranges, and escarpments, grading to moderately deep, fine loamy to fine Vertic Ustochrepts/Ustropepts on gently sloping to moderately sloping pediments; and clayey Vertisols on lower piedmont, floodplain, and coastal plain.

Table 1. Areal extent of different taxa of Vertisols and associated soils in the Indian subcontinent.

Order	Percentage of total black soil area (%)	Area (million ha)	Great Group	Percentage of area covered by order (%)
Vertisols	38	27.7	Chromusterts	61
			Pellusterts	39
Inceptisols	37	27.0	Typic subgroup	4
			Vertic subgroup	96
Entisols	21	15.3		
Aridisols	0.6	0.4	Salorthids	
Alfisols	0.4	0.3	Vertic Haplustalfs	
Impurities mapping rock outcrops, miscellaneous land types, undifferentiated soils, etc.	3.0	2.2		

The areal extent of different taxa on soilscapes of Vertisols and associated soils are given in Table 1.

Climate

The climate of central peninsular India is characterized by well-expressed hot, dry summers and fairly dry, mild winters, with brief periods of monsoon rain in between. The mean annual rainfall varies from 500 to 1500 mm, of which 75 to 90% is received during the monsoon months of June to September. This climatic region can be

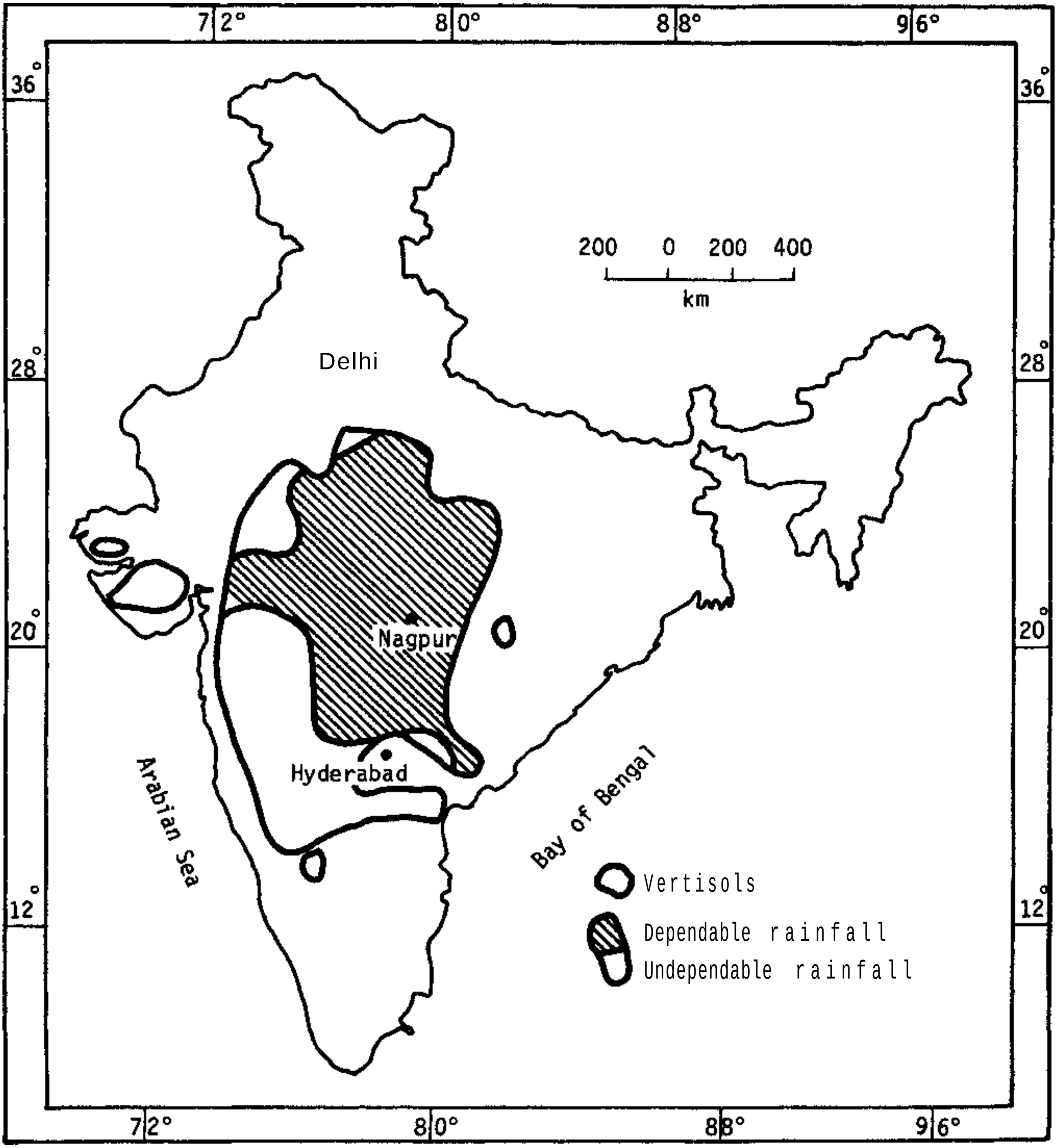

Figure 1. Dependable rainfall (750-1500 mm) and undependable rainfall (below 750 mm) regions in central peninsular India. (Source: Virmani et al. 1978).

divided into two subregions (Virmani et al. 1978): (a) area with dependable rainfall, receiving 750 mm to 1500 mm, and (b) area with undependable rainfall, receiving below 750 mm (Fig. 1).

Genesis and Characteristics

The parent materials of Vertisols and associated soils are normally fine-grained, rich in "mafic" minerals and alkaline earths. These are usually basalts, tuffs, basic metamorphic rocks, limestone, marls, alluvium, and outwash of basic materials. The fine-grained materials on gentle slopes (0-3%) permit restricted leaching. The weathering process of these materials under warm climate and restricted leaching possibly leads to the development of a smectite group of minerals, the prerequisites for development of Vertisols, Thus in a climate of alternate wet and dry periods, materials with a significant amount of 2:1 expanding type of clay minerals and with a high coefficient of shrinking and swelling lead to haploidization by argillipedoturbation, inhibiting the process of horizonation. This process develops Vertisols having AC profiles with a cyclic or intermittent A horizon. Pedons of Vertic intergrades are those with ABC profiles (Bhattacharjee et al. 1977).

Due to their marked swelling and shrinking with changes in moisture, these generate unequal cohesion and compaction within the pedon, resulting in variation of bulk density and movement of soil mass as shear planes, called intersecting slickensides, in the subsoil, with concomitant gilgai microrelief and deep wide cracks on the surface.

Vertisols are deep to very deep clayey soils. Significantly, the fine clay fraction (< 0.2 μ m) accounts for 60 to 90% of the clay content, which is dominantly smectitic. Besides, the high shrink-swell potential, high CEC and saturating cations like Ca^{2+} Mg^{2+}, and Na+ possibly control physical properties such as bulk density, structural aggregates, porosity, consistence and aeration, as well as hydraulic conductivity and available water capacity, significantly affecting the use potential of Vertisols. The soils are very sticky and not workable when wet during the rainy period. During dry periods, wide open cracks separate the soil into prismatic blocks that limit tillage and intercultural operations. Thus workability of these soils is very limited under dry farming, because of the narrow range of workable moisture conditions.

The Benchmark Soils Project

In 1981, a seminar on Vertisols was held in New Delhi to review the inherent limitations and potential of these soils covering extensive parts of the rainfed crop area in India, and to discuss appropriate management and technology. The seminar was sponsored by the Ministry of Agriculture of the Government of India, the Indian Council of Agricultural Research and the International Crops Research Institute for the Semi-Arid Tropics. As a follow up to the decisions made at the seminar, a cooperative project, Benchmark Soils Vertisols, was initiated.

It was expected that there would be scope in such a project to reveal probable shortcomings inherent in the benchmark soils concept. It would also indicate the possibility of transfer models of practical viability. Vertisols were considered an appropriate choice because technology developed in this project could be tested for its applicability in other Vertisol areas. IBSNAT would use the agronomic data base to relate soil factors and site specificity. The project findings would also serve to bring out the interpretative specificity of the criteria to establish taxa for Vertisols in Soil Taxonomy.

This collaborative project of the ICAR, NBSS & LUP, and the ICRISAT Farming Systems Research Program—titled the Benchmark Soils Network for Agrotechnology Transfer—was initiated in April 1982 with the following objectives:

- Predicting suitability of technology developed by ICRISAT, MPAU, JNKW agricultural university, and the Indo-UK Project for use of Vertisols and associated soils in central India.
- Determining the value of a benchmark soils network in planning agricultural research and land use in India.
- Critically studying present critieria for establishing taxa for Vertisols in Soil Taxonomy.

The project area was confined to central peninsular India and located between 17° and 24°N latitude and 75° and 79°E longitude (Fig. 2).

The first phase of the project was:

- to compile and review the data on benchmark soil series identified and reported by the NBSS & LUP in the project area and
- to complete a detailed soil survey (at 1:8000 scale) of villages within the project area adopted by ICRISAT to test the transfer of improved agrotechnology.

The compilation of soil data includes morphological characteristics, physical and chemical properties, climatic and geomorphic situations, and agricultural soil-use data.

It is envisaged that such a review will help to ascertain whether soil families have the same present agricultural land use and potential, and to

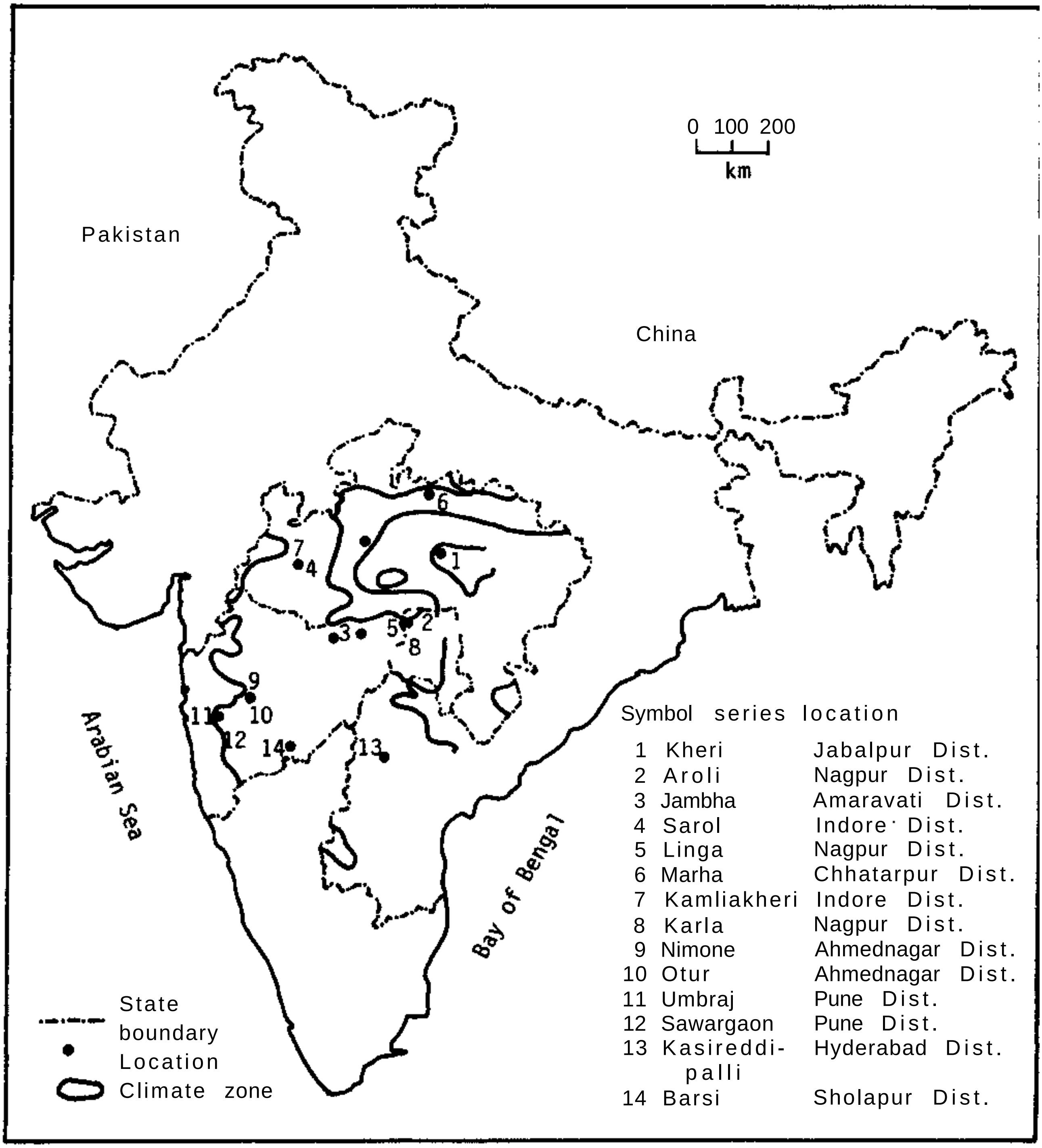

Figure 2. Benchmark Soils Project area and environs in central peninsular India. A. Humid, hot, with large summer water deficiency. B. Moist, subhumid, hot with large summer surplus; C. Dry, subhumid, hot, with large summer surplus; D. Dry subhumid, with moderate summer surplus; E. Semi-arid, hot, with moderate summer suplus; F. Semi-arid, hot, with little omo surplus; G. Arid, hot, with little or no surplus.

assess the transferability of agrotechnology within the same soil family to another within the project area.

Results

Data on 15 soil series representing 12 soil families and extending from semi-arid to subhumid parts of the project area (Fig. 2) have been compiled. Of these, 8 soil families represent Vertisols and 4 represent Vertic subgroups of Inceptisols occurring in association with Vertisols.

The bioclimate, the soil series and their areal extent, and the soil families have been elaborated in Table 2 and the salient characteristics of these soils are given in Table 3.

The Vertisol pedons reviewed are 150 cm or more deep, while those of Vertic intergrades are 50 to 60 cm deep (Table 2). However, all these soils are fine to very fine with a ustic moisture regime. Vertisols are dominantly montmorillonitic, while Vertic intergrades are of mixed to montmorillonitic mineralogy. The soil temperature regime of those occurring below 21°N latitude is isohyperthermic, while those above that latitude are hyperthermic.

During the dry period, polygonal cracks on Vertisols taper and extend vertically to 40 to 50 cm of the surface and then incline, following the shearing plane surface, while in Vertic intergrades, cracks extend to paralithic contact more or less vertically. The upper 40 to 50 cm of the

Table 2. Bioclimate, soil series, and areal extent of soil families in central peninsular India.

Bioclimate	Soil series	Area (ha)	Vertisols - Soil families
Moist subhumid	Kheri	70 000	Very fine, montmorillonitic, hyperthermic, Typic Chromusterts
Moist subhumid to dry subhumid	Marha	1 40 000	Fine, montmorillonitic, hyperthermic, Entic Chromusterts
Dry subhumid	Linga	2 93 300	Very fine, montmorillonitic, hyperthermic, Udic Chromusterts
Dry subhumid	Aroli	2 34 900	Fine, montmorillonitic, hyperthermic, Typic Chromusterts
Dry subhumid to semi-arid	Sarol	2 96 200	Fine, montmorillonitic, hyperthermic, Typic Chromusterts
Dry subhumid to semi-arid	Jambha	46 850	Very fine, montmorillonitic, hyperthermic, Typic Chromusterts
Semi-arid	Barsi	66 000	Very fine, montmorillonitic, isohyperthermic, Typic Chromusterts
Semi-arid	Nimone	3 99 500	Fine, montmorillonitic, isohyperthermic, Typic Chromusterts
Semi-arid	Otur	81 600	Fine, montmorillonitic, isohyperthermic, Typic Chromusterts
Semi-arid	Umbraj	46 800	Fine, montmorillonitic, isohyperthermic, Udic Chromusterts
Semi-arid	Kasireddipalli	14000	Very fine, montmorillonitic, isohyperthermic, Typic Pellusterts
			Vertic Inceptisols - Soil families
Dry subhumid	Karta	86 900	Fine, montmorillonitic, hyperthermic, Vertic Ustochrepts
Dry subhumid to semi-arid	Kamliakheri	2 55 800	Very fine, montmorillonitic, hyperthermic, paralithic Vertic Ustochrepts
Semi-arid	Wadgaon	2 71 400	Fine, mixed, isohyperthermic, paralithic, Vertic Ustropepts
Semi-arid	Sawargaon	419 400	Fine, montmorillonitic, isohyperthermic, Vertic Ustropepts

Table 3. Properties and salient features of benchmark soils in central peninsular India.

Soil family and Series	(0–50 cm) Structure compound (secondary)	(0–50 cm) Consistence	Subsurface (50–150 cm) Structure compound (secondary)	Subsurface (50–150 cm) Consistence	Dry cold bulk density with depth (g/cc)	COLE with depth	Clay content with depth (%)	Proportion of fine clay (<0.2 μm) with depth	Silt content with depth (%)	Organic carbon with depth (%)	CEC of clay (me/100g)	Key cation affecting soil condition	pH (1:2.5) H_2O with depth	Other features
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Kheri family														
Kheri series	3C Pr (3Cabk)	dvh, mvfi, wvs, wvp	Coarse parallelepipeds tilting 30–40° from horizontal (3Cabk)	mvfi, wvs, wvp	1.6–2.0	0.10–0.14	60–65	70–90	20–19	0.5–0.2	80–95	Ca^{2+}	7.0–8.0	Thin (5–10 mm) soft and brittle crust on surfaces. Cracks: 2–3 cm polygonal; root zone aeration poor; allows poor root ramification workability poor
Jambha series	3C Pr (2msbk –2mabk)	dh, mvfi, wvs, wvp	Coarse parallelepipeds tilted 30–40° from horizontal (3 Cabk)	mvfi, wvs, wvp	1.7–1.9	0.08–0.12	62–70		20–12	0.5–0.2	75–90	Ca^{2+} but below 140 cm (Mg^{2+} + Na^{+})	8.4–8.8	Thin (10 mm) pulverized surface mulch; cracks polygonal, 2–3 cm wide. Root zone aeration poor, poor workability
Linga family														
Linga series	3C Pr (3Csbk –3Cabk)	dvh, mvfi, wvs, wvp	Coarse parallelepipeds tilted 30–40° from horizontal (3Cabk)	mvfi, wvs, wvp	1.6–2.0	0.16–0.19	70–75	70–85	20–17	0.6–0.2	80–110	Ca^{2+} but below 50 cm (Mg^{2+} + Na)	8.0–8.5	Surface crust (5–10 mm) thin, soft; cracks 3–5 cm wide; poor drainage; low intake; poor root zone aeration
Sarol family														
Aroli series	3C Pr (3Cmsbk –3Cabk)	dvh, mfi, ws, wp	Coarse parallelepipeds tilted 30–40° from horizontal (3Cabk)	mfi, wvs, wvp	1.6–1.9	0.09–0.11	50–58	70–75	29–32	0.5–0.2	80–95	Ca^{2+}	8.4–8.5	Surface crust (5–10 mm) thin, soft and brittle; cracks, polygonal, 3–4 cm wide
Sarol series	3C Pr (2msbk –3Cabk)	dsh-dh, mfi, wvs, wvp	Coarse parallelepipeds tilted 30–40° from horizontal (3Cabk)	mfi, wvs, wvp	1.5–2.0	0.08–0.11	50–58	75–85	30–38	0.6–0.3	80–100	Ca^{2+} but below 90 cm ESP 10–11	8.0–8.2	Loose granular mulch 20–30 mm covering cracks 3–4 cm wide; severe erodibility, poor subsoil drainage

Continued

Table 3. *Continued.*

Soil family and Series	(0–50 cm) Structure compound (secondary)	(0–50 cm) Consistence	Subsurface (50–150 cm) Structure compound (secondary)	Subsurface (50–150 cm) Consistence	Dry cold bulk density with depth (g/cc)	COLE with depth	Clay content with depth (%)	Proportion of fine clay (<0.2 μm) with depth	Silt content with depth (%)	Organic carbon with depth (%)	CEC of clay (me/100g)	Key cation affecting soil condition	pH (1:2.5) H_2O with depth	Other features
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Nimone family														
Nimone series	3C Pr (2msbk –3Cabk)	dsh-dh, mfr-mfi, wvs, wvp	Strong coarse parallelepipeds tilted 35–40° from horizontal (3Cabk)	mfi, wvs, wvp	1.6–1.85	0.09–0.13	42–58	60–80	22–30	0.6–0.2	70–99	Ca^{2+}	8.0–8.7	Loose granular mulch 20–30 mm, covering cracks 3–4 cm wide; poor root zone aeration, poor intake (0.15–0.25 cm/h)
Otur series	2C Pr (2msbk –2msbk)	dsh-dh, mfr-mfi wvs, wvp	Strong coarse parallelepipeds tilted 30–40° from horizontal (3Cabk)	mfi, wvs, wvp	1.5–1.75	0.09–0.12	50–55		26–30	0.5–0.3	94–101	Ca^{2+}	7.8–8.7	Loose granular mulch 25–30 mm, covering cracks 3–4 cm wide; better root zone aeration than Nimone series
Barsi family														
Barsi series	3C Pr (3Cabk)	dsh-dh, mfr-mfi, wvs-wvp	Strong coarse parallelepipeds tilted 35–40° from horizontal (3Cabk)	mfi, wvs, wvp	1.5–1.85	0.10–0.16	65–77	60–75	25–21	0.5–0.2	89–110	Ca^{2+} but below 60 cm (Mg^{2+} + Na^{+}) Ca^{2+}	8.4–8.5	Loose granular mulch 25–30 mm, covering cracks 3–4 cm wide; subsoil compact; poor root zone aeration, poor permeability
Umbraj family														
Umbraj series	2m Pr (2msbk –2msbk)	dh, mfi ws, wp	Coarse parallelepipeds tilted 30–35° from horizontal (3Cabk)	mfi, wvs, wvp	1.8–1.9	0.09–0.14	50–57		20–12	0.5–0.3	90–114	Ca^{2+}	7.9–8.7	Loose granular mulch 20–30 mm, covering cracks 2–4 cm wide; imperfectly drained, prone to salinity hazards
Kasireddipalli family														
Kasireddipalli series	2 m Pr (2msbk –2Cabk)	dsh, dh, mfr–mfi, wvs, wvp	Coarse parallelepipeds tilted 30–35° from horizontal (3Cabk)	mfi, wvs, wvp			58–67		22–21	0.7–0.2	90–105	Below 60 cm ESP 13–20	8.6–9.4	Loose granular mulch 10–20 mm, covering cracks 2–3 cm wide; poor root zone aeration; drainage poor; alkalinity

Continued

Table 3. *Continued.*

Soil family and Series	(0–50 cm) Structure compound (secondary)	Consistence	Subsurface (50–150 cm) Structure compound (secondary)	Consistence	Dry cold bulk density with depth (g/cc)	COLE with depth	Clay content with depth (%)	Proportion of fine clay (<0.2 μm) with depth	Silt content with depth (%)	Organic carbon with depth (%)	CEC of clay (me/100g)	Key cation affecting soil condition	pH (1:2.5) H_2O with depth	Other features
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Marha family														
Marha series	2 m Pr (2msbk –2mabk)	dh, mfi ws, wp	intersecting slickensides tilted 45° from horizontal (2mabk)	mfi, ws, wp	1.6–2.0		44–51		44–45	0.4–0.2	99–110	Below 90 cm ESP 10–12	8.0–8.1	Thin (5 mm) soft surface crust, cracks 1–2 cm wide
Kamliakheri family														
Kamliakheri series	2m Sbk –3Cabk	dh, mfr-mfi wvs, wvp			1.7–1.9	0.15–0.17	60–65	65–90			95–100	at 45 cm ESP 3–5	7.1–7.4	Favorable root zone aeration; bicuneate structure. Shallow root zone to paralithic contact; cracks 2–3 cm wide.
Wadgaon family														
Wadgaon series	2m Sbk –3Cabk	dh, mfr-mfi, wvs, wvp			1.5–1.7		45–60		26–30	0.4–0.2	95–100	Ca^{2+}	7.1–7.3	Shallow root zone to paralithic contact; cracks 2–3 cm wide
Sawargaon family														
Sawargaon series	2m Pr (2mabk)	dh, mfr-mfi, wvs, wvp			1.5–1.7	0.08–0.10	50–55		20–27	0.5–0.2	80–100	Subsoil ESP 5–6	7.2–8.4	Calcareous, abrupt lime (24–30%) at paralithic contact; shallow root zone
Karla family														
Karla series	2m sbk –2mabk	dh, mfi, ws, wp			1.6–1.65		54–58		22–24	0.5–0.2	70–96	Ca^{2+}	7.5–8.0	

Vertisol pedons are very hard when dry and very firm when moist in subhumid climates, while in semi-arid areas they are slightly hard to hard when dry and slightly friable to firm when moist (Table 3).

Agricultural Land-use Potential

The majority of farmers follow traditional farming practices. Normally they use farmyard manure, either yearly or once in 2 to 3 years. Plowing is done after the onset of the monsoon with a country plow (7 cm to 10 cm). The use of fertilizer is subject to the prevailing economic conditions. Farmers generally raise a local variety, with low-intensity cropping, getting poor yields. However, progressive farmers attempt to adopt improved technology with good returns. The yield data under different management levels are given in Table 4.

In semi-arid parts of Maharashtra receiving 500 to 750 mm annual rainfall, common cultivated soils are those of the Barsi, Nimone, Otur, and Umbraj series, comprising three Vertisoi soil families, and soils of the Wadgaon and Sawargaon series, comprising two Vertic Ustropept families (Table 2). Soils of the Nimone and Sawargaon families cover an extensive area (Table 2). These are located in the undependable rainfall zone (Virmani et al. 1978).

The annual rainfall in the area covers only about 41 to 42% of the annual potential evapotranspiration, resulting in gross annual moisture deficits (about 60%). Weekly rainfall distribution studies carried out at Sholapur reveal that the rainfall normally begins in late June or early July in this part and normally gets interrupted by a dry spell in late July and early August. It has also been observed that dry spells of more than 4 weeks occurring more than three times during the cropping season result in severe crop failure under dry farming (Anonymous 1981).

Since dependability of rain in June, July, and August is very low and rain in September is assured to recharge the hydrologic profiles, farmers prefer to keep Nimone soils fallow in the rainy period and take *rabi* (postrainy-season) crops, mainly sorghum, on stored soil moisture. However, *kharif* (rainy-season) crops like pearl millet, pigeonpea, and sunflower are normally taken on moderately deep Sawargaon soils and other closely similar families.

The remaining soils reviewed occur in the dependable rainfall zone with annual rainfall ranging from 750 to 1500 mm, extending from the semi-arid to subhumid tropics in the project area. The rainfall covers 43 to 55% of the annual potential evapotranspiration in semi-arid parts and 77 to 78% in subhumid parts.

Soils of the Kasireddipalli series form the key soil at ICRISAT Center and adjoining areas in the semi-arid part of Andhra Pradesh. Soils of Aroli, Linga, Jambha, and Karla series occur in northeastern parts of Maharashtra. Soils of the Kheri series occupying a key position in the taxonomy, occur in the Jabalpur region and of the Marha series in the Bundelkhand region, while soils of the Sarol and Kamliakheri series occur in the Malwa region of Madhya Pradesh, extending from subhumid to semi-arid parts.

Studying the distributive pattern of monsoon rainfall in the dependable rainfall zone, it is found that rainfall begins in the middle of June and peak rain is received in July and August, accounting for 33 to 39% of the total monsoon rain in part of Maharashtra and Madhya Pradesh, while ICRISAT and adjoining areas receive two peak periods of rainfall in July and September.

Soils of the Aroli and Linga series, extensive in the dry subhumid tropics of the Nagpur region, are normally cultivated for kharif crops, mainly sorghum and cotton, with pigeonpea as intercrop. During the rabi season, soils are either left fallow or put under sequential crops such as lentil or chickpea; in some places, wheat is taken under supplemental well irrigation.

Soils of the Sarol and Kamliakheri series are extensive in dry subhumid to semi-arid parts of the Malwa region, MP. (Table 2). They are imperfectly drained and highly erodible, forming rills and gullies. In this area, kharif crops suffer from inadequate drainage, while rabi crops suffer lack of available moisture. About 68% of the area is used for rabi crops and 32% for kharif cultivation, mostly on Kamliakheri soils.

The efforts of the Indo-UK project and the AICRPDA at Indore have converted large areas of kharif fallows into kharif cropping areas on Vertisols, using novel dry-farming practices on a watershed basis to make the best use of available land and water resources.

The kharif crops in the area are mainly maize and sorghum, with intercropped pigeonpea or soybean; the rabi crops, wheat with intercropped chickpea or safflower.

Table 4. Grain and fiber yields of sorghum, wheat, and cotton under different levels of management.[1]

Relationship of soil families	Soil family	Sorghum (kg/ha)			Wheat (kg/ha)			Cotton (kg/ha)		
		LT	HT	I	LT	HT	I	LT	HT	I
Same family	Aroli	300–500 (K)	800–400 (K)	1900–2400 (K)	200–300 (R)	1000–1200 (RI)	1500–1800 (RI)	500–700 (K)	1000–1200 (K)	1400–1700 (K)
	Sarol	300–400 (K)	800–1200 (K)	2500–2800 (K)	500–800 (RI)	1000–1200 (RI)	1600–2500 (RI)			
Parallel family	Linga	200–300 (K)	700–1200 (K)	1800–2000 (K)	100–150 (R)	500–800 (RI)	1200–1600 (RI)	200–500 (K)	800–1200 (K)	1400–1800 (K)
	Nimone	500–600 (R)	800–1200 (R–RI)	1700–2000 (R–RI)		900–1100 (RI)	1600–2000 (RI)			
Parallel and closely similar families	Barsi	400–500 (R)	600–900 (R)	1200–1600 (R)						
	Kasireddipalli	300–500 (R)	600–1100 (R–RI)	2000–3100 (R–RI)						

1. LT = low level traditional management; HT = high level traditional management; I=improved high level management; K = *kharif* (rainy-season) crop under dry farming; R=*rabi* (postrainy-season) crop under dry farming; RI=*rabi* season crop under supplemental or full irrigation.

Grain Yields

Comparing grain yields of sorghum and wheat grown with traditional low inputs, sorghum yields are found to be relatively higher on Aroli soils; wheat yields, on Sarol soils (Table 4). Comparing the rooting depths on these soils, it is found that the distribution of clay and silt is somewhat similar in both; however, the fine clay fraction (< 0.2µm) increases with depth in the Aroli soils but abruptly decreases below 60 cm of the surface in the Sarol soils. Moreover, relatively high bulk density and COLE value (Table 3) in subsoil layers of Sarol soils possibly affect root proliferation, subsoil drainage, and aeration during the growing period of rainy-season crops such as sorghum, resulting in poor performance in farmers' fields on the Sarol soils.

The relatively lower bulk density (1.5 g/cc) and favorable consistence of the surface layer in Sarol soils (Table 3) are also conducive to optimum soil aeration, soil temperature, and soil moisture for germination and seedling emergence for the wheat crop (Ghildyal and Tripathi 1971; Nielsen 1974). Wheat-chickpea sequential cropping trials on Sarol soils revealed that the highest percentage of root ramification of wheat (62.6%) and of chickpea (75.6%) was in the top 30 cm (Anonymous 1980), indicating root-zone limitations in Sarol soils affecting crops in both seasons under traditional dryland farming. Crop performance under improved management levels (Table 4), however, indicates the potential of these soils.

Yields of sorghum and wheat on Linga soils, a parallel family, are even lower than on the Aroli and Sarol soils (Tables 3 and 4), possibly due to the limitations imposed by soil properties within the rooting depth.

Comparing the grain yields of sorghum (variety CSH-5 and M-35-1) under low-input traditional practices, it is found that the yields on Nimone soils are better than those on Barsi and Kasireddipalli soils, although all three soils have an isohyperthermic temperature regime (Table 4). Possibly varying contents of fine clay, and dominating cation and bulk density within the rooting depth; differential soil temperature regime; and differential retentivity of moisture at high tension are some of the causes of the differential yields in these soils (Tables 3 and 4), in addition to the interaction of aerial components of the climatic environment.

Minimum Data Set for Optimum Production

Agrotechnology for improving crop production, if it is to succeed, should be based on sound soil information. Moreover, the soil-based technology evolved should be tested for applicability in other areas with similar soil characteristics. This needs comprehensive soil maps (series association level) of a geographical area and compilation of soil resources inventories, including geomorphic features and climate. Correlation and classification of these inventories to the level of the soil family—a group of soils with similar use potential and relating directly to the interpretations of soil survey—would serve as appropriate media for transfer of agrotechnology.

Modern agrotechnology needs specific soil information. A vital area of understanding would be the soil-environment-plant-root relationship. Thus the soil environment, with special emphasis on rooting depth, is of utmost importance. Soil environment comprises soil properties, including geomorphic features, soil temperature, and moisture regime. However, for sound land-use planning it is important also to understand the socioeconomic status of the farmers in a locality.

Thus, the minimum data set for optimum food and fiber production on the benchmark soils network of Vertisols and Vertic Inceptisols in India should include the following:

1. Soil depth.
2. Effective depth of root-ramification zone. The zone of maximum root ramification is most important, because roots cannot ramify in subsoil layers with bulk density exceeding 1.8 g/cc. However, they spread over the shear planes or through cracks.
3. Particle size distribution with special reference to the proportion of fine clay fraction (< 0.2|xm) indicating specific surface. For example, the Division of Pedology of the NBSS & LUP, working on the genesis of Vertisols (Typic Chromusterts) of central India, observed that the fine clay fraction (< 0.2 µm) constitutes about 75% of the total clay, and 80% of this is montmorillonitic, with a smaller amount of mica and vermiculite.
4. CEC and saturating cations.
5. Bulk density and COLE values to measure the compression effect limiting root ramification and conductivity of soil solution.

6. Soil temperature at different moisture tensions and at different levels of compaction within the root zone. Thermal conductivity (X), thermal diffusivity, and volumetric heat capacity have been found to bear a linear relationship with the increase in bulk density and decrease in void ratio. These findings also indicated that lower density (1.0-1.5 g/cc) of soil with optimum soil aeration would be better for crops in which germination and seedling emergence are sensitive to extreme temperatures (Ghildyal and Tripathi 1971). Richard et al. (1952) and Nielsen (1974) observed that soil temperature in the root zone has an important influence on root development.
7. Saturated hydraulic conductivity and depth to water table.
8. Available moisture retentivity of soils in rooting depth at different stages of crop growth.

   The Division of Pedology, NBSS & LUP, observed that the benchmark Vertisols and Vertic intergrades of central India have a high moisture retentivity at 15-bar tension (PWP), in the range of 22 to 29%, while moisture at 1/3 bar ranges from 30 to 60% with depth of soil pedons (personal communication). It is felt that possibly the fine clay fraction would be responsible for high retentivity at 15-bar tension in these soils with depth.
9. Level of available nutrients.
10. Weekly data of climatic components influencing crop production.
11. Socioeconomic status of the farmers and adaptability as well as acceptability of the technology evolved.

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Means of Agrotechnology Transfer in Venezuela: Need and Prospects

Juan A. Comerma*

Abstract

Venezuela, like many other countries, needs to develop efficient ways of transferring agrotechnology. However, the wide range of environments and of crops and cultivars, our limited knowledge of the country's natural resources, and the small number of trained researchers, complicate the task of agrotechnology transfer.

Different means of transfer are envisioned. Those areas with rather uniform land qualities in mappable extensions can be covered by using the analogous areas approach. This is a partial, static, simple, and general method. In Venezuela we have a map with agroecologically homogeneous areas at 1:250 000 scale, that could serve for the transfer of general agricultural systems. For more specific items such as crop adaptability, fertilizer recommendations, etc., smaller scale maps are required.

Those areas in which land use has altered land qualities at the parcel level will require a more complex and dynamic approach; here a model that includes soil-climate-crop-technology variables is necessary.

Precise agrometeorological and edaphological characterization of experimental sites is lacking and we have now begun to emphasize its importance in field experiments. The approach proposed by IBSNAT for testing data will complement currently used methods in Venezuela and we could participate in this multinational experiment with sites representing a range of agroclimatic and soil conditions for rainfed agriculture, as well as a range of crops and cultivars.

Agricultural research in Venezuela, as in many other countries, is subjected to the criticism that the results are not sufficiently transferred to the users. We are well aware that more efficient transfer methods must be developed; however, the situation is complicated by the large variability of agrophysical factors in Venezuela, the large number of crops and cultivars, the many different agricultural systems, and the limited knowledge we have of the country's natural resources (Aguilar and Comerma 1981). According to an agroecological study done at 1:250 000 scale (Sanchez et al. 1982) the northern half of Venezuela has 530 different agroecological land units, which would imply differences in the adaptability of crops or cultivars and in their management. In soils alone, we estimate that when a detailed soil survey is completed, we will have about 3000 soil series or 1000 to 1500 soil families in an area of about 1 million km^2. Moreover, the soil properties will change with use and with added inputs such as fertilizers (Perez Silva et al. 1971), further increasing the variability at parcel level and complicating transfer of agrotechnology.

The wide range of research needs, coupled with the small number of trained researchers, represents a major problem for Venezuela. It is therefore imperative that we choose our ex-

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perimental sites with care and find means to extrapolate our results (Aguilar and Comerma 1981).

Unfortunately, although 250 to 300 field experiments on soils and climate are done annually, soil and weather conditions at the sites are not well documented, so that crop response cannot be accurately interpreted and results cannot be applied at other sites.

Currently Used Means of Agrotechnology Transfer

The most commonly used means of agrotechnology transfer in Venezuela now are (1) the analogous areas method and (2) the statistical model (Perez Silva et al. 1981).

Maps for transfer by analogy are available at different scales. At 1:250 000 there are agroecologically homogeneous areas, an integration of climate, relief, great soil group, and capability subclasses at a given technological level. This kind of units are envisioned to serve for the transfer of generally successful agricultural systems or general land-utilization types (Sanchez et al. 1982). On the other hand, many areas with a semi-intensive use in agriculture have detailed or semi-detailed soil survey studies. In those, soil families or soil series are partially used to extrapolate adaptability of crops or cultivars, of fertilizer recommendations, and a few other soil management practices.

On the other hand, the statistical model approach is used here in one of its simplest versions to recommend P and K fertilizers based on tests calibrated through fertilizer field experiments. Here a transfer is done at parcel level, considering only the fertility level of the soil sample and the crop-specific statistical curve of calibration.

In areas where the use of fertilizers, irrigation, and other practices have not altered significantly the land qualities at parcel level, we can, we believe, successfully continue using the analogous area approach for the transfer of agrotechnology. In areas where certain land qualities have been altered, we can use simple statistical models, like calibration curves, to transfer fertilizer recommendations. But if we want to include other variables, such as climate, and consider other predictions (like planting time, density, yields, etc.) in a more quantitative and efficient way, we must consider the use of simulation models in addition to, or in combination with, the analogue transfer in fields where land use is not so intensive, and/or in combination with statistical models for more intensively used areas, especially if using fertilizers, other soil amendments, and irrigation.

Most areas in Venezuela (and we think a similar situation occurs in many tropical countries with similar kinds and degrees of development) could benefit if the specifications of technological packages to be transferred to a particular situation, produced by simulation techniques, could be physically extrapolated through agroecologically homogeneous areas or through statistical models at parcel level, thus getting the advantages of both approaches and increasing the efficiency of transfer.

Considering our limitations and needs, we have developed the scheme of work shown in Figure 1. The emphasis in this scheme is on the selection and characterization of representative experimental sites. As we have about half of them outside experiment stations, that is, in farmers' fields, this is an extremely important point. The second aim is to improve the amount and quality of data gathered about soils, climate, and crops, so that we can better interpret the experiment and have the necessary data to build up and/or validate simulation models, which include soil, climate, crop, and technology variables, and their interrelationships.

We support the idea of IBSNAT, of an international coordination in the choice of experimental sites. Table 1 shows the six experimental stations selected to participate in this effort. They represent the widest scope that we have available, in tropical areas, for rainfed short growing seasons, and mechanized harvest in Venezuela. They include a wide range of soils of contrasting characteristics and qualities (moisture availability, oxygen deficiencies, natural fertility, high and low pH, different susceptibility to erosion, etc.). In agroctimate, all localities are less than 500 m above sea level, with an average annual temperature above 24°C and rainfall from 900 to 2000 mm, representing a range of areas, from those with long dry periods with only about 4 moist months, to those with excess water and about 9 moist months. Besides the crops listed in Table 1, which are the most common in those areas, we do have excellent Venezuelan cultivars of corn, beans,

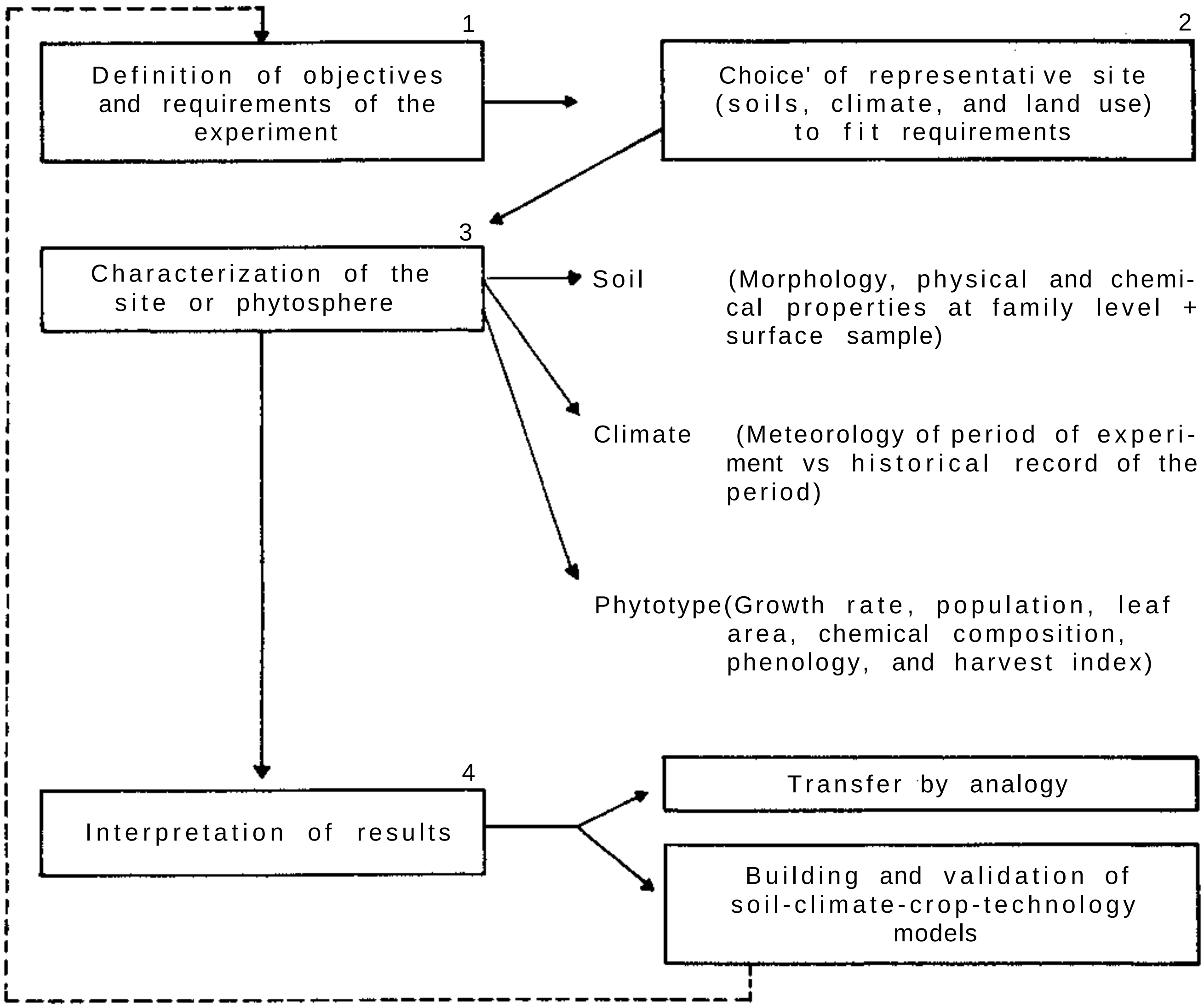

Figure 1. Edaphoclimatic selection and characterization of experimental sites for IBSNAT.

Table 1. Network of Venezuelan sites for IBSNAT.

Site	Rainfall (mm)	No. of wet months	Mean temperature (°C)	Main soils	Main land use/crop
Maracay	950	4-5	24.7	Haplustolls Ustropepts	Sugarcane, corn, bananas, potatoes
Yaritagua	960	4-5	25.8	Paleustalfs Chromusterts	Sugarcane, com, grain legumes
Guanipa	970	4-5	26.0	Paleustults Haplustox	Groundnut, sorghum, corn
Calabozo	1300	6	26.9	Chromusterts Natraqualfs	Rice, pasture, sorghum
Majaguas	1300	7	27.1	Haplustolls Tropaquepts	Sugarcane, rice, sesame
Chama	1800	8-9	27.6	Eutropepts Tropaquepts	Pasture, plantain

cassava, rice, sesame, and sugarcane, which can be used in this effort.

With all this variability, we think we will contribute best to develop and validate simulation models for certain cultivars of the international agricultural research centers, as well as for our best national cultivars, which we also offer for testing in other localities (outside Venezuela) of the tropical environment.

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A Synopsis of The Benchmark Soils Project

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Abstract

The Benchmark Soils Project, established in 1974, is the first comprehensive study done to test the transferability of agrotechnology on the basis of soil classification; specifically, the soil family as defined in U.S. Soil Taxonomy. Preliminary results indicate that soil management practices can be successfully transferred with this approach and yields predicted with considerable accuracy. While the approach has limitations where a high degree of specificity is needed, Soil Taxonomy can be an effective vehicle for agrotechnology transfer in applications such as large-scale land-use planning.

Introduction

The Benchmark Soils Project was established in 1974 to test the viability of an analogue approach to the transfer of agrotechnology in the tropics that is based on soil classification. The project comprises two companion research contracts awarded to the Universities of Hawaii and Puerto Rico in 1974 and 1975, respectively, by the United States Agency for International Development. While the smaller project of the University of Puerto Rico terminated in 1981, the project of the University of Hawaii will conclude its work in 1983.

As the first comprehensive study of its kind, the Benchmark Soils Project ventures to scrutinize scientifically the transferability of agroproduction technology, particularly soil and crop management practices. Central to this effort is the benchmark soils concept and the soil family as defined in the U.S. system of soil classification, Soil Taxonomy (USDA Soil Survey Staff 1975). 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, correlative input-output characteristics, and similar crop production potential. The hypothesis of transfer by analogy that underlies the project 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 comparable members of that family, irrespective of their geographic occurrence.

Project Objectives

The general aim of the Benchmark Soils Project is to evaluate this hypothesis experimentally and statistically. The primary research objectives are:

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 is to expand the knowledge base for the management of tropical soils; in particular, of the economic decision environment

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of the resource-poor farmers in the less developed countries.

Research Activities

In the context of the project, agrotechnology transfer is defined as the extrapolation of a response-input relationship, estimated from a known experimental situation, to other similar agroenvironments. For the scientific and quantitative assessment of the transfer hypothesis, the project chose to study how a test crop would respond to a technology in a number of widely separated locations.

The basic research strategy of the Benchmark Soils Project is to conduct a series of identical experiments in networks of soils belonging to the same families; monitor crop performance and weather and soil conditions; and statistically compare response to management in the form of yields.

In concurrence with the recommendations of a workshop on Experimental Designs for Predicting Crop Productivity with Environmental and Economic Inputs, held in Honolulu, Hawaii, USA, in 1974, the design used in the transfer experiments is a randomized complete block with 16 treatments, replicated 3 times. The first 13 treatments are according to Escobar's modified 5^2 partial factorial, described by Laird and Turrent (1981). This design has 13 of the 25 possible combinations of the five levels of each of the two factors. It covers the design space well, thus allowing the fitting of a second-order response surface from a limited number of treatments. Variables in the transfer experiments are levels of phosphorus and nitrogen, with maize as the indicator crop. All transfer experiments are drip-irrigated and standardized throughout the network. (For details and field procedures, see Benchmark Soils Project Staff 1982.)

The transfer experiments are complemented by pragmatic soil and crop management experiments designed in collaboration with host country institutions to provide information on economic and efficient agronomic practices. Variety trials were conducted in the early stages of the project to identify cultivars that are well adapted to the various agroenvironments and responsive to the fertility variables used in the transfer experiments. Three contrasting soil families, representing three distinct agroclimatic zones of the tropics, were selected for experimentation: the thixotropic, isothermic Hydric Dystrandepts; the clayey, kaolinitic, isohyperthermic Tropeptic Eutrustox; and the clayey, kaolinitic, isohyperthermic Typic Paleudults,

The project has established a research network that comprises 23 experiment sites in Brazil, Cameroon, Hawaii, Indonesia, the Philippines, and Puerto Rico. Collaborating with the project are the Empresa de Pesquisa Agropecuaria de Minas Gerais in Brazil, the General Delegation for Scientific and Technical Research in Cameroon, the Philippine Council for Agriculture and Resources Research in the Philippines, and the Center for Soil Research in Indonesia.

To date the project has completed 217 experiments at the various locations (Table 1).

Table 1. Experiments completed at 23 sites in the Benchmark Soils Project.

	Experiment		
Soil	Transfer	Variety	Management
Dystrandepts	57	3	22
Eutrustox	51	4	13
Paleudults	49	5	13
Subtotal	157	12	48
Total 217			

The yield data from the transfer experiments were analyzed with a methodology for quantitative evaluation of transfer, developed by the project (Cady et al. 1982). General aspects of formulating the transfer model have been given by Beinroth et al. (1980). An outline of the procedure is as follows (Benchmark Soils Project 1982b):

1. Calculating a site-specific prediction equation for each of the k sites, based only on yield data for that site. The differences between the site-specific predicted yields and the observed yields are called site-specific residuals.
2. Identifying the general nature of the transfer model. The simplest model would include the same components as the site-specific prediction equation of the first step. More complex transfer models incorporate uncontrolled site variables.

3. Estimating the selected transfer model for each set of (k-1) sites.
4. Predicting yield 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 observed yields are called transfer residuals and are calculated for each site.
5. Calculating the ratio of the transfer residual sum of squares to the site-specific residual sum of squares, where both sums are added over k sites. This specific criterion is called the prediction or transfer statistic (P).

Preliminary Results

Applying the P-statistic to the yield data gathered from the three soil families, the following results were obtained (Benchmark Soils Project 1982a, 1982b):

Dystrandepts	P = 1.06
Eutrustox	P = 1.50
Paleudults	P = 1.15

Since P-statistic values of 1.0 and slightly higher than 1.0 demonstrate predictability and transferability, the above values indicate that the response to applied phosphorus can be transferred among the sites of the same family, provided a measure of soil phosphorus is included in the transfer model. The relatively large P value for the Eutrustox reflects a moderate distortion of prediction but nonetheless supports the transfer hypothesis, although less conclusively.

In addition to the P-statistic, the confidence interval procedure and a graphical method were used for the Eutrustox yield data. These techniques also gave positive evidence for transferability (Benchmark Soils Project 1982a).

The management experiments conducted by the project dealt with cropping systems, nitrogen-fixing fuelwood trees, phosphorus source and placement, plant pests, liming, mulching, plant population density, irrigation, and soil erosion. A summary of these experiments and their results is given in two recent project reports (Benchmark Soils Project 1982a, 1982b). These reports also contain other project accomplishments such as training activities; symposia, workshops, and conferences; communication and dissemination; and publications.

Conclusion

The preliminary results of the Benchmark Soils Project show that transfer of soil management practices can be successfully achieved and yields can be predicted with considerable accuracy on the basis of Soil Taxonomy families, if additional site factors are taken into account. By implication, this validates the concept of the soil family as postulated in Soil Taxonomy and the principle of benchmark soils. A comparison of the results obtained in soil fertility and management experiments at the various sites of the project network also shows that Soil Taxonomy stratifies the agroenvironment into distinct niches'of agroproduction and allows qualitative predictions of soil potential and management requirements. In conjunction with soil surveys, Soil Taxonomy thus defines the geographic and pedologic applicability of agronomic experience.

At the same time, the project results allude to the limitations of analogue transfer of agrotechnology based only on Soil Taxonomy taxa. Soil Taxonomy constitutes an effective vehicle for agrotechnology transfer in cases where a high degree of specificity is not needed, such as in large-scale land-use planning. Transfer of agrotechnology to specific farm situations, however, requires a more holistic approach that should be based on systems analysis and employ computer simulation techniques to model the soil-weather-crop-management continuum.

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A Proposal for an Oceania Benchmark Sites Network for Agrotechnology Transfer (OBSNAT)

David M. Leslie*

Abstract

This paper describes the status of soil resource information and the agricultural economies for the 20 countries within the area served by the South Pacific Commission (SPC): American Samoa, Cook Islands, Fiji, French Polynesia, Guam, Kiribati, Nauru, New Caledonia, Niue, Norfolk, Papua-New Guinea, Pitcaim, Solomon Islands, Tokelau, Tonga, Trust Territory of the Pacific Islands, Tuvalu, Vanuatu, Wallis and Futuna, and Western Samoa. The constraints to agricultural development, unique to the region, are discussed.

Based on available information, the paper summarizes: map scale, percentage area coverage, and soil classifications employed for completed national soil surveys and those in progress; available regional manpower in soil and agricultural science; and laboratory facilities and parameters measured at regional laboratories; and analytical support available from outside the region. National requirements for regional standardization in soil resource information, soil correlation, and classification are discussed.

The major subsistence and cash crops of the region are listed and discussed in the context of the crops researched at the 50 agricultural research stations in the region. For the latter, the area, scale of soil survey, soil classification employed, and soil families are described for stations where known. The paper proposes establishment of an Oceania Benchmark Sites Network for Agrotechnology Transfer (OBSNAT) and steps to implement it The important soil great groups of the SPC region that would be suggested for study in a regional network are listed.

The Region

The Oceania region referred to in this paper is that area served by the South Pacific Commission (SPC) and comprises some 20 territories: American Samoa, Cook Islands, Fiji(+), French Polynesia, Guam, Kiribati(+), Nauru(+), New Caledonia, Niue, Norfolk, Papua-New Guinea(+), Pitcairn, Solomon Islands(+), Tokelau, Tonga(+), Trust Territory of the Pacific Islands, Tuvalu(+), Vanuatu(+), Wallis and Futuna, and Western Samoa(+). Those indicated (+) are independent nations.

The land area of these territories, with the exception of Papua-New Guinea, is small, and the nations are scattered across a vast ocean expanse from the Tropic of Cancer in the north to the Tropic of Capricorn in the south, and between longitudes 130°W and 130°E. Statistics for population and land area, by territory, are given in Table 1.

Background

The South Pacific region, although it has a few larger continent-like island nations, such as Papua-New Guinea, Fiji, and the Solomon Is-

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Table 1. Land area and population (at latest census) for territories served by the South Pacific Commission.

Territory	Land area (km^2)	Population	Census year
American Samoa	197	29 190	1974
Cook Islands	240	18 127	1976
Fiji	18 234	588 068	1976
French Polynesia	4 000	133 828	1977
Guam	544	84 996	1970
Kiribati	719	56 452	1978
Nauru	226	6 966	1977
New Caledonia	18 653	133 233	1976
Niue	259	3 578	1979
Norfolk	34.5	1 683	1971
Papua-New Guinea	462 243	2 489 935	1971
Pitcaim	4.5	74	1976
Solomon Islands	28 530	196 823	1976
Tokelau	10	1 575	1976
Tonga	699	90 085	1976
Trust Territory of the Pacific Islands	1833	115 251	1973
Tuvalu	26	7 357	1979
Vanuatu	14 700	112 596	1979
Wallis and Futuna	125	9 192	1976
Western Samoa	2 952	151 983	1976
Total	544 229	4 230 992	

lands, comprises in the main some of the world's most extreme examples of small, isolated, and neglected archipelagic states, such as French Polynesia, Kiribati, Northern Cook Islands, etc.

The importance of agriculture in the region and the problems in developing it have been highlighted in many reports and surveys, the most recent, comprehensive review being commissioned by the Asian Development Bank (Ward and Proctor 1980).

The economies of these countries, with the notable exception of phosphate-rich Nauru, find their main base in agriculture. More than 50% of the region's total export is agricultural, and of this, more than 25% is coconut-based. Perhaps more significant is the subsistence element of agriculture, for it is the preoccupation of the majority of the region's 4.25 million people who still live and work on atolls or in small, traditional villages located in rural areas.

Most Pacific countries are either politically independent or are in the process of becoming so. Most want to achieve economic independence but, with few exceptions, face many deep-seated problems of social and economic development. These include the relative scarcity of exploitable natural resources; vast distances from metropolitan countries and from each other; the small size and often widely scattered nature of the islands; low rates of capital formation; shortage of trained personnel, and difficulty in finding markets. High population growth rates in recent years have been invariably in excess of the rates of growth in production. The sheer weight of numbers has become a strain on available resources and any increase in production is immediately consumed, leaving little, if any, surplus for economic growth.

However, most Pacific countries are promoting social and economic development aimed at self-reliance, under formal development plans that have been in operation for many years.

There is a general recognition of the role that foreign aid can play in the form of capital grants, loans, technical assistance, equipment, and volunteers, and, clearly, without adequate foreign aid, most development projects would not leave the drawing board.

The increasing interest taken by the industrialized nations in the South Pacific region promises to lead to greatly accelerated aid flows. In addition to regular aid from Australia, New Zealand, and the European Economic Community, aid is now also coming from the USA, Japan, China, the USSR, and others, as well as from UN agencies, international financial institutions, and subregional and regional organizations.

For the region as a whole, and the larger countries in particular, regional cooperation offers scope for overcoming some of the problems unique to the area, and some agencies are already attempting to promote and develop regionalism. However, regional goals may conflict with national objectives: Pacific island economies are often competitive rather than complementary. The costs of regional cooperation can be very high because of the distances between island countries. More important, the total population, resources, and markets in the region are unevenly distributed and, in some cases, too small to provide significant economies of scale.

Constraints to Agriculture

What are some of the common regional constraints to agriculture?

1. Pacific countries are characteristically small, in both land area and population size. Only the larger islands of Papua-New Guinea, New Caledonia, Vanuatu, Solomon Islands, and Fiji appear to have significant agricultural potential and scope for diversification. Of the remaining island nations, the economies of the majority are based on agricultural production but in many cases the export of only one or two cash crops, such as copra or bananas. This results in marked economic specialization, with subsequent heavy dependence on foreign trade to supply products and services that are not available locally.
2. Situated thousands of kilometers from the markets for their products and from sources supplying their imports, Pacific countries find transport and communications both difficult and costly, and many small and medium-sized island groups cannot afford these facilities of the standard required for modern international trade and commerce. Consequently they are prevented from benefiting from many opportunities for the agricultural diversification that would otherwise arise fom international trade and investment.
3. The small population offers few opportunities for import substitution and economic diversification through food processing, for example. There are often shortages of skills, particularly specialist ones that only a large country can afford. Likewise, there are often not enough people to warrant investment in a full range of educational institutions (Fiji and Papua-New Guinea are exceptions). As a result, much training is carried out overseas.
4. The majority of Pacific nations are in a state of transition and have unique traditional, social, and political institutions that are at variance with modern concepts and standards. These institutions are often formidable barriers to economic change and, while modern agricultural development can be a disruptive process, it may well require changes in the traditional economic and social organization and, in many respects, a break from the past traditional ways.
5. While agriculture remains of major importance in the region, its role is increasingly that of providing employment rather than contributing to total output. For example, in Papua-New Guinea, agriculture occupies 85% of the labor force (only 30% in predominantly commercial agriculture) but contributes only 35% to total output.
6. Although most countries are dependent on agriculture, there has been a shift of people away from the rural to the urban areas, causing labor shortages in the former and unemployment and associated social problems in the latter. Some countries also experience net outward migration to such a degree, as for example, the Cook Islands, Tonga, Niue, and Western Samoa, that there is also a serious brain drain.
7. Despite its importance, agriculture as a profession has low status, with only a few educated citizens looking to farming as a desirable career. The majority see employment with the Public Service as being much higher on the social ladder. For these reasons, the major initiative in agricultural development comes from government rather than from the villagers or from private-sector investment.
8. In many countries of the region there is an apparent lack of motivation to produce food and fiber; guaranteed commodity prices and more constant cash returns, plus improved infrastructures, would provide the motivation for increasing production from the land.
9. Although traditional land-tenure systems vary from country to country, they all make the consolidation of land difficult and are a major constraint to cash crop development. Introduction of new technology and modern approaches to agriculture and land use will be necessarily slow if applied within the traditional sociocultural frameworks. Rationalization of land tenure (with minimum disruption of social structures) is vital if significant short-term increases in productivity from the land are to be achieved.
10. There are apparent conflicts between village production (subsistence) and production for local sale or processing and export (cash crops); i.e., the so-called mixed subsistence-cash-cropping system established by the colonial governments.

Ward and Proctor (1980) have shown that the mixed system has achieved little success as an income earner. Although Western consumerism has increasingly penetrated economies, changes in social (and economic) structures have not kept pace with this influx of material goods and mental transformations that have occurred over the last 100 years.

11. Although foreign aid inputs to agriculture for the region have been substantive, some Pacific leaders and planners are sceptical of the quality of the aid, which often fails to recognize the development priorities of recipients. Projects are often inadequately monitored and there are also problems with technically deficient or inexperienced advisers, both expatriate and local. There is considerable scope for improving the effectiveness of foreign aid to the region, and indications over the last 2 to 3 years show this is happening.
12. Manpower resources are not seen as constraints, but lack of skills in certain key areas of agriculture are. For example, there is only one indigenous pedologist in the region experienced in soil survey, soil correlation, and soil classification procedures, although there are about six others with some experience in soil surveying. Countries have relied on soil survey expertise from ORSTOM, DSIR, CSIRO, USDA, and LRD/DOS.
13. Longer term development planning is often inadequate, both at the national level and within Ministries of Agriculture. Also, too often there is excessive government involvement in agricultural production, with insufficient attention to product marketing and the development of infrastructures.
14. There has been an overall downturn in agricultural production in the last 10 to 15 years. All Polynesian countries have achieved self-government in this period and, with the natural aspiration of achieving self-reliance, have localized key staff positions and reassessed development priorities, often toward manufacturing at the expense of agriculture.

These are some of the major constraints facing agricultural development in the Pacific region served by the SPC. Many are unique to this area, while others apply to the humid tropics as a whole.

Potential for Improvement

Agrotechnology is available to the region and has been for some time. The geography of the region, combined with social, economic, and political factors, explains in part why this knowledge has not been utilized. What is desperately needed is a realistic mechanism through which agrotechnology can be effectively applied through the region within the socioeconomic framework described. An Oceania Benchmark Sites Network for Agrotechnology Transfer could provide the mechanism.

With the exception of the atolls and smaller islands where the land resource is limited, the majority of the larger Pacific countries (Fiji, Papua-New Guinea, Vanuatu, New Caledonia, Solomon Islands, and, to a lesser extent, Western Samoa, Tonga, and French Polynesia) have available large tracts of unused or underutilized land, much of which has significant potential for agriculture and forestry.

Finally, it can be said that the South Pacific as a region has only recently been "rediscovered" by some of the major industrial nations. To date, the area has been apolitical in a power-bloc global sense, with ties of the individual countries continuing primarily on an economic basis with past colonial governments. Regional political identity for the independent nations (with New Zealand and Australia) has arisen through FORUM (and its Secretariat, SPEC). French nuclear testing, Japan's proposals to dump nuclear wastes, marine economic zones, decolonization of Pacific French territories, etc., have been unifying issues addressed by the FORUM nations.

Overtures to some Pacific countries by the USSR over the last 2 to 3 years have been responsible for the rediscovery of the South Pacific, and aid money from Western nations is flowing in at an accelerated rate. Whether this trend in aid will continue, in view of world recession, massive unemployment in the industrialized nations, and donor nations' reassessment of aid contributions, is problematical. The region could see a neocolonialist element arising whereby donor countries assume a greater role in determining where and on what the aid dollar is to be spent.

Status of Soil Resource Information in the SPC Region

The status of soil resource information for the region, as at November 1981, was prepared based on the best available information at that time (Leslie 1982). A questionnaire was distributed to SPC member countries during 1982 to further update the information, and although response fell short of 100%, sufficient material is available to review the current status of: mapping (completed or in progress) for national soil coverage; manpower in soil and crop science; laboratory facilities; agricultural research stations; main crops being researched; and the major national economic crops for the countries of the region.

Soil Surveys for National Coverage

Table 2 lists by country both the completed soil surveys of national coverage and those in progress, with the soil classification systems employed for each.

Assuming that the soil surveys in progress will be completed by the end of 1985, 12 countries will have national soil maps available of scales < 1 ;100 000, with a number having more detailed (1:15 000-1:50 000) national soil maps. Of the remainder, Kiribati, Tavalu, and Tokelau are atolls; Nauru, the phosphate island; and Pitcairn, a very small precipitous volcanic island. Thus, New Caledonia, Papua-New Guinea and the Solomon Islands, the larger island nations, stand out as having only broad-scale national soil maps for land-use planning and agricultural development. However, New Caledonia, while having no national mapping program per se, has active detailed soil surveys in operation for the important agricultural regions in the country. The level of soil characterization for major soils in New Caledonia is high.

The Solomon Islands have available very comprehensive modern national land system maps at 1:250 000 scale, again with a high level of soil characterization for the major soils of the country.

Soil characterization of the major soils for Papua-New Guinea (Bleeker and Healy 1980) is impressive, but soil mapping coverage is inadequate for national planning and development purposes. Papua-New Guinea, the largest nation of the region, with significant soil resource potential, requires a national soil mapping program to identify priority areas for agricultural development and to make available soil maps on which to base sound land development planning without causing soil problems.

Of the 15 countries with national soil maps, 11 have employed Soil Taxonomy as the primary classification or have soil series correlated to it.

Regional Manpower in Soil and Agricultural Science

Table 3 lists by country the professional and technical manpower in the areas of soil survey, laboratory support, research on subsistence and cash cropping, and livestock and pasture.

For soil survey, soil correlation, and classification only one indigenous person (Fiji) has the experience and capability in the region, with most nations relying on expatriate (USDA, DSIR, CSIRO, ORSTOM) expertise to undertake all aspects of a soil survey. A number of indigenous officers have the experience to conduct the field phase of a soil survey, but in reality such surveys form a minor input to land-use capability mapping.

Several countries (Guam; Fiji, 3; French Polynesia; Papua-New Guinea, 2; Solomon Islands; and Western Samoa) have laboratories at which research and routine analytical work on soils can be carried out. The Cook Islands and Tonga also have smaller laboratories to perform a restricted number of analyses.

Regional manpower in laboratory support is adequate, but for some countries there is a heavy dependence on expatriate officers, and apparent lack of training programs for indigenous staff.

Laboratory Facilities

Table 4 lists the laboratories by country, the major instruments available, and the parameters that can be measured. It also identifies the institutions overseas where soil samples are sent for certain analyses that cannot be done locally. Many of the laboratories have old instruments and a modern replacement program for instruments is urgently required.

Regional Agricultural Research Stations

The region has 50 operational agricultural research stations administered by Ministries of Agriculture or their equivalents. It is not known whether there are operational stations in the Trust

Table 2. Summary of the current status of soil resource information for the South Pacific Region.

	Soil surveys for national coverage					
	Completed surveys			Surveys in progress/preparation		
Country (area)	Scale	Area	Classification	Scale	Area	Classification
American Samoa (197 km^2)	1:100 000 (Wright 1963)	70%	Local (after Cline 1957)	1:24 000	100%	Soil Taxonomy
Cook Islands (240 km^2)	1:15 000 (Leslie et al. 1974)	95%	New Zealand Genetic Soil Taxonomy FAO			
Fiji (18 234 km^2)	1:126 720 (Wright 1965)	98%	Local (after Cline 1957)	1:50 000	100%	Soil Taxonomy (correlation to FAO)
French Polynesia (4000 km^2)				1:100 000	60%	CPCS (correlation to Soil Taxonomy and FAO)
Guam (544 km^2)	1:25 000 (Park 1978)	100%	Soil Taxonomy	1:25 000	50%	Soil Taxonomy
Kiribati (719 km^2)						
Nauru (226 km^2)						
New Caledonia (18 653 km^2)	1:1 000 000 (Denis 1971)	100%	CPCS			
Niue (259 km^2)	1:63 360 (Wright 1965)	100%	None	1:50 000	100%	Soil Taxonomy (correlation to FAO)
Norfolk (34.5 km^2)	1:50 000 (Stephens and Hutton 1954)	100%	Australian			
Papua-New Guinea (462 243 km^2)	1:250 000	40% (plus 60% extra-polation)	Selected profiles FAO Soil Taxonomy			
Pitcairn (4.5 km^2)						
Solomon Islands (28 530 km^2)	1:250 000 (Hansell and Wall 1974-1979)	100% (land systems)	Soil Taxonomy			
Tokelau (10 km^2)						
Tonga (699 km^2)	1:25 000 (Orbell et al. 1975)	90%	New Zealand Genetic Soil Taxonomy			

Continued

Table 2. ***Continued,***

Country (area)	Soil surveys for national coverage					
	Completed surveys			Surveys in progress/preparation		
	Scale	Area	Classification	Scale	Area	Classification
Trust Territory of the Pacific Islands (1833 km^2)	1:25 000 (Orbell et al. 1975)	90%	New Zealand Genetic Soil Taxonomy			
Tuvalu (26 km^2)						
Vanuatu (14 700 km^2)	1:100 000 and 1:50 000 (Quantin 1976-1981)	100%	CPCS FAO Soil Taxonomy			
Wallis and Futuna (125 km^2)	1:100 000 (Tercinier 1960)	90%	Local (based on French)	1:20 000	100%	CPCS
Western Samoa (2952 km^2)	1:31 680 (Upolu) 1:100 000 (Savaii) (Wright 1963)	100%	Local (after Cline 1975)			

Territory of the Pacific Islands. In terms of land area, only Kiribati and Wallis and Futuna are territories that would be expected to have at least one experimental station, the remainder (Pitcairn, Norfolk, Tokelau, Nauru) being too small in population and land area to justify one.

Table 5 lists by country the research stations of the region, their land area, the major crops being researched, and the scale of the most detailed soil map for each station. Only 16 stations (for Fiji and Cook Islands; Nessadion, New Caledonia; Vaini, Tonga; Tenaru, Solomon Islands; and Alafua and Togitogiga, Western Samoa) have soil maps of a scale adequate for research purposes.

Coconuts, cocoa, coffee, bananas, fruit and nut trees, root crops and vegetables, with pasture research in the larger countries, are the major crops researched on stations in the region. The main economic crops for domestic consumption and export (not in order of importance) are given in Table 6 and these match well with those under research.

Some plant breeding/hybridization research is undertaken and some work on varietal evaluation, soil fertility, and pest and disease control.

Although there are gaps in the data for some countries, Table 7 gives an overview of the important soil families on stations where known, and elsewhere the regional or national representativeness of soils at stations.

Standardization of Soil Resource Information for the Region

To take advantage of and to participate in agrotechnology transfer, Papua-New Guinea, the Solomon Islands, and New Caledonia require a policy that will produce national soil maps of

Table 3: Manpower in soil and agricultural sciences in the South Pacific Region.[1]

Country	Basic soil survey	Soil survey correlation classification	Laboratory		Subsistence crops		Cash crops		Livestock/pasture	
			Research officers	Technicians	Research officers	Technicians	Research officers	Technicians	Research officers	Technicians
Cook Islands	1	–	–	1	–	–	4 (1 expatriates)	–	–	–
Fiji	4	1	5 (2 expatriates)	14	1	6	8 (2 expatriates)	25	3 (2 expatriates)	4
French Polynesia	1 (ORSTOM)	1 (ORSTOM)	1 (ORSTOM)	2 (ORSTOM)	–	–	1	7	–	–
Guam	–	1 (USDA)	2	2	–	–	1	?	–	–
Niue	–	–	–	–	–	–	3 (2 expatriates)	–	1	–
Papua-New Guinea	9 (6 expatriates)	–	3	?	35	?	35	?	6	?
Solomon Islands	2	–	–	3	–	–	2	4	–	–
Western Samoa	–	–	2 (expatriates)	2	6	?	7	?	–	–

1. No data for American Samoa, Kiribati, Nauru, New Caledonia, Tonga, Trust Territory of the Pacific Islands, Tuvalu, or Wallis and Futuna.

Table 4. Laboratory facilities, parameters measured, and analytical support for soil testing and analysis.

	Instruments											Parameters measured															
Country	AAS	Flame Photometer	Absorptiometer	Gas Chromograph	Infrared	U.V. visible spectrophotometer	Pressure plates	X-ray	Colorimeter	pH meter	Laboratory	pH	Carbon	Nitrogen	Phosphorus	Sulfur	CEC	Cations	Fe	Al	BS (%)	1/3 15-bar water	Particle size	Clay mineralogy	Trace elements	Bulk density	Laboratories overseas where samples are sent for analysis
Cook Islands										*	Totokoitu Research Station	*											*			*	Soil Bureau DSIR, New Zealand University of Hawaii, USA
Fiji	*	*	*	*	*	*	*	*	*	*	Fiji Sugar Corp, USP-INR; and Koronivia (MAF)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	Soil Bureau DSIR, New Zealand Massey University, New Zealand DPI, Australia
French Polynesia	*						*		*	*	ORSTOM	*	*	*	*		*	*	*		*	*	*			*	ORSTOM, Bondy, France
Niue																											MAF (Ruakura), New Zealand Soil Bureau, DSIR, New Zealand
Papua-New Guinea	*	*		*		*			*	*	Uni. Technology at Lae; and DPI Agric Chem.	*	*	*	*	*	*	*	*	*	*						Land resources (CSIRO) Australia Analytical Services Ltd. New Zealand
Solomon Islands	*	*				*				*	Dodo Creek	*	*	*	*	*	*	*			*						INR-USP, Fiji (Soil Taxonomy only)

Continued

Table 4. *Continued*

Country	Instruments: AAS	Flame Photometer	Absorptiometer	Gas Chromograph	Infrared	U.V. visible spectrophotometer	Pressure plates	X-ray	Colorimeter	pH meter	Laboratory	Parameters measured: pH	Carbon	Nitrogen	Phosphorus	Sulfur	CEC	Cations	Fe	Al	BS (%)	1/3 15-bar water	Particle size	Clay mineralogy	Trace elements	Bulk density	Laboratories overseas where samples are sent for analysis
Vanuatu										*																	ORSTOM, Noumea, New Caledonia
Western Samoa	*	*				*			*		USP-SOA, Alafua	*	*	*	*		*	*			*						Soil Bureau, DSIR, New Zealand University of Hawaii, USA (mineralogy only)
Guam	*			*		*				*	Agricultural Experiment Station	*	*	*	*	*	*	*	*		*					*	USDA, USA University of Hawaii, USA

* Have/can do;

Table 5. Agricultural research stations in the South Pacific Region.

Country/Station(s)	Area (ha)	Crops researched	Soil survey scale
American Samoa			
Taputimu	12	Not known	1: 24 000
Cook Islands			
Totokoitu	18	Citrus, bananas, pineapples, vegetables	1; 2 376
Fiji			
Wainigata	115	Cocoa, coconut, cardamom	1
Naduruloulou	97	Cocoa, macadamia, vanilla, cardamom	1 3 000
Legalega	45	Pulses, sorghum, peanuts, macadamia	1 3000
Tutu (proposed)	50	Cocoa, coffee, vegetables (all proposed)	1 3000
Sigatoka	325	Pasture, passionfruit, papaya, vegetables	1 5000
Nawaicoba	344	Pastures	1 3 000
Koronivia	168	Pastures, rice, root crops, cocoa	1 3000
Seaqaqa	100	Citrus, pasture, cardamom	1 3000
Waidradra	202	Citrus, cocoa, pasture	1 3000
Dobuilevu	50	Cocoa, root crops, pasture, rice	1 3000
			3000
Fr. Polynesia			
Papara	7	Crops not specified for the 3 stations. Research	1: 40 000
Taravao	2	emphasis: improvement of varieties (hybrids);	1: 40 000
	10	cropping systems; and fertility of coral sand soils for coconuts	1: 40 000
Guam			
Agric. Expt. Stn.	?	Vegetables, flowers, tree crops, livestock	1: 25 000
Kiribati	None	-	
Nauru	None	-	
New Caledonia			
Nessadion (Bourail)	200	not known	1: 5000
IFCC (Ponerihouen)	30	not known	?
Niue			
Vaipapahi	20	Passionfruit, citrus, coconuts, bananas	1
Vaiea	= 50	Pastures, root crops, coconuts	1 50 000
Airport Farm	10	Passionfruit, tomatoes, papaya	1: 50 000
			50 000
Norfolk	None	-	
Papua-New Guinea			
Lowland Agric. Expt. Stn.	720	Coconuts, cocoa, spices, food crops	1:250000
Bubia	260	Coconuts, rice, other food crops	1:250 000
Kuk	?	Tea, citrus	1:250 000
Aiyura	?	Coffee, subsistence crops	Semidetailed
Sepik	?	Rubber, cocoa, coffee, subsistence crops	1:250 000
Dami	?	Oil palm, cocoa, coconuts	Semidetailed
Laloki	?	Sweet potato, cassava, tomato, citrus	
Pitcairn	None		

Continued

Table 5. ***Continued.***

Country/Station(s)	Area (ha)	Crops researched	Soil survey scale
Solomon Islands			
Tenaru	20	Root crops, fruit and nut tree crops, vegetables	1: 2 500
Tenavatu	Dispersed plots	Pasture, cocoa, rice	1:250 000
Dodo Creek	25	Essentially research administrative	
		Plant pathology, entomology	1:250 000
Dala (closed)	100	Cocoa, root crops, spices, vegetables	1:250 000
Tokelau	None	-	
Tonga			
Vaini	30		1: 5 000
Vava'u	20		1: 25 000
Ha'apai	4	Coconuts	1: 25 000
Trust Territory of the Pacific Islands	Not known	-	
Tavalu			
Elisefou	?	Coconuts, pit vegetables	No map
Vanuatu			
Saraotou, Santo	400	Pasture, tree and vegetable crops	1: 15 000
Tagabe, Vate	?	Cocoa, coffee	1: 50 000
Wallis and Futuna	None		
Western Samoa			
Nafanua	7	Fruit trees, breadfruit, vegetables, ornamentals	1: 40 000
Togitogiga	400	Pasture, bananas, fruit trees	1: 10 000
Avele	15	Pasture (dairying)	1: 40 000
Asau	2500	Forestry, cattle, fruit trees	1: 20 000
Alafua	31	Root crops, pulses, bananas, passionfruit, citrus	1: 4 000
Lemafa	240	Beef cattle	1: 40 000
Vaiaata	Not known	Not known	1: 40 000
Moamoa	7	Intercropping coconuts, root crops	1: 40 000
Vailima	Not known	Forestry	1:100 000
Laloanea	40	Root crops, banana, fruit trees, passionfruit	1: 40 000
Nu'u	73	Vegetables, root crops, cocoa, banana, grains	1:100 000
Vaea	48	Quarantine	1: 40 000

scales < 1:1000 000; the atoll nations (Kiribati, Tuvalu, Tokelau), at a scale of < 1:25 000.

Countries should undertake detailed soil surveys of those research stations that do not have special surveys. For stations > 25 ha in area, mapping scales of 1:3000 would be recommended and for those < 25 ha a scale of 1:1500.

For these and other soil support needs, countries can approach the following organizations to undertake the work required, under bilateral aid programs:

USDA: American Samoa, Guam, Trust Territory of the Pacific Islands

DSIR : Cook Islands, Fiji, Niue, Tokelau, Tonga, Western Samoa

CSIRO: Vanuatu, New Caledonia, French Polynesia, Wallis and Futuna

EEC : Solomon Islands, Tavalu, Kiribati.

There seems to be a need for some independent evaluation (possibly by an organization such as ISNAR) of existing research stations and the possible termination of some, plus identification of new stations to meet national agricultural goals and objectives.

Regular biennial meetings should be held of regional soil scientists (USDA, DSIR, CSIRO,

Table 6. Major regional subsistence and cash crops in the South Pacific Region.

Subsistence crops	Cash crops
Coconut[1]	Cocoa
Taro[1]	Coffee
Yam	Ginger
Cassava[1]	Citrus
Sweet potato	Rice
Yagona	Pulses
	Pineapple
	Mangoes
	Guava
	Avocadoes
	Passionfruit
	Bananas
	Wide range of vegetables
	Papaya
	Oil palm

1. For all countries of the region.

ORSTOM, and Universities), possibly under the auspices of the SPC, to review progress, outline methodology for standardization in regional soil correlation/classification, and provide support to the agrotechnology transfer network within the region.

Governments of larger countries in the region must address themselves to the training needs in soil survey and laboratory soil science, to establish a national capability in these areas. The following countries require and can justify national expertise in soil survey plus laboratory supportive services: Fiji, French Polynesia, New Caledonia, Papua-New Guinea, Solomon Islands, Vanuatu, and Western Samoa.

Some form of regional evaluation of laboratory services is required, perhaps by the USDA Soil Management Support Services. Laboratory instruments in many instances are outdated (replacement parts are often unavailable) and should be replaced. In the process of re-equipping, it would be desirable to standardize

Table 7. Agricultural research stations in the South Pacific Region: classification and soil representativeness.

Country		Soil classification
American Samoa		
Taputimu (12 ha)		Not known
Cook Islands		
Totokoitu (18 ha)		Soils typical of southern Rarotonga Is. only but atypical for remaining islands of the Southern Cook Group.
	30%	Fluvaquentic Haplaquoli, very fine, kaolinitic, isohyperthermic
	20%	Typic Tropofluvent, sandy-skeletal, mixed, isohyperthermic
	15%	Typic Hapludoll, fine, mixed, isohyperthermic
	10%	Typic Tropudalf, fine, mixed, isohyperthermic
	10%	Typic Humitropept, fine, mixed, isohyperthermic
	10%	Cumulic Hapludoll, fine, mixed, isohyperthermic
Fiji		
Wainigata (115 ha)		Atypical soils of limited areal extent
	35%	Typic Tropudalf
	30%	Aquic Tropudalf
	20%	Aerie Tropaqualf
	5%	Typic Eutropept
	5%	Fluventic Eutropept
Naduruloulou (97 ha)		Typical soils for 'wet' zone
	35%	Typic Humitropept, fine, silty
	25%	Typic Humitropept, fine
	15%	Terric Tropofibrist
	10%	(Histic) Hydraquent

Continued

Table 7. *Continued*

Country		Soil classification
Fiji, contd.		
Legalega		Soils at family level of limited areal extent
(45 ha)	30%	Typic Eutrustox, fine loamy, mixed, isohyperthermic
	20%	Aquic Paleustult, fine, kaolinitic, isohyperthermic
	15%	Aquultic Haplustalf, fine, kaolinitic, isohyperthermic
	10%	Oxic Ustropept, coarse loamy, siliceous, isohyperthermic
	10%	Cumulic Haplaquoll, very fine, kaolinitic, isohyperthermic
Tutu		Very representative soils of the drier zone of Taveuni
(50 ha)	40%	Altic Hydrotropand, medial over medial-skeletal
	20%	Aerie Hydric Haplotropand. medial
	15%	Altic Hydrotropand, ashy-skeletal
	15%	Typic Hydrotropand, medial over medial-skeletal
	10%	Hydric Haplotropand, medial
Sigatoka		Both alluvial and hill soils important and representative of the
(325 ha)		'intermediate' zone
	20%	Lithic Haplustoll, fine loamy, montmorillonitic
	20%	Lithic Haplustoll, clayey over loamy-skeletal, montmorillonitic
	20%	Lithic Haplustoll, loamy, mixed,
	20%	Oxic Haplustalf, clayey, kaolinitic
	10%	Fluventic and Fluvaquentic Haplustolls, fine silty, kaolinitic
Nawaicoba		Typical soils of rolling hill country in the dry zone
(344 ha)	55%	Typic Ustropept, fine, montmorillonitic
	7%	Lithic Ustorthent, loamy-skeletal, montmorillonitic
	15%	Vertic Ustropept, fine, montmorillonitic
	7%	Ustoxic Tropohumult, clayey, kaolinitic
	10%	Udic Haplustalf, fine, montmorillonitic
Koronivia		Alluvial soils representative for 'wet' zone
(168 ha)		Hill soils of limited areal extent
	20%	Aerie Tropaquept, fine, kaolinitic
	15%	Humoxic Tropohumult, fine silty, kaolinitic
	15%	Typic Eutropept, fine silty, mixed
	15%	Fluventic Eutropept, fine silty, kaolinitic
	15%	Fluvaquentic Tropofibrist, dysic
Seaqaqa		Very representative soils of the dry' zone
(100 ha)	35%	Typic Acrustox, very fine, oxidic, isohyperthermic
	35%	Oxic Paleustult, very fine, oxidic, isohyperthermic
	15%	Typic Paleustult, very fine, oxidic, isohyperthermic
	5%	Typic Umbriorthox, fine, oxidic, isohyperthermic
	5%	Typic Haplustox, fine, oxidic, isohyperthermic
Waidradra		Typical of 'wet' zone hill country
(207 ha)	40%	Oxic Humitropept, fine, kaolinitic
	40%	Typic Humitropept, fine, kaolinitic
	5%	Oxic Dystropept, coarse loamy, mixed
	5%	Oxic Humitropept, coarse loamy, oxidic
Dobuilevu		Most representative soils of the 'intermediate' zone
(50 ha)	35%	Fluventic Eutropept, loamy
	20%	Ultic Tropudalf
	20%	Lithic Hapludoll
	10%	Typic Tropudalf

Continued

Table 7. *Continued.*

Country		Soil calssification
French Polynesia		
Papara		Not known
Taravao		Not known
Opunohu		Not known
Guam		
Agricultural Experiment Station		Lithic Ustropept (comprises 35% of the land area of Guam)
New Caledonia		
Nessadiou		Not known
IFCC (Ponerihoueu)		Not known
Niue		
Vaipapahi		Representative soils
(20 ha)	60%	Typic Haplustoll, clayey over sandy-skeletal, crandillitic
	20%	Udic Haplustoll, clayey, crandillitic
	20%	Oxic Haplustoll, clayey over sandy-skeletal, oxidic
Vaiea		Representative soils
(= 50 ha)	65%	Oxic Ustropept, clayey, gibbsitic
	35%	Typic Ustipsamment, clayey over fragmental, oxidic
Airport Farm	100%	Typic Ustipsamment, clayey over sandy-skeletal, oxidic
Papua-New Guinea		
Lowland Agricultural Experiment Station		Representative of recent volcanic ash soils of New Britain and Northern Province
Bubia		Not known
Kuk		Ash and peat soils found in large areas of the Highlands
Aiyura		Not known
Sepik		Not known
Dami		Not known
Laloki		Representative soils of the 'dry' coastal zone
Solomon Islands		
Tenaru (20 ha)		
Tenavatu (plots)		
Dodo Creek (25 ha)		
Dalo (100 ha)		
Tonga		
Vaini (30 ha)		
Vava'u (20 ha)		
Ha'apai (4 ha)		
Tavalu		
Elisefou		Not known

Continued

Table 7. *Continued*

Country	Soil classification
Vanuatu	
Saraotou, Sento	Very representative of coralline soils and the 'clayey' plateau soils
Tagabe, Vate	Not known
Western Samoa	
12 Western Samoan stations reflect the national soil pattern of:	Lithic Dystropepts Typic Dystropepts Typic Hydrandepts Lithic Hydrandepts Typic Humitropepts Lithic Humitropepts

instruments on a regional basis, as well as to standardize laboratory methods. Centralized regional laboratory servicing for the smaller nations should also be considered.

Considerable crop data exist on fertility, and management within the region, but there is no mechanism available for systematic collation, synthesis, and dissemination. In this regard the International Service for National Agricultural Research (ISNAR) could review agricultural research on a regional, as well as on a national, basis (as recently done for Fiji) so as to minimize duplication, ensure sharing of information, and help establish areas of specialization in agriculture.

As for crop data, there is need for systematic climatological recording within the region—cooperation in preparation of water balances, for example, and testing of the soil moisture and temperature regimes prescribed by Soil Taxonomy.

An Oceania Benchmark Sites Network for Agrotechnology Transfer (OBSNAT)

In 1976, the South Pacific Commission (SPC) arranged the Regional Technical Meeting on Soil Science and Land Use in Suva, Fiji. Several of the recommendations formulated there, more than 6 years ago, relate to the present OBSNAT proposal and are summarized here.

- Detailed (soil) surveys (scale 1:5000) should be conducted for all agricultural research stations in the region.
- Governments should review their programs of basic resource surveys to provide effective backup for soil and related land-use surveys.
- An active program of characterization, classification, and correlation should be established to give complete coverage of research stations and imprortant agricultural areas within 3 years.
- Areas with soils covered by the Benchmark Soils Project should consider participating in the project to draw on available knowledge of these soils. The concept of a regional benchmark soils project on soils important to the region, using crops important to the region, should be accepted as a basis for a follow-up soils and land-use program.
- A system should be developed to ensure that basic resource data collected in an uncoordinated manner are effectively used in crop production terms for the socioeconomic benefit of the country concerned.

These recommendations were not acted upon for various reasons. However, the 1976 conference did bring together for the first time soil scientists and institutions working in the region and since then there has been increasing contact and some collaborative work. The Regional Forum on Soil Taxonomy held in Suva in 1981 demonstrated the significant new soil work completed or in progress since 1976 and reaffirmed much of the thinkng embodied in the 1976 SPC Report. Based on similar programs in operation, and the international technical support available, an OBSNAT proposal is seen as being technically feasible. It would also be socially desirable and environmentally sound, with the potential to rapidly increase agricultural productivity. OBSNAT has yet to be tested for regional political acceptability, and the regional administrative umbrella under which it should operate is yet be to determined. The SPC would seem to be the most appropriate body.

Goal of an OBSNAT

The goal of such a program would be to render the countries of the Pacific region self-sufficient in the production of food and fiber and eventually to have surpluses for export.

Broad objectives of an OBSNAT would be: (a) To develop increased agricultural research efficiency within the region, (b) To share resources and knowledge and avoid duplication of effort in agricultural research, (c) To provide a sound scientific basis (benchmark site network) on which agrotechnology from outside the region can be transferred in, field-evaluated on research stations, and disseminated both within and between nations of the Pacific region.

National Potential for OBSNAT Participation

Because the range of soil families varies from country to country, many countries will not have all the soil orders that are regionally important; thus, the larger countries will have the greatest level of participation in an OBSNAT project.

An important prerequisite would be to determine, among other matters, which soil families should be studied. Appendix 1 lists the important great groups and soil families (where nationally determined) for Cook Islands, Fiji, Guam, Niue, Solomon Islands, and Tonga. Papua-New Guinea, Vanuatu (with more Andepts), and New Caledonia (with more Oxisols) are considered to have a classification pattern similar to that given for Solomon Islands and Fiji, while the predominantly atoll nations will comprise Psamments.

Specific Recommendations for OBSNAT

1. That a network of benchmark sites be established within the region served by the SPC to understand the basic relationships between characteristics of the land (soil, climate, etc.) and crop requirements for optimum growth and to facilitate agrotechnology transfer.
2. That initially the network comprise sites located on existing agricultural research stations, and that the soils selected for trials reflect the major soil families for countries and those occurring in the important agroecological zones of the region.
3. That the establishment of the network be undertaken in close association with those institutions/agencies that have the expertise in agrotechnology transfer (IBSNAT, BSP) based on Soil Taxonomy, with the funding organizations with regional involvement in agricultural development (Asian Development Bank, World Bank, Economic and Social Council for Asia and the Pacific) and under the auspices of a regional body, such as SPC, which would administer the project.
4. That the research undertaken be on a wide diversity of important soils but under well-defined conditions, and focus primarily on determining
   a. Simple production functions relating crop yield to single soil characteristics, particularly soil moisture.
   b. Medium-term effects of sustained crop production; for example, changes in soil characteristics, rates of erosion over the next 10 to 20 years under various possible or actual levels of management.
5. That the research design and methodology include: full characterization of the environmental and agroecological conditions at each benchmark site, including detailed soil survey; physical, chemical, and mineralogical properties; soil properties, soil classification in all major taxonomic systems (FAO, French, Soil Taxonomy); and continuous monitoring of weather. They should also include:
   - Biometric analysis of the results of relevant research previously conducted at the benchmark sites.
   - Determination, for a wide range of crops (current and new crops to the region), of plant requirements by way of experiments designed specifically for this purpose. Soil use at three levels of management is recommended, as indicated in Chapter 11 of the new Soil Survey Manual (in press). The middle level should be variable from place to place, related to current economic optima.
   - Use of existing checklist (based on BSP) of parameters to be measured for soil, plants,

and climate; and standardization of methods for their determination.

- Determination of the most appropriate means of transfer from site to site within the network and from the network to national soil surveys. The possibilities of transfer within mapping units of existing large-scale soil maps from the region should not be overlooked. Vertical transfer within national systems is of primary importance to help make these surveys valid and useful.
- Modeling and interpretation of relationships between soil characteristics, soil taxa, land qualities, and crop requirements and performance.
- Establishment of linkages for relevant soil families from OBSNAT to existing international networks.
- Utilization of existing computerized storage/retrieval systems for modeling and synthesis of network data.

6. That an educative/training component to OBSNAT be included such that the region quickly develops a capability to maintain research efficiency of the standard OBSNAT will demand.
7. That OBSNAT be counseled by an advisory board of international, regional, and interdisciplinary composition.

Suggestions for OBSNAT Implementation

The South Pacific Commission regional Directors of Agriculture meeting is scheduled for Noumea, New Caledonia, November 1983. They are the appropriate body to which the initial OBSNAT proposal paper be presented, for the reason that SPC is really the only regional umbrella in existence.

The South Pacific Bureau for Economic Cooperation (SPEC), the other regional institution, is more of a political/economic planning organization that embraces the independent nations (Cook Islands, Fiji, Niue, Papua-New Guinea, Kiribati, Tavalu, Western Samoa, Solomon Islands, Tonga, and Vanuatu) of the Pacific region with New Zealand and Australia. Thus, the American and French territories with the SPC area would be excluded were SPEC to be the umbrella for OBSNAT.

On the assumption that funding for OBSNAT will be forthcoming (SPC would not be asked to provide funds), a technical proposal paper explaining OBSNAT and the regional implications needs to be prepared for the SPC November meeting. It is vital that an IBSNAT representative be in attendance to formally present the paper and be available to answer questions.

The support of Directors of Agriculture from Cook Islands, Fiji, Niue, Western Samoa, Tonga, and New Zealand for OBSNAT is almost certainly guaranteed. Lobbying in other nations is necessary and the support of the USDA, DSIR, ORSTOM, and CSIRO in this regard must be sought.

Given the approval for OBSNAT by regional Directors of Agriculture, the proposal would then be forwarded to the next full SPC meeting at which regional political acceptance would be sought and a request that OBSNAT be included in the SPC agricultural administration and budget. Thus, the SPC would have the administrative responsibility for implementation of OBSNAT.

The next stage would be a request to IBSNAT/USAID to provide an initial planning grant of U.S. $50 000 to undertake a pre-feasibility study for OBSNAT. An officer(s) would be required to visit agricultural research stations in the region, discuss proposals with Ministers of Agriculture in the respective countries, and prepare a detailed project outline (forward work plan, budget, personnel, etc.). This phase is vital for obtaining future cooperation by countries for OBSNAT.

Concurrent with the pre-feasibility study, aid-donor countries (New Zealand, USA, Australia, France, EEC) with their respective institutions (DSIR, USDA, CSIRO, and ORSTOM) should be approached to undertake (by way of existing bilateral programs) detailed soil surveys for research stations, and carry out discussions, where required for longer term national soil surveys.

On completion of the OBSNAT pre-feasibility report, an advisory counseling group should be appointed to consider the OBSNAT report before presentation to SPC. The counseling group would be the body to arrange funding for OBSNAT. With the assurance of financial support and regional cooperation, SPC would logically accept responsibility for implementation of OBSNAT, which would be the vital regional collaboration of IBSNAT in the South Pacific.

Soils for Consideration in a Regional Network

Most countries in the region have tended to utilize fully their more fertile soils, and soils of the alluvial systems and soils on the more gently sloping land in hill country are under crops or pasture. Population pressures are forcing new developments onto less fertile land with problem soils, and in most cases national research is not designed to solve these soil problems. Thus, a significant number of developments are failing or crop yields are well below expectations. These problem soils are in the main various great groups of the Ultisol and Oxisol orders, specifically: Plinthohumults; Palehumults; Tropohumults; Paleudults; Eutrustox; Haplustox; Haplorthox. It is the soils of these great groups that would be the basis of regional and international site networks for agrotechnology transfer.

Other soils that are regionally important, though having fewer soil problems, and would justify involvement with networks are Tropudalfs, Haplustalfs, and Paleustalfs of the Alfisol order.

American Samoa, Cook Islands, Fiji, French Polynesia, Guam, New Caledonia, Papua-New Guinea, Solomon Islands, Vanuatu, Wallis and Futuna, and Western Samoa are countries that could all participate in networks of either Oxisols, Ultisols, or Alfisols.

From soil surveys in Fiji it is becoming apparent that lithic and entic subgroups of Mollisols in the ustic SMR are extensive, and this is likely to be the case for parts of New Caledonia, Solomon Islands, and Papua-New Guinea.

Should a regional network be considered, Ustipsamments and Tropopsamments are two important great groups of Entisols, one or the other of which all countries of the region have. Although not extensive in total area, they are very important soils in the atoll nations.

Andepts are not extensive in the region but they are important soils with significant potential for development. Papua-New Guinea, Solomon Islands, Vanuatu, and Fiji are countries that could participate in an Andept network.

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Appendix 1. Important soils of the South Pacific Region.

Cook Island—families (isohyperthermic)

Widespread (>10% total area)
- Typic Tropopsamment, carbonatic
- Lithic Rendoll, sandy-skeletal, carbonatic
- Typic Eutropept, clayey-skeletal, montmorillonitic

Common (5-10% total area)
- Oxic Tropudalf, very fine, kaolinitic
- Typic Plinthohumult, clayey, kaolinitic
- Orthoxic Palehumult, clayey, oxidic
- Humoxic Tropohumult, clayey, kaolinitic

Local (<5% total area)
- Typic Hapludoll, fine, mixed
- Typic Tropudalf, fine, mixed
- Cumulic Hapludoll, fine, mixed
- Orthoxic Palehumult, clayey, kaolinitic
- Fluventic Eutropept, very fine, mixed

Fiji—great groups

Widespread (>10% total area)
- Eutropepts
- Hurnitropepts
- Ustropepts
- Haplustolls
- Haplustalfs
- Tropohumults

Common (5-10% total area)
- Hapludolls
- Tropudalfs
- Dystropepts
- Eutrustox
- Haplustox

Local (<5% total area)
- Tropaquepts
- Tropofibrists
- Tropofluvents
- Ustipsamments
- Tropopsamments
- Sulfaquepts
- Argiudolls
- Haplohumox
- Paleustults
- Paleustalfs
- Ustorthents
- Acrustox
- Rhodustults
- Vitrandepts
- Eutrandepts
- Dystrandepts

Guam—families (isohyperthermic)

Widespread (>10% total area)
- Typic Ustropept, very fine, kaolinitic (19.75%)
- Lithic Ustropept, fine, gibbsitic (37.78%)
- Tropeptic Eutrustox, very fine, kaolinitic (10.31%)

Common (5-10% total area)
- Lithic Vertic Ustropept, very fine, montmorillonitic (9.2%)

Continued

Guam, *Contd,*

Local (<5% total area)
- Typic Ustipsamment, carbonatic (1.79%)
- Udic Pellustert, clayey, montmorillonitic, nor -acid (1.70%)
- Aquic Dystropepts, very fine, mixed (1.45%)
- Entic Chromustert, fine, montmorillonitic (1.75%)
- Oxic Ustropept, very fine, kaolinitic (1.30%)

Niue—families (isohyperthermic)

Widespread (>10% total area)
- Oxic Ustropept, clayey, oxidic
- Oxic Ustropept, clayey, gibbsitic
- Typic Ustipsamment, clayey over sandy-skeletal, oxidic
- Oxic Haplustoll, clayey over sandy-skeletal, oxidic

Common (5-10% total area)
- Typic Haplustoll, clayey over sandy-skeletal (crandillitic)
- Oxic Ustropept, clayey over sandy-skeletal, oxidic
- Udic Haplustoll, clayey (crandillitic)

Local (<5% total area)
- Lithic Oxic Ustropept, clayey, gibbsitic
- Typic Ustipsamment, clayey over fragmental, oxidic

Solomon Islands—Great groups

Widespread (>10%> total area)
- Tropudalfs
- Dystropepts
- Eutropepts
- Haplorthox
- Tropohumults
- Palehumults

Common (5-10% total area)
- Humitropepts
- Eutrorthox
- Tropudults
- Paleudults

Local (<5% total area)
- Plinthaqualfs
- Haplustalfs
- Paleustalfs
- Sulfaquents
- Tropaquents
- Tropofluvents
- Troporthents
- Tropopsamments
- Tropofolists
- Sulfihemists
- Tropohemists
- Hydrandepts
- Vitrandepts
- Ustropepts
- Rendolls
- Argiudolls
- Paleudolls
- Hapludolls
- Haplustolls
- Haplohumox
- Acrorthox
- Haplustox

The Prospects for Philippines CoHaboration with IBSNAT

C.R. Escano*

Abstract

The paper touches on the present state of Philippine agriculture and on the problems basic to the attainment of the desired agricultural development in the country. Emphasis is on the essential task of increasing food production per unit area, quantified in terms of higher farm output and income as well as optimum utilization of available resources. The collaboration with IBSNA T is viewed as one vital approach that would promote the rational use of available resources, particularly soil and land resources, for production of food and fiber, not only for local consumption, but also for export.

The country's proposed collaboration with IBSNAT is justified by considering relevant aspects and priorities of the national agricultural research and development programs. The mandate and activities of the Philippine Council for Agriculture and Resources Research and Development (PCARRD), the agency that administers the national research system on agriculture, are reviewed and discussed to emphasize the strong capabilities that our system has to make the proposed collaboration a truly successful one.

Finally, some past and proposed activities that could be directly related to what IBSNAT wants to achieve are presented and discussed to show the deep commitment of resources being offered by the Philippines to the proposed collaboration.

Agriculture is expected to remain the Philippines' economic lifeblood for many years to come and its continued development is a prerequisite to the nation's economic growth and well-being. To be economically stable, the country must come to grips with key elements of the agricultural problem. While it is desirable also to consider the problems of industry for a well-rounded economic growth, it is essential to treat the task of increasing food production as the primary challenge and to put into practice approaches such as the IBSNAT approach to foster agricultural development.

Increased productivity—quantified in terms of higher farm output and income as well as optimum utilization of available resources—should be the chief goal of such development.

The Philippines is endowed with resources that offer untapped potential for higher production per unit area; these therefore should be appropriately exploited if the nation is to strike a balance between production and consumption. It has been accepted, for instance, that the basic resources in the development of Philippine agriculture are the soil and land resources that are farmed and the farmers who till the soil. On these depend the production of food and fiber not only for local consumption, but also for export. However, the pressure to produce more from this finite resource (30 million ha) grows proportionately

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with the rapid increase in population, the increasing cost of inputs, and the low or diminishing productivity of the soil due to improper management.

Research promotion and support are central to this continuing activity of providing for basic human needs and building up reserves for export and for future use. At the very core of all development efforts is research—its capability to be useful, timely, and relevant, as a tool to fashion utilizable products and improved technology, to predict recurrent events in the field and to formulate a basis for making decisions and policies.

The Mandate of the PCARRD

In the Philippines, national coordination and planning of agriculture and resources research is a major task of the Philippine Council for Agriculture and Resources Research and Development (PCARRD). This agency was organized in recognition of the fact that to streamline the national research system, a central authority was needed to coordinate and manage all available research manpower, facilities and funds, and program resources to: (1) promote land and labor productivity; (2) increase the farmer's income and improve distribution of benefits; (3) further diversify Philippine agriculture; and (4) ultimately facilitate the country's development and social justice in the tradition of sharing the fruits of science and technology.

Specifically, the PCARRD is entrusted with the following tasks:

1. Define goals, purposes, and scope of research necessary to support progressive development in agriculture, forestry, fisheries, and mining for the nation on a continuing basis.
2. Using the basic guidelines of relevance, excellence, and cooperation, develop the national agriculture and resources research program, based on a multidisciplinary, interagency, and systems approach, for the various component commodities.
3. Establish a system of priorities for agriculture, forestry, fisheries, and mining research, and devise mechanisms for updating these priorities.
4. Develop and implement a fund-generating strategy supporting agriculture and resources research.
5. Program the allocation of all government revenues earmarked for agriculture and resources research to implement a dynamic national research program.
6. Assess the progress of and update the national agriculture and resources research program.
7. Establish, support, and manage a national network of centers for the various research programs in crops, livestock, forestry, fisheries, farm resources and systems, and mineral resources, and also socioeconomic research related to agriculture and natural resources.
8. Establish a repository for research information in agriculture, forestry, fisheries, and mining.
9. Develop a mechanism for full communication among workers in research, extension, and national development.
10. Provide for a systematic program of agriculture and resources research, manpower development, and improvement.
11. Provide for appropriate incentives to encourage topnotch researchers.
12. Enter into agreements or relationships with other similar institutions or organizations, both national and international, in the furtherance of the first 11 purposes.

In relation to these tasks; the PCARRD has the authority to call on any department, bureau, office, state university or college, commodity institute, or any other agency of the government for assistance in the form of personnel, facilities, and other resources as the need arises. The PCARRD also has the authority and responsibility, as part of the scope of its operations, over all government-supported and -funded research on mineral resources except petroleum and other mineral oils.

In order to perform effectively its designated tasks, the PCARRD exercises two vital powers: (1) the power to review all research proposals in agriculture and natural resources; and (2) the power to recommend research proposals to the office of Budget and Management (OBM) for funding.

The National Research Program

The national research program formulated by the PCARRD becomes the guideline for all research activities in agriculture and natural resources in the country. It defines the goals, priorities, and scope of national research, ensuring support to government development plans.

The research program directs and coordinates all individual activities in the country to make sure that gaps between knowledge and application are bridged, that resources for research are wisely used, and that research results are effectively harnessed for national development.

Relevance, priority, and cooperation are the three main criteria in preparing the national research program in relation to commodity/ industry benchmark information, problem areas, identified commodity/industry objectives and priorities, and national development goals.

The PCARRD's overriding concern is to keep the national research program dynamic and receptive to current and anticipated needs. To keep track of this, periodic assessments and consultations are conducted.

Demands for the dynamic development of the various sectors of the Philippine economy require the PCARRD to be sensitive and responsive to change. Thus, it has to check constantly on the trends and problems in the various commodities/ industries, and accordingly adjust its operations to respond effectively to new developments.

The National Network of Research Centers and Stations

This is the core of the national research system—a solid base of research centers of excellence, strategically located throughout the country. Equipped to grapple with identified research problems, the national research network translates into action the national research program. It is manned by researchers working on national, regional, and location-specific research activities. It also assists the core staff in implementing programs from technology generation, verification, and packaging to technology dissemination and utilization.

Today, the network consists of 4 multi-commodity national research centers, 7 single-commodity centers, 8 regional research centers, and 130 cooperating stations.

To further strengthen the network, ten research consortia were organized and are now operational. Under the scheme, two or more research centers and stations within a defined service area of a region form a scientific community to pool efforts in research and outreach activities. Consortium members share and maximize the use of scarce resources.

Relationships and Linkages

The PCARRD is fully aware that research efforts in agriculture and natural resources must relate and contribute to the achievement of national goals. Thus, relationships and linkages are forged with other agencies and institutions that also aim at national development.

Development Planning

The PCARRD uses the National Development Plan prepared by the National Economic Development Authority as a main frame of reference in program planning at the national and regional levels.

Educational Institutions

Collaboration in research both benefits and enhances the effectiveness of the PCARRD and the agricultural educational institutions. A memorandum of agreement, signed on 7 September 1973, between the PCARRD and the Association of Colleges of Agriculture in the Philippines (ACAP), fosters such research cooperation.

Likewise, an agreement reached between the PCARRD and the Educational Development Projects Implementing Task Force (EDPITAF) provides for close coordination between the two entities in the development of agricultural schools.

Ministries of Agriculture and Natural Resources

Basic cooperative relationships were established between the PCARRD and the Ministries of Agriculture and Natural Resources and their bureaus soon after the PCAR started operations. This move reflects the commitment of the three agencies to the optimum use of research resources.

National Science and Technology Authority (NSTA)

The PCARRD was attached to the then National Science Development Board for better coordination of the national scientific programs in the country, under which agriculture and natural resources research were subsumed.

With its reorganization, the NSDB, now the National Science and Technology Authority, has lined up for the PCARRD national thrusts in science and technology as related to agriculture and resources research and development.

Private Sector

Efforts are continuing at the PCARRD to enhance cooperative undertakings with the private sector through more frequent interactions/consultations, technical exchanges, and financial support. Collaborative projects with the private sector envision the creation of an agricultural and resources research foundation that will actively involve the private sector/industry in the identification of constraints and logistic support for the country's research capability. Working agreements with the Twin Rivers Research Center in Tagum, Davao del Norte; the ANSA Cattle and Crop Farms in South Cotabato; the Virginia Ranch in Zamboanga del Norte; and the Philippine Coconut Research and Development Foundation are a few of the PCARRD's attempts at such collaboration.

International, Regional, and National Research Organizations

New scientific and technological developments around the world make it imperative for national research systems to keep in close contact with other similar institutions in the Asian region and around the world.

Such linkages facilitate exchanges in research findings, methodology, germplasm materials, and more importantly, the transfer or borrowing of appropriate technology.

At present, the PCARRD maintains collaborative arrangements, linkages, or relationships with some 27 international research and funding institutions.

With the creation of the Planning Development Staff-International Projects Division (PDS-IPD) within the PCARRD Secretariat, it is envisioned that the PCARRD will continue to expand its international linkages to include as many international research cooperators and donors as possible—both public and private.

Past and Proposed Activities Related to IBSNAT

To develop our manpower capability in soil classification, and to make more meaningful interpretations of results from the cropping systems research done throughout the country, training courses and workshops on Soil Taxonomy were conducted in the Philippines by the University of Hawaii-PCARRD Benchmark Soils Project in 1978 and 1979. One output of this training was the classification of ten research centers/stations of the PCARRD, each representing a different agroenvironmental region. Visayas State College of Agriculture (VISCA) represents a relatively dry area (mean monthly rainfall 27 mm) compared with Central Mindanao University (CMU) (mean monthly rainfall 192 mm).

A summary of the reports submitted for at least six stations is shown in Table 1. It should be noted that each center or station is responsible for research and development on a particular commodity; for instance, PTRTC is the national center for tobacco, while VISCA is the national research center for abaca and root crops.

Visayas State College of Agriculture (VISCA)

The majority of the soils in this study area belong to the order of Inceptisols; a very small portion belongs to the Entisols. A major portion of the Inceptisols (200.67 ha)—the very fine, mixed, isohyperthermic Oxic Dystropepts located on the 18% slopes—is devoted to coconut and ipil-ipil *(Leucaena glauca).* The portions planted to root crops belong to different soil families: (1) fine loamy, mixed, isohyperthermic Typic Eutropepts and (2) fine, mixed, isohyperthermic Aquic Eutropepts.

Philippine Tobacco Research and Training Center (PTRTC)

There are three soil orders identified in the study area (773 ha). Vertisols are the dominant soils (about 40%) in this area. About 33% of the area belongs to the Inceptisols and about 18% to the Alfisols.

Tobacco is predominantly grown on fine, montmorillonitic, isohyperthermic' Vertic or Fluventic Ustropepts. Upland crops (rainfed rice, garlic, mungbean) are grown on (1) fine, montmorilloni-

Table 1. Classification of soils of the research centers in the Philippines.

Region	Research Center	Soil family	Subgroup	Order	Land use
1	PTRTC Batas Ilocos Norte 773 ha 15°01′ to 15°04.5′ N 120°31.5′ to 120°33.5′ E 124 mm mean monthly rain fall	Fine, montmorillonitic, isohyperthermic, 20–40% slope, slightly eroded	Typic Haplustalfs (138 ha)	Alfisols	Kakawatu, bamboo, ipil-ipil (*Leucaena glauca*)
		Fine, montmorillonitic, isohyperthermic, 1–2% slope	Fluventic Ustropepts (76 ha)	Inceptisols	Vegetables, legumes, rainfed rice (WS), tobacco (DS)
		Fine, montmorillonitic, isohyperthemic, 2–5% slope	Vertic Ustropepts (70 ha)	Inceptisols	
		Very fine, montmorillonitic, isohyperthermic, 1–2% slope	Typic Pellusterts (242 ha)	Vertisols	Rice, tobacco, garlic, cotton
		Very fine, montmorillonitic, ishohyperthermic, 0–1% slope	Udic Pellusterts (30 ha)	Vertisols	Rice (WS), garlic (DS)
		Very fine, montmorillonitic, isohyperthermic, 0–1% slope	Typic Chromusterts (39 ha)	Vertisols	
		Very fine, montmorillonitic, isohyperthermic, 0–1% slope	Vertic Ustropepts (34 ha)		Rainfed rice (WS) garlic, mung bean (DS)
		Very fine montmorillonitic, isohyperthermic, 1–2% slope	Vertic Ustropepts (74 ha)		
		Isohyperthermic, 2–5% slope	Typic Chromusterts-Fluventic Ustropepts complex (30 ha)		
		Isohyperthermic, 2–5% slope	Typic Pellusterts-Fluventic Ustropepts complex (30 ha)		
5	Bicol Agricultural Research Center (BARCC) CSAC, Pili, Camarines Sur	Fine, mixed isohyperthermic, 0–2% slope; 2–5% slope	Typic Argiudolls (47.84 ha); (10.72 ha)	Mollisols	Vegetables

Continued

Table 1. *Continued*

Region	Research Center	Soil family	Subgroup	Order	Land use
	1015 ha	Fine, mixed, isohyperthermic, 0–2% slope; 2–5% slope	Fluventic Hapludolls (20.16 ha); (10.56 ha)	Mollisols	Corn
	13°34′ N 123°18′ E	Very fine, mixed, isohyperthermic, 0–2%, 2–5% slope	Vertic Argiaquolls (292.88 ha); (64.51 ha)	Mollisols	Cassava, string beans, irrigated rice
	192.2 mm mean monthly rainfall 26.7°C mean annual temperature	Fine, nonacid, mixed isohyperthermic, 0–2%, 2–5% slope	Vertic Haplaquolls (41.36 ha); (1.12 ha)	Mollisols	Talahib, rice
		Very fine, mixed, isohyperthermic, 0–2% slope; 2–5% slope, 7 others	Typic Argiudolls (160.52 ha); (67.36 ha)	Mollisols	Groundnut, corn, sugarcane, coconut, sweet potato
8	Visayas State College of Agriculture (VISCA) Baybay, Leyte	Coarse silty, mixed, nonacid isohyperthermic, 0–2% slope	Typic Hydraquents (1.99 ha)	Entisols	Rice
	10°44′ N 124°47′ E	Fine silty, mixed, isohyperthermic, 0–2% slope	Lithic Tropaquepts (2.44 ha)	Inceptisols	Rice, patches of coconut
	27 mm mean monthly rainfall	Fine loamy, mixed, isohyperthermic, 0–1% slope	Typic Eutropepts (3.98 ha)	Inceptisols	Aroids, cassava
		Loamy skeletal over fragmental, mixed, isohyperthermic, 1–2% slope	Lithic Troporthents (6.90 ha)	Entisols	Coconut
		Fine loamy, mixed, isohyperthermic, 0–2% slope	Fluventic Eutropepts (18.44 ha)	Inceptisols	Diversified crops
		Fine, mixed, isohyperthermic, 1–2% slope	Aquic Eutropepts (20.44 ha)	Inceptisols	Aroids, lowland rice
		Very fine, mixed, isohyperthermic, 18% slope	Oxic Dystropepts (200.67 ha)	Inceptisols	Coconut, ipil-ipil
7	Marcos Corn Experiment Station, Bohol	Fine, mixed, isohyperthermic, 2–5% slope	Ultic Tropudalfs (407.08 ha)	Alfisols	Citrus, coconut, cassava, corn, mung bean, pasture, open grasslands

Continued

Table 1. *Continued*

Region	Research Center	Soil family	Subgroup	Order	Land use
10	Central Mindanao Univeristy Research Station (CMU), Musuan, Maramag, Bukidnon	Fine, clayey, mixed, isohyperthermic, 0–2% slope	Aeric Tropaquepts (23.04 ha)	Inceptisols	Paddy rice, corn, legumes, vegetables, sugarcane
	3079.83 ha 7°54′ N	Clayey, mixed, isohyperthermic, 2–5% slope	Aeric Tropaquepts (35.44 ha)	Inceptisols	Paddy rice, corn, legumes, vegetables, sugarcane
	125°05′ E Within vast plain of Pulagi River, southern Bukidnon	Very fine, mixed, isohyperthermic, slightly flooded, 0–2% slope	Typic Pelluderts (19.76 ha)	Vertisols	Paddy rice, sugarcane, legumes
	194 mm mean monthly rainfall	Very fine, mixed, isohyperthermic, 0–2% slope	Aquentic Chromuderts (155.92 ha)	Vertisols	Paddy rice, legumes
	26.03°C mean annual temperature	Very fine, mixed, isohyperthermic, 0–2% slope	Typic Pelluderts (145.44 ha)	Vertisols	Paddy rice, sugarcane, vegetables, corn
		Fine, mixed, isohyperthermic, 0–2% slope	Typic Eutropepts (56 ha)	Inceptisols	Sugarcane, corn, vegetables, paddy rice
		Mixed, isohyperthermic, 2–5% slope	Typic Eutropepts (69.04 ha)	Inceptisols	Sugarcane, corn vegetables, paddy rice
11	Davao Research Center, Bago-Oshiro, Davao City (Set on the footslopes of Mount Apo)	Fine, clayey, mixed, isohyperthermic, 0–5% slope	Typic Tropudalfs (99 ha)	Alfisols	Experimental coconut, cover-cropped with kudzu
	189 ha 07°05′ N 125°37′ E	Fine, clayey, mixed, isohyperthermic, 0–3% slope	Ultic Tropudalfs (5 ha)	Alfisols	Experimental coconut, cover-cropped with kudzu
	186.53 mm mean monthly rainfall	Very fine, mixed, isohyperthermic, 0–6% slope	Typic Paleudalfs (19 ha)	Alfisols	Experimental coconut, cover-cropped with kudzu
	22°C mean annual temperature	Very fine, mixed, isohyperthermic, 0–2% slope	Typic Paleudalfs (66 ha)	Alfisols	

tic, isohyperthermic Vertic Ustropepts, (2) very fine, montmorillonitic isohyperthermic Typic Pellusterts, and (3) very fine, montmorillonitic isohyperthermic Typic Chromusterts.

Central Mindanao University (CMU)

The total area covers about 3074.83 ha, of varying topography, vegetation, and soils. About 33% of the area is devoted to pasture; 20% to upland crops; 13% to irrigated rice; and the rest to other uses.

The soils are mainly Inceptisols and Vertisols, grown to paddy rice, corn, legumes, sugarcane, and vegetables. Vertisols occupy a vast majority of the area. Paddy rice is grown on different soil families of the Vertisols—(1) very fine, mixed, isohyperthermic Aquentic Chromuderts and (2) very fine, mixed, isohyperthermic Typic Pelluderts—as well as on Inceptisols—(1) fine, mixed, isohyperthermic Typic Eutropepts and (2) clayey, mixed isohyperthermic Aerie Tropaquepts. Corn is grown on the following soil families of the Inceptisols: (1) fine clayey, mixed, isohyperthermic Aeric Tropaquepts, and (2) fine, mixed, isohyperthermic Typic Eutropepts.

PCA-Davao Research Center

The area consists mainly of Alfisols grown to coconut. The three soil families of Alfisols are the following: (1) fine clayey, mixed, isohyperthermic Typic Tropudalfs, (2) fine clayey, mixed, isohyperthermic Ultic Tropudalfs, and (3) very fine, mixed, isohyperthermic Typic Paleudalfs.

Rainfall (monthly average 186.53 mm) and temperature (> 22°C) do not limit coconut production in this area.

Marcos Corn Experiment Station

The study area covered is about 600 ha, predominantly Alfisols (67%). The rest (33%) are Inceptisols. Corn is grown on the fine, mixed, isohyperthermic Ultic Tropudalfs, the single soil family of Alfisols identified so far. The same soil family is grown also to citrus, coconut, and mung bean. The single soil family of Inceptisols classified is the coarse, loamy, mixed, isohyperthermic Fluventic Dystropepts, grown to fruit trees, rice, and coconut.

Conclusion

There is no common soil family among research stations classified as yet. A particular crop is grown virtually on different soil families. On the other hand, different crops are also grown in one soil family. It appears that up to a certain limit imposed by the agroenvironment (soils, climatic), any crop can be suitably grown provided there is a good match between the crop requirements and the agroenvironment.

The ASSP II Program: An Overview

The ASSP II is a program on soil classification, using Soil Taxonomy for agrotechnology transfer. The growing concern about effective agrotechnology transfer has paved the way for a viable research program on soil classification; i.e., the use of Soil Taxonomy in classifying all research centers or stations in the country. In the Philippines, results of research on soil-basd technology could not be extrapolated to other areas or locations because of the lack of soil information on the experimental sites.

Too often interpretations of results are limited only to the site where research was conducted. Since Soil Taxonomy provides a grouping of soils on the basis of similarities in properties contained in each taxon, transfer of information on technology could be based on these similarities. However, because properties can vary within a certain limit even between soils of the same family, and because some factors affecting crop performance, such as weather or incidence of pests, etc., are not contained in detail in the taxonomic name, crop performance on two soils on the same family may naturally vary. In other words, the use of this soil classification requires interpreting the classification for managing the soil, improving productivity, etc., and agrotechnology would need to be tested to determine whether the properties contained in the taxa would be sufficient for such a transfer or whether additional information on the microclimate, incidence of pests, etc, is needed.

We have amassed a large amount of soil data that need to be interpreted for various uses and disseminated for various clienteles. The time now is ripe to develop and maintain a soil information system or a soil data bank that will serve as the repository of information on soils that will support cropping systems research in the country.

Program Components

Project 1 : Soil classification of different research centers/stations starting in 1983.

Project 2 : Agrotechnology transfer tests within and among soil families, starting in 1983.

Project 3 : Establishment of data base, information storage and retrieval system, starting in 1984.

Mechanics of Implementation

Maximum coordination and cooperation among agencies such as the PCARRD, the Benchmark Soils Project (BSP) the University of the Philippines at Los.Banos (UPLB), and other cooperating stations in the PCARRD network will be needed to put the program into action. While the mechanics of implementation are still being resolved, it is envisioned that the BSP will do the field work to survey and classify the soils and do the correlation. The UPLB will identify or design appropriate experiments at the particular sites or on particular soil families.

Agroenvironments of a Network of Soil Families and Agrotechnology Transfer in the Philippines

A.A. Briones*

Abstract

Agroenvironments that are linked directly to the production of economic crops refer to the soil environment and the weather, which are known to vary within short distances. Effective agrotechnology transfer is expected to be realized among similar agroenvironments. Stratification of these agroenvironments is one of the keys that can provide rational transfer of experience or technology from one location to another. In addition to stratification, the influence of the socioeconomic setting must be assessed to determine its role in profitability of production, particularly in the cultivation of maize, wheat, and quality upland rice.

Transfer of agrotechnology, which connotes all those practices and inputs that can guarantee profitable results of production on the farm, is a very complex process. Continuous adoption of the agrotechnology by farmers is understood to mean that the innovations have recognized and taken advantage of the favorable features of the agroenvironments, considering the socioeconomic setting that affects productivity either directly or indirectly.

These technical and socioeconomic sets of factors are not easily separable in dealing with individual or groups of farmers. Still, it is possible to distinguish the role each of these sets of factors plays in the production of economic crops, so that location-specific studies may be extended to larger areas or to more farmers. In the Philippines, at present, attention is being directed to corn, wheat, and to quality upland rice, considering first the agroenvironments favorable to the production of these cereals.

The gaps that persist between potential productivity, often realized under the controlled conditions of experiment stations, and the actual production on farmers' fields signify that, despite the research already undertaken, further studies must still be pursued. These should be designed to assess how and how much agroenvironments and socioeconomic factors affect production at the farm level.

Stratification of Agroenvironments

The question, then, is how we can consistently obtain farm-level production comparable to that obtained in research stations. The comparison is not realistic because the controlled, man-made environment of the experiment station cannot be duplicated anywhere else.

Agroenvironments directly linked to production are those related to soil differences and the weather. Stratification of soil environments has been successfully demonstrated by the Benchmark Soils Project of the Universities of Hawaii and Puerto Rico, specific to soils belonging to a certain family taxon. In addition, the first set of evidence that agrotechnology can be transferred across soil families has come from experiments by the University of the Philippines at Los Banos and the Philippine Tobacco Research and Training Center, which assumed on reasonable grounds that the weather was constant across the network of sites when the tobacco plants were growing.

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International Crops Research Institute for the Semi-Arid Tropics. 1984. Proceedings of the International Symposium on Minimum Data Sets for Agrotechnology Transfer, 21-26 March 1983, ICRISAT Center, India. Patancheru, A.P.502 324, India: ICRISAT.

Stratification was achieved using Soil Taxonomy, specifically that of the soil family category, which then implies that this level can be used to distinguish production potentialities of soils. Even so, such research efforts, while capable of demonstrating tranferability of agrotechnology, cannot as yet translate the results directly to farmers' fields.

The same care and attention must be given to the weather elements that clearly affect productivity and which can vary within short distances at any given time. In theory, such weather variations are believed implied when a soil is identified using Soil Taxonomy criteria, but this is not accurate in actual practice, when at the same site, weather elements even for one season of cropping remain essentially unpredictable.

In the tropical Philippines, agricultural productivity remains at the mercy of the weather. This refers not only to the well-known typhoons that visit the country with regular frequency every year, but also to droughts during the dry season when, paradoxically, solar radiation is most favorable to photosynthetic activity of plants.

The idea is that if it is not possible to modify the weather, then our objective must be to use it rationally if possible. By so doing, disasters may be avoided, and what are currently drawbacks may conceivably be used to advantage, particularly in the production of economic crops during the dry season, when typhoons are rare and solar radiation is at an optimum for growth and reproduction of plants.

Stratification of agroenvironments serves to organize the approach to production concerning soil areas and intervals of time in any given year that are favorable to production activities. Scientifically, such stratification or identification of factors provides a basis to establish cause-and-effect relations between environmental constraints and crop performance, so that management and cropping practices can be adjusted to obtain profitable crop performance.

It follows that an orderly identification of agroenvironments is essential to the delivery of appropriate practices to each location and for the discovery of new relations between soil manipulation and the immediate aerial environment and crop performance. Such identification could help reduce trial-and-error methods to a minimum. Agrotechnology transfer studies can bridge the gaps that exist between the location-specific results of experiments and the requirements of broad-based production recommendations. Such researches are attempts to provide the answer to as many farm problems as possible, obtained from as few sites as possible.

Data-base Requirement

Delineating agroenvironments will require an exhaustive determination of all soil properties that may allow a detailed identification of soils and the

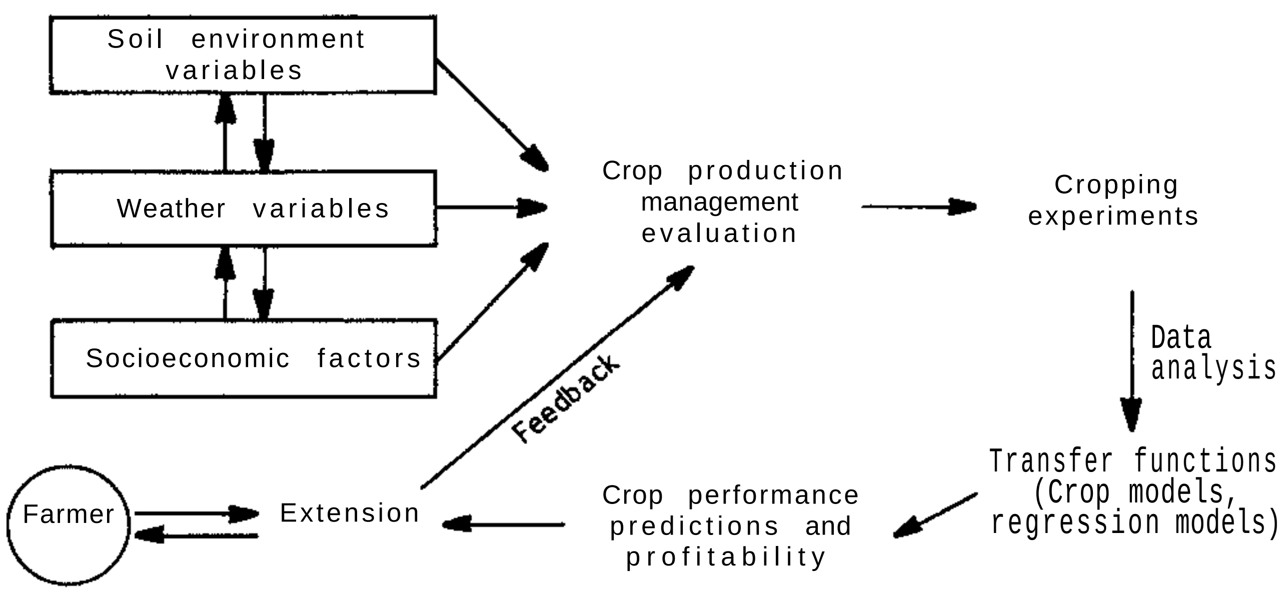

Figure 1. Generalized model for agrotechnology transfer.

determination of weather components. This includes the well-established roles of soil and air temperatures, solar radiation, wind velocity and direction, humidity, and rainfall.

To minimize adverse effects of inclement weather such as typhoons and prolonged dry spells, probability relationships should be established and tested across the network of soil families that are intended to be used in the network. Such sets of data will allow a determination of agroenvironmental conditions that can be stratified according to expected crop performance and the accompanying soil management needed. Crop production forecasts may thus be made to project export or import of food crops with greater accuracy and sophistication.

Generalized Model for Agrotechnology Transfer

To such agroenvironmental stratification, the socioeconomic factor must be added. To what extent does this factor influence or affect farm productivity? How sensitive is this productivity in relation to individual farms or groups of farms cultivating various kinds of crops? Stratification of the socioeconomic conditions appears to be indicated, such as the identification of the so-called homogeneous agricultural zones (HAZ). The parameters for such classification need to be assessed and their influence specifically determined insofar as production and profits are concerned. The generalized model for such studies can be approximated as in Figure 1.

Soil Capability Assessment Network (SCAN) Project of Pakistan

Aurangzeb Khan*

Abstract

Pakistan is primarily an agrarian country, with 75% of its 80.5 million population engaged in agriculture. To meet the needs of the population, which is growing at the rate of 3% per year, it is imperative to increase crop production per unit of land.

The Soil Capability Assessment Network (SCAN) Project was formulated in this context by the Pakistan Agricultural Research Council (PARC), to develop a procedure based on soil families for making recommendations to farmers on fertilizer use, soil management, and crop production.

Initially, it is planned to investigate the fertilizer response of selected soil families. Other aspects of soil, water, and crop management will be included subsequently to develop the appropriate package of agrotechnology based on soil families.

Field experiments to test crop response to various levels of nitrogen and phosphorus have been laid out for the current wheat crop on five soil families. Experimental design is the randomized complete block, with three replications in the irrigated and four in the rainfed area. Total number of plots per replicate is 16. Parameters kept constant are: quantity and quality of water, crop variety, time of sowing, insecticides/pesticides, and land preparation.

The indications available so far are encouraging. The effect of different fertilizer treatments on the growth of wheat is distinctly visible. Similarities within one soil family network, but contrast of crop growth between soil families, both under irrigated and rainfed cultivation, are showing up.

The Soil Capability Assessment Network (SCAN) Project was formulated by the Pakistan Agricultural Research Council (PARC) to test the hypothesis that soils belonging to one soil family should have nearly the same management requirements for agricultural production. Initially, we plan to investigate and compare fertilizer response of soils within the same family and between families. Other aspects of soil, water, and crop management will be included subsequently, to develop the most appropriate package of agrotechnology for each soil family.

The project was started in February 1982 at two locations, and will be progressively extended to other sites as additional funds and knowhow become available.

Project Objectives

1. To determine mineralogical (clay) composition of important soil series of Pakistan for their classification at soil family level.
2. To develop nitrogen and phosphorus yield response curves of the major crops at soil family level in various agroecological regions of the country.
3. To correlate soil tests and crop-yield response to fertilizers on various soil families.
4. To develop a procedure based on soil families for making recommedations to farmers on fertilizer use, soil management, and crop production.

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International Crops Research Institute for the Semi-Arid Tropics. 1984. Proceedings of the International Symposium on Minimum Data Sets for Agrotechnology Transfer, 21-26 March 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: ICRISAT.

5. To coordinate research work amongst various agencies engaged in soil survey, soil fertility, and crop-production research,

SCAN and the Benchmark Soils Project (BSP)

The idea of the Soil Capability Assessment Network and transfer of agrotechnology based on soil family was taken from the Benchmark Soils Project, established in Hawaii, USA, in 1974. Thus, the SCAN Project is similar to the BSP, with the same assumptions, goals, and objectives.

Basis for the Use of Soil Family to Achieve SCAN Objectives

Under the Rapid Soil Fertility Survey Program in various provinces of Pakistan, fertilizer trials have been conducted in farmers' fields during the last two decades. The data from these experiments are used to formulate general fertilizer recommendations for main crops for a large area—for example a district—but it is not possible to formulate site-specific fertilizer recommendations according to type of soil.

The Department of Soil Survey of Pakistan has carried out a systematic reconnaissance soil survey of more than 540 000 km^2 that includes all the agriculturally important areas of the country. In addition, detailed soil survey of about 225 000 ha has been completed. These surveys have provided the basic information about the kinds of soils in the country, together with the extent and location of each soil. The soils have been classified into soil series according to the *Soil Survey Manual* (USDA 1969). About 400 soil series have been recognized and these are grouped into soil families, subgroups, great groups, suborders, and orders according to Soil Taxonomy (USDA 1975). The great groups and higher categories occurring in Pakistan are presented in Table 1.

Tentatively, 90 soil families have been set up to include soils of the whole country; of these, 25 are very extensive, covering about 80% of the agriculturally important land. The setting up of the soil families is based on the assumption that there are no marked variations in clay minerals in most of our soils, except in one or two families, as the parent material of our soils, derived from Himalayan rocks, is in the initial stages of weathering. These points have been confirmed by analysis of some clay samples taken from selected soils. However, more clay samples will have to be analyzed to confirm the classification.

Table 1. Soil categories in Pakistan.

Order	Suborder	Great Group
Aridisols	Orthids	Camborthids Calciorthids Salorthids Halorthids[1]
Entisols	Orthents	Ustorthents Xerorthents Torriorthents Halorthents[2]
	Fluvents	Ustifluvents Torrifluvents
	Aquents	Halaquents[2]
	Psamments	Ustipsamments Torripsamments
Inceptisols	Ochrepts	Ustochrepts Eutrochrepts Xerochrepts
	Aquepts	Haplaquepts
Vertisols	Usterts	Chromusterts
	Torrerts	Torrerts
Alfisols	Ustalfs	Haplustalfs

1. Orthids having more than 40% exchangeable sodium and very slow permeability in the Cambic horizon; this is a new Great Group to be included in Soil Taxonomy.
2. Orthents/Aquents having more than 40% exchangeable sodium and very slow permeability in the subsoil; this is a new Great Group to be included in Soil Taxonomy.

Work Plan of SCAN Project

The project was designed to be started simultaneously in all the four provinces of the country, with the collaboration of the following agencies:

1. Soil Survey of Pakistan, Lahore, Punjab.
2. Department of Soil Science, Agricultural University, Tandojam, Hyderabad, Sind.
3. Department of Soil Science, Agricultural University, Peshawar, North West Frontier Province.
4. Agricultural Chemistry Division, Agricultural Research Institute, Sariab, Quetta, Baluchistan.

Due to financial constraints, the work was started in the Punjab Province of Pakistan through two collaborating units, the Soil Survey of Pakistan and the Pakistan Agricultural Research Council (PARC).

Fertilizer experiments will be carried out in farmers' fields, in known and extensive soil families, on the following crops: wheat, rice, cotton, maize, and sugarcane.

Experiments on wheat started in the 1982-83 season on five soil families (Table 2), three in the irrigated and two in the rainfed areas of the Punjab. The location of existing and proposed research sites is shown in Figure 1.

After the collection of data from these experiments and conversion into a meaningful information system through computer data analysis/ synthesis techniques, the work will be extended to other provinces in the next fiscal year, 1983-84.

For data analysis and development of computer models, SCAN may need the help of IBSNAT,

Table 2. Soil famities in Pakistan, their location, and main characteristics.

Soil family	Grid location	Soil series chosen for experiments	Main characteristics of soil series[1]
Coarse loamy, mixed[2], calcareous hyperthermic. Typic Camborthids (Common name Rasulpur family)	31° 45' 44" N 73° 45' 50" E	Rasulpur	Nearly level, somewhat excessively drained *sandy loams* with very weak coarse subangular blocky structure; moderately calcareous; pH 8.0 to 8.2; EC less than 2 mmhos. The series is developed in Late Pleistocene mixed alluvium under semi-arid climate
Fine loamy, mixed[2], calcareous hyperthermic. Typic Camborthids (Common name Hafizabad family)	31° 45' 44" N 73° 45' 50" E	Hafizabad	Level, well-drained *loams* with weak coarse subangular blocky structure; moderately calcareous, pH 8.0-8.2; EC less than 2.0-3.0 mmhos. The series is developed in Late Pleistocene mixed alluvium under semi-arid climate
Fine, mixed,[2] noncalcareous, hyperthermic. Aquic Ustochrepts (Common name Miranpur family)	31° 53' 52" N 73° 47' 37" E and 31° 51' 36" N 73° 48' 30" E	Miranpur	Nearly level, seasonally imperfectly drained silty *clays* with weak coarse and medium subangular blocky structure; noncalcareous; pH 7.8-8.0; EC 0.6-1.0 mmhos. The soil is developed in Late Pleistocene and Early Holocene mixed alluvium under semi-arid climate
Fine, mixed, noncalcareous thermic. Typic Ustochrepts[3] (Common name Guliana family)	33° 33' 13" N 72° 39' 41" E	Guliana	Nearly level, well-drained silty clays with moderate medium angular and subangular blocky structure; noncalcareous; pH 7.6-8.0; EC 0.5-1.0 mmhos. The series is developed in Late Pleistocene mixed, calcareous loess under subhumid and humid climates
Fine loamy, mixed calcareous, thermic. Typic Ustorthents (Common name Rajar family)	33° 33' 13" N 72° 39' 41" E	Rajar	Sloping, excessively drained *silt loams* with massive structure; moderately calcareous; pH 8.0-8.2; EC 0.5-7.0 mmhos. The series is developed on Subrecent and Recent erosional surfaces in Late Pleistocene mixed, calcareous bess under semi-arid and subhumid climates

1. Base saturation in all these soils is more than 80%.
2. A mixture of minerals that has less than 40% of any one mineral other than quartz of feldspars. Classification of clay minerals is tentative; subject to confirmation by further analysis.
3. Clay movement is clear, but not enough to place this in Alfisols. Study of then soil sections needed to confirm classification.

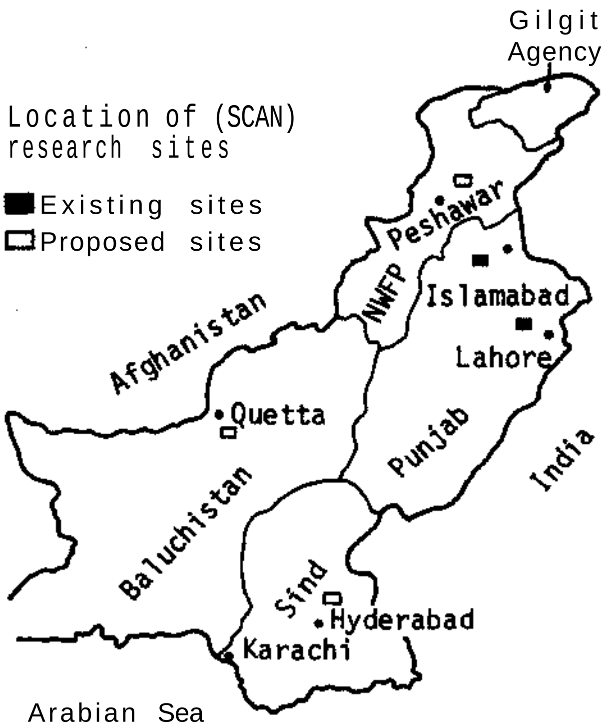

Figure 1. Map of Pakistan, showing location of SCAN sites.

University of Hawaii, as such facilities in the field of agronomy and soil science are not available in Pakistan.

Wheat Experiments, 1982-83

Selection of Soil Families

Five soil families of moderate extent have been selected. Their nomenclature, location, and the main features of the component soil series selected for conducting fertilizer experiments are presented in Table 2. The available physical and chemical data on these soil series are given in Annexures 1 and 2.

Sampling of Soil Families

For precise characterization, ten model profiles of each soil family have been described and sampled to about a 150 cm depth. Five to six soil samples were collected from each profile for analysis.

Soil Analysis

The following determinations will be made:

Physical. Particle size; bulk density; total pore space; infiltration rate; and hydraulic conductivity on undisturbed core samples.

Chemical, $CaC0_3$; organic matter; total and mineral N; available P_20_5 and K_20; CEC; base saturation; pH of saturation paste; pH of saturation extract; pH of 1:5 soil-water suspension; EC x 10^3 of saturation extract; cations and anions in saturation extract.

Clay Mineralogy. About 1 to 2 g of clay will be separated from each of the soil samples, to determine clay minerals in order to firmly establish soil families.

Meteorological data. Average rainfall, temperature, and humidity for stations for the last 30 years in the area of each soil family.

Compilation of Available Data

To define the range in properties of each soil family, available soil analysis data will be collected from the records of the Department of Soil Survey of Pakistan.

Crop Varieties

High-yielding wheat varieties—Punjab 81 for irrigated areas and Lyallpur 73 for rainted areas—have been selected. The salient features of these varieties are given in Table 3.

Table 3. Salient features of wheat varieties chosen for fertilizer experiments in Pakistan, 1982-83.

Wheat variety	Sowing period	Salient features
Punjab-81 (Irrigated)	1 Nov to 10 Dec	Medium duration; yield potential 7 100-12 600 kg/ha
Lyallpur-73 (Rainfed)	20 Oct to 15 Nov	Short duration; yield potential 8 770-9 030 kg/ha

Fertilizer Treatments

Yield-response curves will be developed for nitrogen and phosphorus, while potassium will be kept constant throughout by applying a basal dose, because potassium in our soils is usually sufficient.

Table 4 shows the rates of nitrogen and phosphorus applied under irrigated and rainfed conditions. The experimental design used was the randomized complete block, with three replications in the irrigated and four in the rainfed areas, and a total of 16 plots per replicate.

Parameters kept constant were: basal dose of K; quantity and quality of water applied; fallow field (no crop was grown in the previous season); time of sowing; crop variety; land preparation for crop sowing; insecticides/pesticides.

Variables were: nitrogen, phosphorus, and soil characteristics.

Figure 2 shows the experimental layout plan. We used two experiment sites per soil family, the experimental area at each site being completely uniform.

A

Replicate 1		Replicate 2		Replicate 3	
1	16	13	10	5	7
10	4	14	1	2	9
7	5	11	15	3	11
9	15	4	12	6	14
6	3	2	3	16	1
2	13	8	5	12	13
8	11	16	6	4	15
14	12	9	7	8	10

Block size: 0.23 ha

B

Replicate 1				Replicate 2			
9	3	1	7	5	2	4	5
14	5	10	8	13	11	1	9
16	2	12	15	7	16	3	10
8	13	11	4	12	15	8	14

Replicate 3				Replicate 4			
13	4	8	1	3	7	6	11
16	10	3	5	16	2	15	10
14	2	9	7	12	14	9	13
12	15	11	6	5	8	4	1

Block size: 0.05 ha

Figure 2. Layout plan for fertilizer experiments on wheat in Pakistan, 1982-83. A. Irrigated wheat. B. Rainfed wheat.

Indications from Wheat Experiments (1982-83)

The current (1982-83) wheat experiments have shown the following results to date:

1. The effects of different fertilizer treatments on the growth of wheat are distinctly visible and show similarities within one soil family.
2. Both under irrigated and rainfed conditions, crop stands differ markedly between soil families.

Table 4. Treatment rates used in fertilizer experiments[1] on wheat in Pakistan, 1982--83.

Crop	Plot size (m)	Harvest area (m)	Fertilizer level (kg/ha) Phosphorus P1	P2	P3	P4	Nitrogen N1	N2	N3	N4
Irrigated wheat (Punjab-81)	8 x 6	4 x 2	0	50	100	150	0	75	150	225
Rainfed wheat (Lyallpur-73)	4 x 2	3 x 1	0	50	100	150	0	50	100	150

1. K kept constant throughout, with a basal dose applied.

3. One site each of the Hafizabad and Miranpur soil families received heavy rain before seedlings emerged. The Miranpur soil developed a strong surface crust, which kept about 20% of the seedlings from emerging. On the Hafizabad soil, however, surface crust was weak and did not hinder seedling emergence. This implies that Miranpur soil calls for special soil management practices, but Hafizabad does not.

Future Plan of Work

The progress made by the SCAN Project so far is encouraging, and we plan to expand its scope in the next year.

1. Two more work units will be started in Sind and North West Frontier provinces during the fiscal year 1983-84.
2. Fertilizer experiments will be conducted on maize and wheat crops on the five soil families mentioned in Table 2. Attempts will be made to include and test one additional member of each soil family.
3. Description of soil profiles and sampling (disturbed and undisturbed samples) for laboratory analysis and clay mineralogy will be done in order to confirm the classification of soil families.

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Annexure 1. Physical data on soil families in Pakistan.

Soil family	Horizon and thickness[1] (cm)	% Sand U.S.	% Silt U.S.	% Clay U.S.	Texture class	Bulk density (g/cc)	Vol % moisture at pF of 2.0	Vol % moisture at pF of 4.2	Available moisture[2] (Vol %)	Air pF 2.0 (Vol %)
Rasulpur	B2 (12-127)	71	22	7	Sandy loam	1.40	17	4	13	31
	B3 (127+)	67	24	9	Sandy loam	1.55	24	9	15	17
Hafizabad	B21 (10-100)	39	43	18	Loam	1.62	29	11	18	10
	B22 (100-130)	34	49	17	Loam	1.63	31	10	21	7
	B3 (130+)	57	32	11	Sandy loam	1.63	24	6	18	14
Miranpur	B1 (9-19)	16	39	45	Clay	1.69	38	16	22	
	B21 (19-72)	18	32	50	Clay	1.67	40	17	23	
	Buried B (117+)	19	48	33	Silty clay loam					
Guliana	(0-10)	18	52	30	Silty clay loam					
	(10-15)	17	52	31	Silty clay loam					
	(15-52)	17	42	41	Silty clay					
	(52-80)	16	41	43	Silty clay					
	(80-105)	14	41	45	Silty clay					
	(105-138)	19	42	39	Silty clay loam					
	(138-150)	19	48	33	Silty clay loam					
Rajar	(0-3)	10	69	21	Silt loam					
	(3-12)	9	67	24	Silt loam					
	(12-75)	1	67	32	Silty clay loam					
	(75-150)	1	63	36	Silty clay loam					

1. The figures in parentheses indicate the thickness of horizon in cm.
2. Available moisture calculated as the difference between the pF 2.0 and pF 4.2 moisture percentages.

Annexure 2. Chemical data on soil families in Pakistan.

Soil family	Horizon and thickness (cm)[1]	$CaCO_3$ (%)	Organic matter (%)	CEC (meq/100g)	pH	$ECX10^3$	Soluble ions (meq/L)							
							$CO3''_3$	HCO'_3	Cl'	SO''_4	Ca^{+++}	Mg^{++}	Na^+	Gypsum
Rasulpur	B2 (12-127)	1.50	0.20	8.80	8.05	0.42		1,80	0.60	1.80		3.00	1.20	
	B3 (127+)	4.50	0.10	13.60	9.40	1.70	0.40	4.60	0.70	11.30		2.00	14.80	
Hafizabad	B21 (10-100)	5.0	0.38	15.20	8.40	2.40		5.00	4.50	14.50		4.00	20.00	
	B22 (100-130)	5.0	0.17	15.20	8.10	7.30		2.00	26.60	44.40		13.00	60.00	
	B3 (130+)	19.50	0.17	21.60	8.40	5.20		2.00	24.60	25.40		5.00	47.00	
Miranpur	B1 (9-19)	3.57	0.41	25.60	8.00	0.56								
	B21 (19-72)	1.75	0.62	17.20	8.00	0.78								
	Buried B (117+)	4.00	1.20	23.20	8.10	0.65								
Guliana	(0-10)				7.80	036								
	(10-15)				7.80	0.26								
	(16-62)				7.60	0.20								
	(52-80)				7.80	0.28								
	(80-105)				7.70	0.30								
	(105-138)				7.90	0.24								
	(138-160)				7.80	0.15								
Rajar	(0-3)				7.80	0.55								
	(3-12)				7.80	0.53								
	(12-75)				8.00	0.47								
	(75-150)				8.00	0.46								

1. Figures in parentheses indicate thickness (in cm) of horizon.

Crop, Water-balance, Nutrient, and Erosion Models

A Sorghum Simulation Model, SORGF, as a Research Tool in Agrotechnology Transfer

A.K.S. Huda and S.M. Virmani*

Abstract

A grain sorghum simulation model (SORGF) developed at Texas was used as a framework to initiate crop modeling research at ICRISAT. This model requires daily radiation, maximum and minimum temperature, and precipitation as input weather data. The initial plant and soil information needed includes date of sowing, depth of sowing, row spacing, plant density, potential number of leaves and their maximum size, maximum water-holding capacity of the soil, and available soil water at sowing. Different phenological stages, including emergence, panicle initiation, anthesis, and physiological maturity, are simulated.

Potential dry matter is calculated from radiation intercepted, and the net dry matter is estimated by accounting for temperature and moisture stress. The final grain yield per unit area is calculated by multiplying plant density by grain weight per plant at maturity.

Preliminary investigation revealed that several subroutines needed modification for the overall validation of the model: phenology, light interception, soil water, leaf area, and dry-matter accumulation and partitioning. Accordingly, these subroutines were revised, based on data for several sorghum genotypes, collected over 3 years from 11 locations ranging from 11 to 31 °N latitude. New algorithms were developed based on day length and temperature effects to determine phenological stages. Considerable improvement was made in simulating these growth stages of sorghum. For example, time from emergence to maturity can now be determined within ± 3 days, as compared with ± 18 days with the original model. Relationship between quantum flux density and solar radiation was also altered. The functions for estimating extinction coefficient and maximum light transmission were revised. Incorporation of a layered soil water model works reasonably well for the nonirrigated sorghum. Leaf senescence computation was improved, accounting for stage of development and soil moisture availability. A simpler relationship for calculating daily dry matter from intercepted radiation was developed. Our studies showed that partitioning of dry matter to leaf, culm, head, and grain depended on genotype and soil water. Thus suitable revisions were carried out in the dry-matter partitioning scheme.

Simulation results for each of these processes were compared with observed field data. For final grain yield (n = 59), revisions improved the coefficient of determination (R^2) by 47% (SORGF = 0.27; REVISION = 0.74). The root mean square error for grain yield was reduced from 1479 to 591 kg/ha.

We have shown the applicability of the model in various situations and believe that it can find a role in the transfer of agrotechnology envisaged under the IBSNAT project

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Note: Details of the model described in this abstract may be obtained from the authors.

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A Cassava Growth Model

James H. Cock*

Abstract

A cassava growth model has been constructed for near-ideal constant conditions near the equator. The bases of the model are that (a) crop growth rate is a simple function of leaf area index; (b) that leaf area development can be described if leaf formation rate, leaf size, and leaf life are known at all stages of the crop cycle; (c) preference is given to top growth over root growth; (d) top growth is defined by leaf formation rate and the weight of each nodal unit; (e) storage root growth rate is the total crop growth rate minus the top growth rate. The model was primarily designed to determine the ideal plant type under good growth conditions. It is one of the few models that takes careful consideration of the genotypes used and can readily be modified for different genotypes if characters such as branching habit, maximum leaf size, leaf life under unshaded conditions, and unit node weight are known.

For modeling under different environmental conditions the model will need to be modified. The following areas need specific attention: water stress, nutrient stress, photoperiod, and diseases and pests. Considerable information is available on how soil water stress affects plant development and also on the effects of leaf to air vapor pressure deficit on stomatal response. Data are almost non-existent on feeder root development The overall effects of nutrient stress on growth and development are moderately well described; however, the effects of individual nutrients have not been quantitatively determined. Photoperiod, in the form of long days, is known to increase top growth at the expense of root growth but present data do not allow a very accurate quantitative description of the effect. The effects of temperature on development are relatively well described and could be incorporated into the present model with little difficulty. Disease and pest modeling in cassava is in its infancy; however, damage such as reduction in leaf size, defoliation, or reduction in photosynthesis could readily be incorporated.

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Note: Details of the model described in this abstract may be obtained from the author.

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SOYGRO: Soybean Crop Growth Model

J. W. Jones, J.W. Mishoe, and K.J. Boote*

Abstract

The model SOYGRO is a process-oriented model that calculates daily soybean growth and development in response to environmental, soil, and pest conditions. Processes of photosynthesis, respiration, transpiration, nitrogen remobilization, and tissue synthesis are included. The phenological development of the crop determines the partitioning of new growth, the initiation of seed production, and the onset of maturity. A very important recent development was that of a phenological submodel to predict the timing of vegetative and reproductive events of various soybean cultivars, based on temperature and night length.

SOYGRO—tested against 5 years' data from two locations in Florida for two cultivars—gave simulated yields that were within 10 to 15% of field-measured yields.

The model is now being used as the basis for several application-oriented models. A strategy analysis model (Soybean Integrated Crop Management or SICM) has been developed for studying various irrigation and pest-management strategies using long-term weather records. Interactive interfaces were developed for using SOYGRO (1) to recommend irrigation scheduling within a growing season based on current weather, rainfall probabilities, expected yield increases, and irrigation costs and (2) to schedule insecticide application based on projected yield loss due to insect defoliators and costs of pesticide. Another implementation has been developed to allow yield forecasting for various fields.

Current activities include collection of several soybean data sets from different locations for evaluating SOYGRO. The soil submodel is being modified to be compatible with that of the com and wheat models from Texas. In addition, we have modified several parameters and processes in the model to evaluate our ability to simulate groundnut growth and yield. This paper describes the SOYGRO model, the various ways in which it has been used, and the modifications made to adapt it for use on groundnut, as well as future plans for evaluating and refining the model.

The study of crop production systems is complicated by many interactions between the crop and its physical and biological environments. Traditional approaches of multiyear replicated experiments or field trials are expensive, and results are usually specific to the location of the experiments.

The overall goal of our soybean modeling work, therefore, has been to develop a crop production model that can be used to study soybean growth and yield as affected by management strategies for various soil types, soybean cultivars, and locations. Our initial emphasis has been on the study of irrigation and pest management strategies.

The crop in the system integrates environmental, soil, and pest stress conditions. Therefore, we have focused on developing a soybean growth model that is sensitive to these conditions, yet is also simple enough to integrate into a system for studying management scenarios.

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The soybean crop growth model, SOYGRO, was developed to evaluate tactical farm management decisions and strategies (Wilkerson et al. 1983; Swaney et al. 1983). The model responds to daily weather inputs—temperature, rainfall, solar radiation, potential evapotranspiration, and night length—and is so structured as to include the effects of drought, insect, and disease stress, studied singly or in combinations, and to represent the crop's flexibility in compensating for these stresses.

The model includes explicit representation of phenological development as affected by variety, latitude, planting date, and temperature. Because the model was to be used for management applications, simplifications of process descriptions were used when possible to keep computer memory and run-time requirements at acceptable levels.

Currently, SOYGRO is in release number 4.2. This version has been tested for Florida conditions at two locations and on two sandy soils. It has been documented and is available for further testing. The purpose of this paper is to describe the model briefly, to discuss various ways it has been implemented, and to describe how it was modified by Boote et al. (1983) to simulate groundnut growth and development.

Model Description

Crop Phenology

For many crop plants, the partitioning of dry matter to growth in the different plant parts depends on the stage of development. In order to predict accurately the growth and yield of these crops, one must be able to predict accurately the timing and duration of the various crop growth stages. Soybeans have several distinct stages of development between planting and final maturity. The stage of development for soybean described by Fehr et al. (1971) were adapted in SOYGRO. Figure 1 shows a hypothetical leaf area index (LAI) curve in which the timing of leaf area development is described versus a phenological time scale in which only those stages used by the model are included. The stage ENDSET was not described by Fehr et al. (1971) but was found to be needed for soybeans. ENDSET corresponds to the last date that new pods can be produced by the plant when it is not source-limited. A submodel was developed for predicting the timing of these reproductive growth stages and is discussed in detail by Mishoe et al. (1983).[1] Here, we present a synopsis of the model.

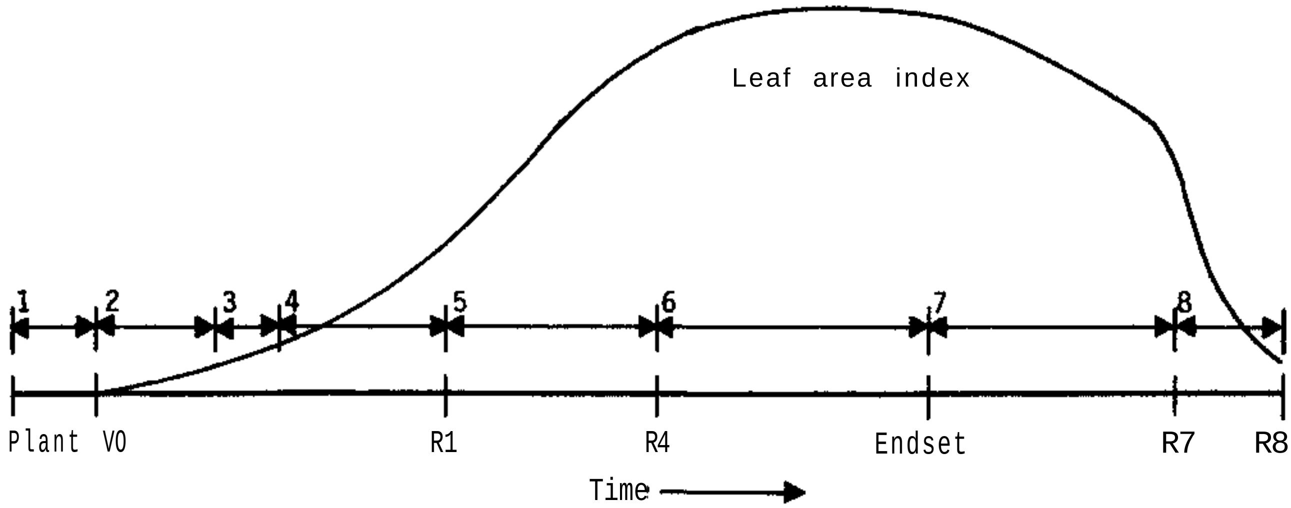
The reproductive (R) stages of soybean depend primarily on temperature and photoperiod. Soybeans flower sooner with long nights than with short ones. Some cultivars are highly sensitive to night length, whereas others are not. Soybean sensitivity to night length is the major source of soybean adaptation to various latitudes of production (Hartwig 1973). The phenology model was developed to allow one to predict the timing and duration of stages under a range of latitudes and planting dates.

The model was formulated and tested using data from Quincy, Florida, USA (36°40'N latitude) (Mishoe et al. 1983) and compared with data from Urbana, Illinois, (40°07'N latitude), as reported by McBlain et al. (1983).

The development of the soybean crop was divided into eight phases (Fig. 1). The model predicts the length of each phase based on a developmental time concept. The durations of stages 1,2,4, and 8 were determined to be affected by temperature and were not affected by night length. Phase 8 was found to be dependent on cultivar, whereas our data did not allow discrimination between cultivars for stages 1, 2, and 4. Physiological time was defined to relate the rate of development to real time at different temperatures. Figure 2A shows how physiological time is based on temperature. For example, at 30°C, one real day is the same as one physiological day. Since development slows with cooler or warmer days, physiological time decreases. For temperatures less than 30°C, this relationship is equivalent to degree-days with a base temperature of 7 and 23 degree-days is the same as one physiological day.

Sensitivity to night length differed among cultivars. This was modeled by a night time-temperature accumulator based on the functions in Figures 2 B and 2 C, with parameters N1, NO, TH, and DH that differ among cultivars. A rate of development, X, is calculated each day by taking the inverse of phase duration for the current night length and multiplying it by the physiological time based on night temperature. Cumulative develop-

[1] J.W. Mishoe, J.D. Hesketh, K.J. Boote, D. Herzog, and J.W. Jones, 1983, Phenology of soybean, development of a model (in preparation).



Phase description

1 germination and emergence, sensitive to temperature

2 juvenile phase, sensitive to temperature but not to night length

3 flower induction, sensitive to night length and temperature

4 flower development and expression, depends on temperature

5 transition to reproductive growth, sensitive to night length and temperature

6 shell expansion, pod set, decreasing vegetative growth, completion of transition, sensitive to night length and temperature

7 pod fill, sensitive to night length and temperature

8 rapid leaf senescence, completion of seed growth, sensitive to temperature

Figure 1. Schematic of a hypothetical leaf area index (LAI) curve for soybean, plotted against a phenological time scale showing the stages used in SOYGRO. (Source: Wilkerson et al. 1983.)

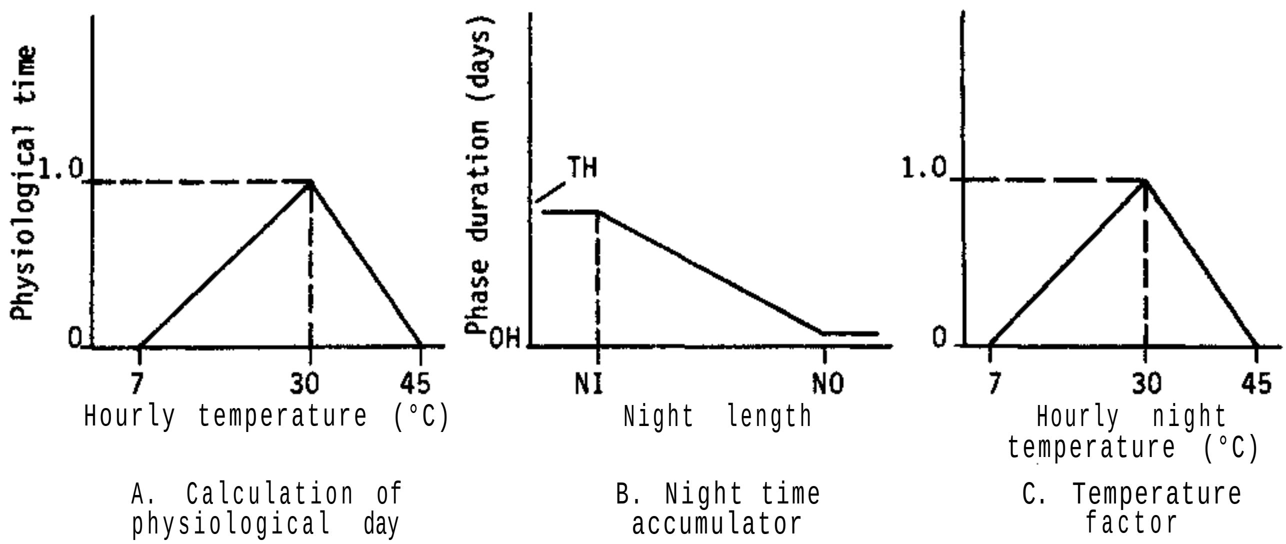


Figure 2. Schematic of the relationships between phase duration and temperature and night length for soybean, as described by Mishoe et al. (1983).

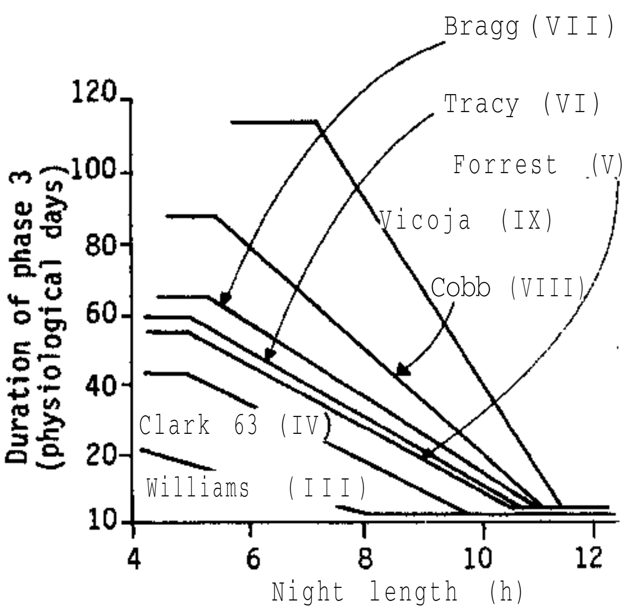


Figure 3. Duration of phase 3 of development in seven soybean cultivars, as a function of night length. (Source: Mishoe et al. 1983.)

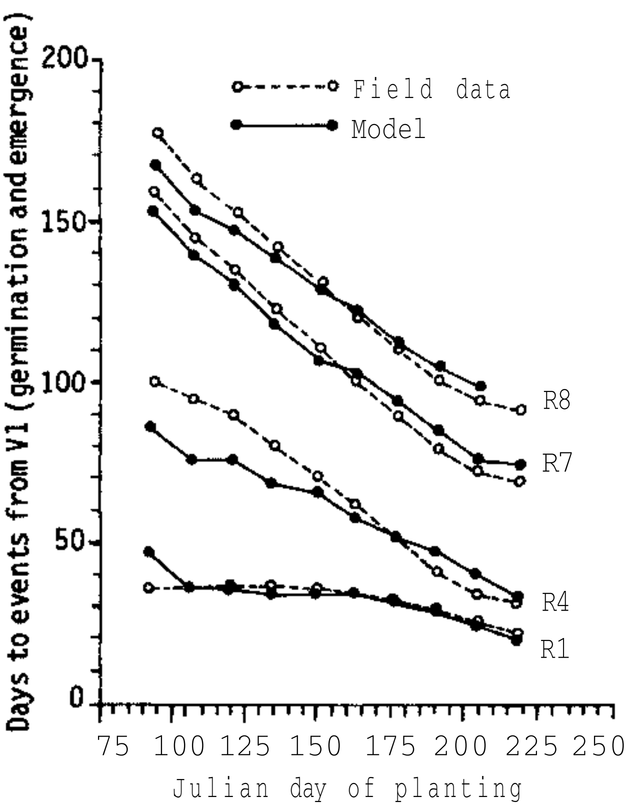


Figure 4. Comparison of phenology model predictions with field data for soybean cv Bragg grown in Quincy, Fla, USA (Mishoe et al. 1983). (For phase description, see Fig, 1.)

ment, XM, is the day-to-day sum of X. XM was scaled so that when XM = 1 ,o, flowering occurs. Lengths of phases 5 and 6 depend on cultivar and were based on the Quincy data. Data from McBlain et al. (1983) were used to verify the model for the same cultivars grown in Urbana, Illinois (see Mishoe et al. 1983). Figure 3 shows the differences among six soybean cultivars in sensitivity to night length. Figure 4 shows the resulting model predictions of reproductive events for soybean cv Bragg, planted on different dates, using 1978 weather data from Quincy, Florida.

Carbon Balance

Biomass growth of the crop is based on a carbon balance that includes photosynthesis, respiration, partitioning, remobilization of protein, and senescence (Wilkerson et al. 1983). Carbohydrate is the basic molecular unit in SOYGRO used in photosynthesis and respiration calculations, whereas plant part weights are based on dry weight. Carbohydrate supply is from gross photosynthesis (PG) which is based on daily photosynthetically active radiation (PAR), temperature, leaf-area index, water stress, and nitrogen concentration of leaves. Carbohydrate is used for carbon skeletons of tissue products and for energy in driving the enzymatic reactions for synthesis. On a mass basis, one g of CH_2O can be converted to φ_p g of protein, requiring G_{rp} g of CH_20 for growth respiration. Thus, the efficiency (E) of converting CH_20 to protein is $E_p = 1/(\varphi_p + G_r p)$. Nitrogen fixation is currently limited only by CH_20 supply to nodules which receive CH_20 on demand to supply any nitrogen needed for growth. Presently, nitrogen fixation is assumed to be equivalent to the cost of nitrate assimilation and reduction in SOYGRO, but this can be changed easily. Efficiencies of conversion of CH_2O to fat and structural carbohdrate, calculated from the work of Penning de Vries (1976), are shown in Table 1. Thus, the efficiency of conversion of CH_2O into leaves, stems, roots, pods, and seeds can be calculated by knowing the concentrations of protein, fat, and structural carbohydrates in each component. Because CH_2O partitioning varies with phenology and stresses, the overall efficiency, E, of converting CH_20 to plant biomass changes during the season. For other crops, such as maize or peanuts, E would be different because of different fractions of protein, fat, and

Table 1. **Carbohydrate required for synthesis of 1 g of new product (protein, fat, structural carbohydrate).**

Product	Condensation,	Respiration (G_{ri}) g CH_2O/g product	Total ($(\varphi+G_r)_i$) —-	Efficiency of CH_2O utilization (E_i) g product/g CH_2O
Protein				
NO_3 source or N_2-fixation	1.33	1.14	2.47	0.41
Remobilized	0.00	0.26	0.26	3.86
Fat	1.94	1.09	3.03	0.33
Structural carbohydrate	1.13	0.08	1.21	0.83

Source: Wilkerson et al. 1983.

structural carbohydrate in each plant part and differences in partitioning.

The overall carbon-balance equation is written as

$$\frac{dW}{dt} = E(P_G - R_m) - S_L - S_s \qquad (1)$$

where W = plant biomass, g/m^2
R_m = maintenance respiration
S_L = leaf senescence rate and
S_s = stem plus petiole senescence rate.

Partitioning of biomass into various plant parts is based on partition coefficients that vary with phenology, sink strength, and stress. For example, X_L partitions new growth into leaves by:

$$\frac{dW_L}{dt} = X_L\,[E(P_G - R_m)] - S_L - M_L \qquad (2)$$

where W_L = leaf weight, g/m^2
and M_L = protein remobilization rate, g/m^2 per day.

The value of X_L changes with phenology and is recalculated on a daily basis. For a more complete description of partitioning, see Wilkerson et a!. (1983).

A very important process in SOYGRO is that of setting shells or pods and the initiation of seed growth. Flowers are considered plentiful and their mass is ignored, whereas shell growth depends on phenology as well as on carbohydrate supply. The number of seeds per shell, seed size, and growth rate per seed are varietal characteristics required for running SOYGRO. Shells are initiated at a rate determined by temperature and by the average number of seeds (at their potential growth rate) that the plant could have supported during the last 7 days, starting at R4 reproductive event. Stresses that reduce carbohydrate supply reduce shell initiation. After shell expansion, the number of seeds to start growth is based on the photosynthate supply, less maintenance respiration. Seeds have first priority for CH_2O over other plant parts. Stresses that reduce photosynthate supply can delay fruit initiation and growth. However, the soybean plant is flexible in that a full seed load may be set after a short delay if stress is alleviated. Cultivars with longer pod-addition phases will have more flexibility in recovering from short periods of stress than those with short pod-addition phases (Cure et al. 1983).

Stress Effects

SOYGRO is sensitive to PAR, to temperature, and to water and various pest-induced stresses. A soil water model calculates water availability on a daily basis. Differences in soil types are expressed by maximum root depth, soil water-holding capacity, and maximum potential evaporation from the soil surface. When water availability falls below a turgor threshold, leaf area expansion is reduced in proportion to remaining soil water. As water availability is further reduced below a second threshold, P_G is reduced. Thus, supply of CH_2O and leaf area growth may change due to limited water.

Insect defoliators reduce leaf area and may affect both P_G and transpiration. In addition, availability of N for remobilization to seed is reduced by leaf eaters. Pod-feeding insects reduce seed number and sink strength for CH_2O. Weeds have been interfaced on a trial basis by allowing weeds to compete for light and water. Foliar diseases reduce efficiency of leaves for fixing CH_2O and reduce the light interception of unaffected leaves. Nematodes have been interfaced on a trial basis by modifying the water-stress relationship to simulate increased resistance to water uptake by roots. A paper by Boote et al. (1983) describes more details of pest interactions.

Model Validation Results

Our first objective was to evaluate the ability of SOYGRO to simulate soybean growth and yield. Our approach was to compare simulated results with observed data from several years and under various water- and pest-stress conditions in order to gain confidence in the ability of SOYGRO to describe soybean yield response for Florida conditions. A total of 4 years of data from Gainesville and 1 year of data from Quincy have been compared with simulated results. These experiments included 4 years of treatments in Gainesville with widely varying irrigation and rainfall patterns, with 1 year in which natural insect defoliation was superimposed on irrigation treatments in a split-plot design. The experiment in Quincy in 1979 had defoliation level as a treatment for comparison with protected plots. Data from the protected plot in the Quincy experiment were used to estimate some model parameters as described by Wilkerson et al. (1983). Figures 5 and 6 show comparisons between simulated and measured leaf area index and seed weight for the 1979 Quincy defoliation experiment and the 1978 Gainesville water-stress experiment, respectively. Yield was reduced about 15% due to 45% defoliation in Quincy.

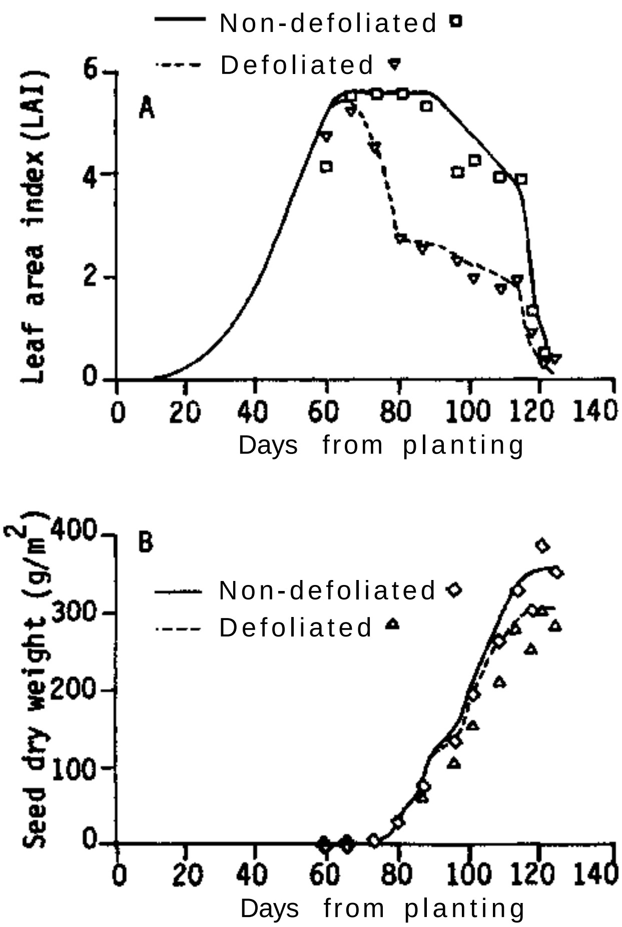


Figure 5. Simulated and observed soybean leaf area index (A) and seed weight (B) from the 1979 experiment in Quincy, Fla, USA. (Source: Wilkerson et al. 1983.)

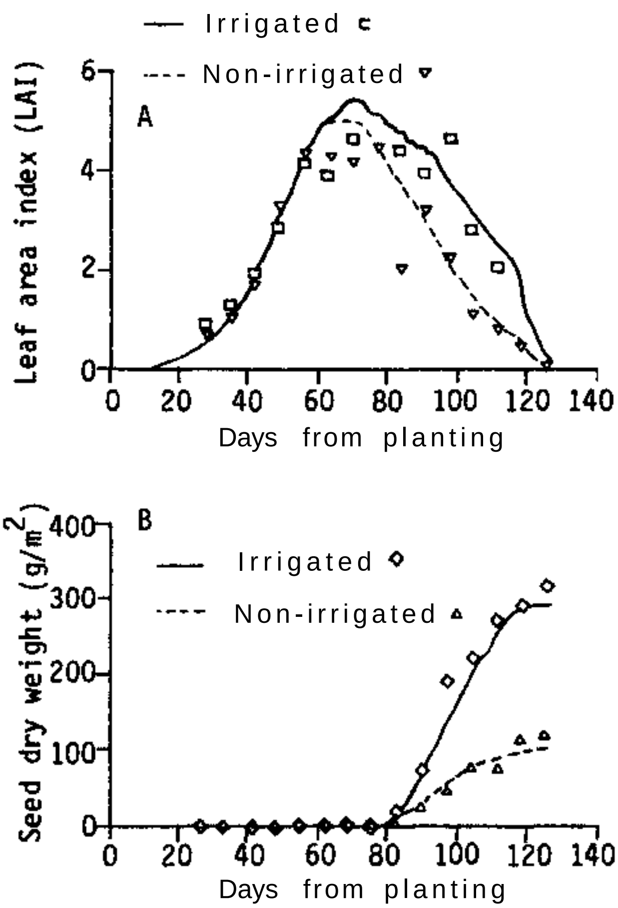


Figure 6. A. Simulated and observed soybean leaf area index, and B. Seed weight from the 1978 experiment in Gainesville, Fla, USA. (Source: Wilkerson et al. 1983.)

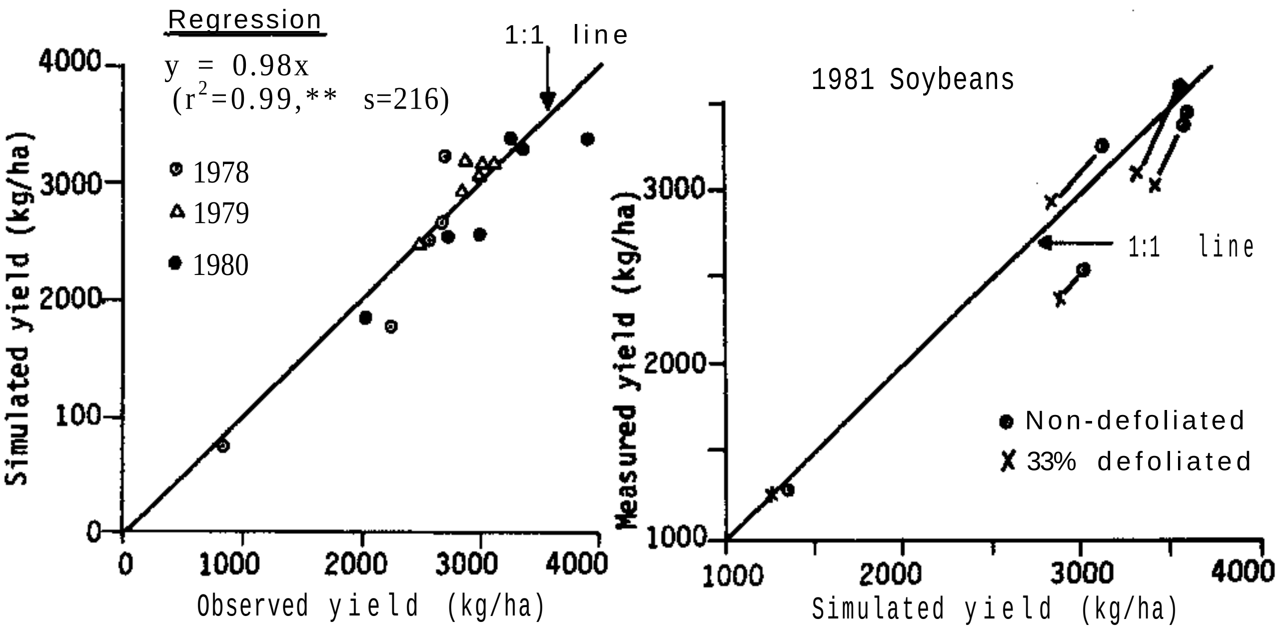


Figure 7. Simulated soybean yields plotted against measured yields from 4 years of experiments in Gainesville, Fla, USA.

Nonirrigated plots yielded about 30% of irrigated plots in the 1978 Gainesville experiment due to an extended drought that occurred just after R4 and continued until maturity. Figures 7A and 7B show simulated versus measured yield response for treatments over 4 years of Gainesville experiments (Jones et al. 1982; K.J. Boote, J.M. Bennett, L.C. Hammond, and J.W. Jones, unpublished data from 1981).

A sensitivity analysis indicated that SOYGRO was sensitive to P_G and respiration terms and to the length of the pod-filling phase. When either water or pest stresses occurred in the model, sensitivity of yield to any parameter generally increased in magnitude.

Model Implementation

SOYGRO has been used as a basis for several application-oriented models. Figure 8 presents an overview of our operational versions of the model. The center of the diagram displays the components used to produce each implementation version which are referred to as SICM, STRATEGY, IRDEC, SOYYIELD, SOYGAME, and PESTDEC (Mishoe et al. 1982).

To meet educational needs, we have developed SOYGAME, which is similar in approach to the interactive cotton model described by McClendon et al. (1979). This model uses historical weather data and allows the users to practice growing a crop of soybeans. Each user must manage the crop based only on the current crop status and any information before today's date. He must decide when to scout his field, when to spray for insects, and when to irrigate. No decision rules are provided and the model will respond to each of the above management practices the manager selects. At the end of the season, outputs include final crop yield and net profit. As an example of its use, a grower can experiment with a known season and evaluate alternative strategies for management.

The preseason STRATEGY model uses historical weather data and expected market information to develop strategies to manage future cropping seasons. Currently, this model implementation cannot be used directly by the grower; however, it has been used to study long-term strategies for irrigation management (Boggess et al. 1981), to determine the value of weather forecasts (Swaney et al. 1982), and for certain pest control practices such as scouting interval. Plans are to incorporate several crop models to study multicropping systems and to allow for farm-level optimization using multifield integration techniques. Because the strategy analyses are directed to future seasons,

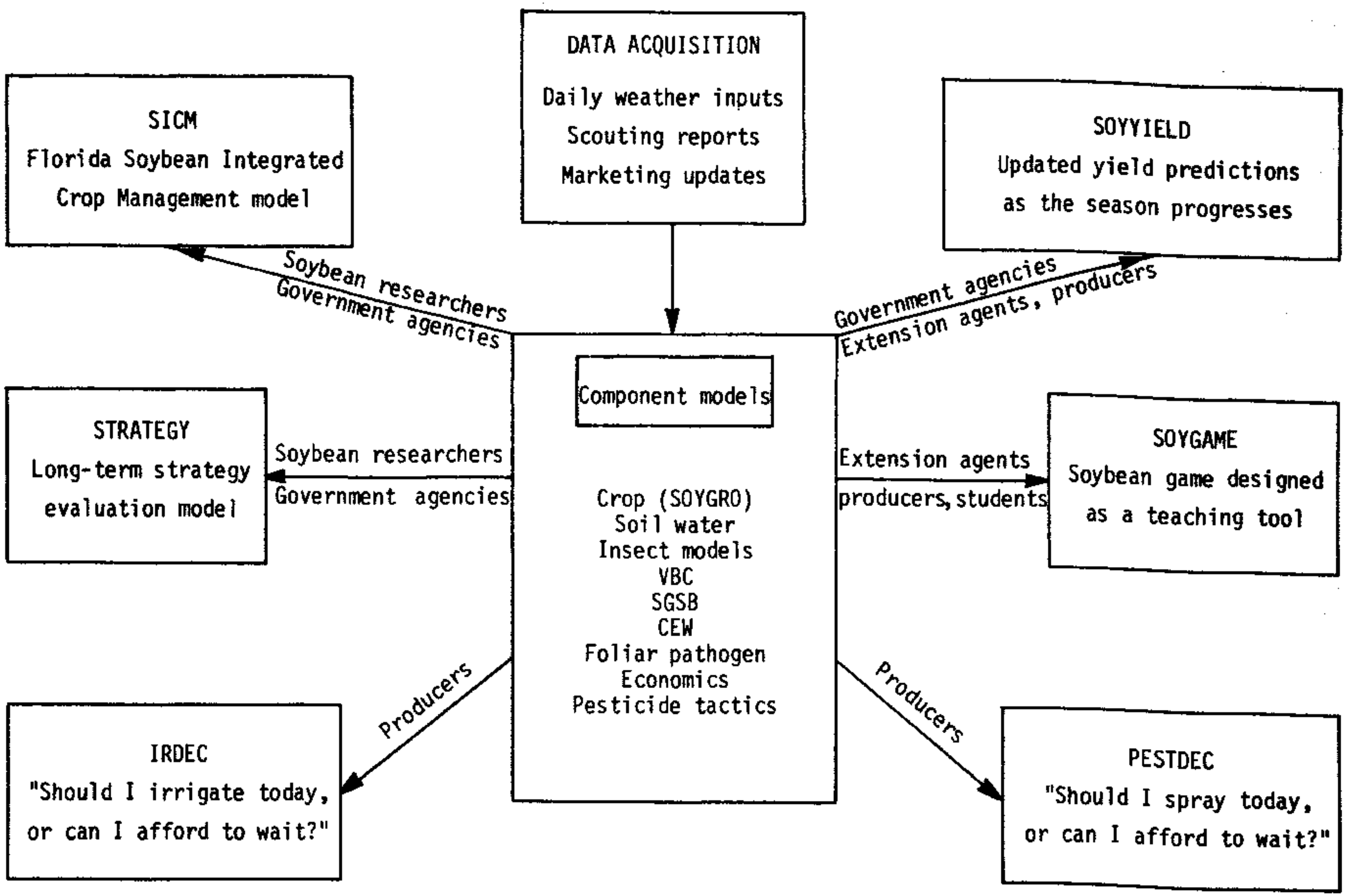


Figure 8. Diagram showing the relationships of various component models in the implementation of user-oriented models for specific applications. (Source: Mishoe et al. 1982.)

some relationship between historical weather data and future seasons must be established. Several options exist. These include the use of weather models (Larsen and Pense 1981) which generate weather patterns based on probabilities derived from historical records, the use of historical means, or the use of selected classes of years.

The importance of knowing weather information can be seen in the yield prediction study presented in Figure 9. This graph was developed by simulating two different experimental plots,[2] grown in Gainesville, Fla, in 1981. Each data point represents the predicted yield using actual weather data until "today" and assuming no water stress after today, for the well-watered treatment and assuming no irrigation for the rainfed treatment. Seventeen years of historical weather records were used from "today" through harvest to provide a measure of variability for the predicted yields. The model used to simulate the crop was SOYGRO implemented in the model version called SOYYIELD. Predicted yield for the treatment that was well-watered during the entire season was approximately equal to a maximum yield by assuming no water stress. The error in prediction for the rainfed treatment is due mostly to the lack of knowledge of future rainfall patterns.

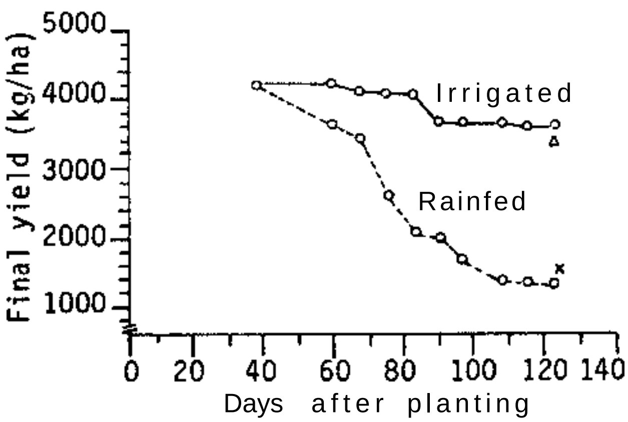


Figure 9. Weekly yield predictions made by SOYGRO for two treatments in an experiment conducted in Gainesville, Fla, in 1981 by K.J. Boote, J. M. Bennett, L. C. Hammond, and J. W. Jones (unpublished). Yields measured at the end of the season are denoted by Δ (irrigated treatment) and by X (rainfed treatment).

[2]Unpublished experiments, K.J. Boote et al., Department of Agronomy, University of Florida. Gainesville, Fla, USA.

The measured final yields are marked on the graph for each of the two treatments.

The within-season decision models are intended to supply information specifically for a given crop and are designed to assist in making optimal decisions at a point in time based on the best information at hand. Procedurally, these models simulate a crop from planting until "today," using actual weather data. If necessary, the model can be calibrated using any known information to allow the model to best represent the known state of the crop. From "today," the model simulates various decisions. The optimal decision selection is therefore based upon the best expected profit and/or the individual's preference for risk aversion. The risk factor is generated by running the model from today's date until the end of the season using a sample of historical weather years. The statistics reported reflect short-term weather probabilities, the expected profit, and the probability of one decision being better or worse than the other decision.

The decisions that have been implemented using this framework are pest control decisions (PESTDEC) and irrigation scheduling (IRDEC). In each case the optimization of the decision is constrained by the state of the crop today and the management rules under which the crop will be managed after the current decision interval. In reality there can be no assurance that the decision made today is an actual seasonal optimum; however, it will represent a local optimum. The model IRDEC was used to study the sensitivity of today's decision to the remainder of the season's management strategy (Swaney et al. 1982).

The models are being implemented on the Institute of Food and Agricultural Science (IFAS) Computer Network. A considerable effort has gone into software development for user-friendly, interactive application of each version. Screen formating and menu selectable options allow the user to run each model without a knowledge of any programming language. The IFAS Network, when completed, will have three or four VAX 11/750 computers distributed across the state for use through county extension offices. Currently, SICM, SOYGAME, and a weather data acquisition system called AWARDS (Agricultural Weather Automatic Retrieval and Delivery System, Mishoe et al. 1982) has been implemented and been used on the IFAS Network. We are in the process of implementing other versions on the system.

Modeling Groundnut Growth

In an effort to evaluate the effect of leaf-spot damage on groundnut growth and yield, Boote et al. (1983) first converted SOYGRO to a groundnut model. Because groundnut is also a legume and has phenological stages similar to soybean (Boote 1982), we felt that the model structure of SOYGRO could be used with only minor changes. Since a submodel for describing groundnut phenology was not available, we input critical reproductive events for groundnut. The partitioning of CH_2O to various plant parts was again modeled as a function of crop developmental phenological growth phases. We found that the transitions in partitioning could be keyed to the same R-stages as for soybeans, although absolute values of partitioning were changed to reflect groundnut partitioning for cv Florunner, using unpublished data of Boote, Bennett, and Hammond (1981). Since protein, oil, and structural carbohydrate compositions of groundnut plant parts differed slightly from those of soybean, the efficiencies of converting CH_2O into seeds, leaves, stems, roots, and shells were changed. Finally, the algorithms for pod initiation, potential seed growth rates, and potential seed sizes were changed. Other relationships and the overall model structure remained unchanged.

The model was then used to evaluate the effects of *Cercospora* leafspot on growth and yield of the 1981 groundnut crop. Canopy photosynthesis data of Boote et al. (1980) for disease-free and Cercospora-infected canopies were used to develop a relationship to describe P_G as affected by disease and photosynthetically active radiation (PAR):

$$P_G = \frac{(1 - D - K_1) P_{max} (PAR)}{(1 - D k_2) K_m + PAR} \qquad (3)$$

where D = fraction visible leaf spot,

k_1, k_2 = parameters to modify photosynthetic efficiency of leaf area without visible spots, and

P_{max}, K_m = Michaelis-Menten constants used to describe canopy P_G for groundnut in the absence of disease.

This function allows modification of P_{max} and K_m as affected by disease and allows for a toxic effect versus fraction visible disease in the canopy.

Leaf defoliation was also included and modeled as a Gompertz function based on work by Berger (1981). Thus, we accounted for disease effects due to (1) leaf area loss, (2) self-shading of healthy leaf area by leaf spots, and (3) toxic effect of leaf-spot disease on photosynthetic rate. We found that overall canopy photosynthesis was reduced from 26.1 g for nondiseased canopy to 16.8 g CH_2O/m^2 per day for the highly diseased canopy. Total leaf areas were 5.0 and 3.14 for healthy and diseased canopies and the diseased leaf area index (D) was 0.61 for the diseased canopy. Under these conditions, reduced leaf area accounted for 33% of the loss in P_G About 17% of the reduction was accounted for by self-shading caused by the 0.61 leaf area index of diseased leaves, and 51% was attributed to altered photosynthetic efficiency of the remaining "healthy" leaf area.

Figure 10 shows the observed and simulated results of vegetative and pod weights for non-diseased plots for the 1981 crop. There were no disease treatments in the 1981 experiment. We presumed a moderate rate of disease progress similar to other years observed by Berger (1981). Simulated groundnut vegetative and pod weights in response to the presumed incidence of disease are also shown in Figure 10. Although these results have not been validated, we feel that the model was useful in describing groundnut growth and yield in the absence of disease and that further work is warranted to evaluate groundnut

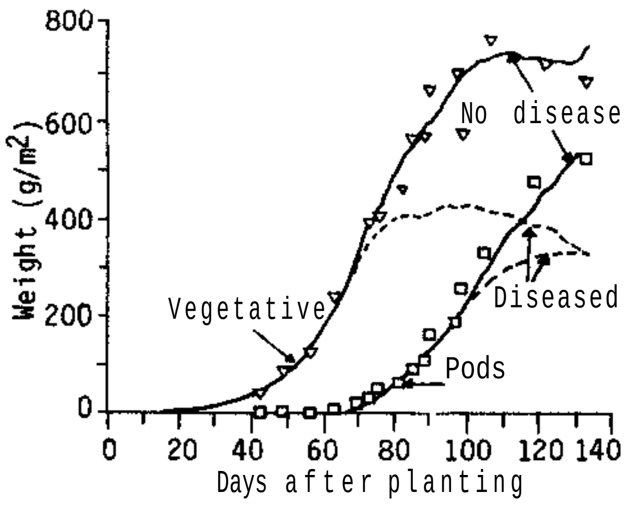


Figure 10. Experimental data of vegetative (Δ) and pod (□) dry weights for disease-free groundnut and for an assumed incidence of *Cercospora* leaf-spot disease were obtained with the SOYGRO-converted groundnut growth model (Source: Boote et al. 1983.)

response to disease and drought. Future efforts are projected, as is development of a phenology model for groundnut.

Current Development Activities and Future Plans

Currently, we are in the process of evaluating SOYGRO version 4.2 for use on various cultivars grown in Missouri, Illinois, Iowa, and Mississippi. We are trying to collect other data sets for testing at other locations in the USA. Version 5.0 has been designed and is in the development process. The new version will utilize the same soil model that was developed in Texas and is reported in this symposium by D. Godwin. This will enhance the adaptation of our soybean model into an overall system with maize, wheat, and other crop models. Apparently, this can contribute directly to IBSNAT. In addition, early vegetative growth will be modified, as will maintenance respiration and leaf senescence functions. These changes are to be based on recent data.

We will continue efforts to implement and test pest models (weeds, nematodes, disease, and insects) in SOYGRO under the USDA-funded Consortium for Integrated Pest Management project (CIPM)—Soybean Subproject, in cooperation with experimentalists throughout the USA. Four hands-on workshops have been held at the University of Florida for experimentalists in entomology, weed science, and nematology. These workshops were designed for participants to conduct "computer experiments" in their area of pest management using the SICM model[3] and to define experimental needs for their future research as a part of the CIPM project. Future workshops are planned to integrate new data on weed, insect, nematode, and disease interactions with the crop.

The effort on the groundnut model is only a beginning and further work must be done before we can evaluate its effectiveness. We plan to continue that effort as resources and time permit.

[3]G.G. Wilkerson, G.W. Mishoe, J.L Stimac, J.W Jones, DP. Swaney, and W.G. Boggess, 1982, SICM—Florida Integrated Crop Management Model: Model Description and User's Guide, Unpublished Manuscript, Agricultural Engineering Department. University of Florida, Gainesville, Fla, USA.

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The CERES Wheat and Maize Models

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Abstract

The Crop-Environment Resource Synthesis (CERES) wheat and maize models have been developed by multidisciplinary team of soil scientists, agronomists, and crop physiologists. The models are designed to simulate crop phenological development, growth, and economic yield wherever the crops can be grown. They operate on a daily time step, are user-oriented, are computationally efficient, and require minimal weather, soil, and genotype-specific inputs. Weather inputs are daily maximum and minimum air temperatures, solar radiation, and precipitation. The soil water component of the models requires estimates of volumetric water contents at the drained upper limit and at the lower limit of plant-extractable water. Differences among crop cultivars result from differences in genotype-specific coefficients related to photoperiod, temperature response, thermal time required for certain phenological events, and dry-matter partitioning.

Introduction

The CERES wheat and maize simulation models are being developed by the USDA-ARS Crop Systems Evaluation Unit (CSEU) at the Grassland, Soil, and Water Research Laboratory, Temple, Texas. The following have contributed to the development and testing of the models: J.T. Ritchie (leader), P. Dyke, D.C. Godwin, W. Iwig, C.A. Jones, J. Kiniry, M. Kirby, D. Knieval, H. Nix, S.I. Otter, D. Upchurch, D. Wallach, and others.

The CERES models are in the final stages of development and testing, and they will be published in mid-1984. Two versions of each model are available: the first simulates the effects of weather, soil water, and genotype on crop growth and yield; the second simulates these processes as well as nitrogen dynamics in the soil and crop. The models are user-oriented and require a minimum of readily available soil and weather data. They are computationally efficient. When neither the water balance nor the nitrogen components are used, about 0.5 seconds are required to execute a 1-year simulation on a high-speed computer. This time increases to about 2 seconds when all components are used. The purpose of this paper is to describe in very general terms the simulation of crop phenology and growth in the simpler versions of the CERES wheat and maize models. The minimum data sets required for model testing and the results of preliminary tests are also discussed. The soil water and nitrogen components of the CERES models will be discussed in another paper at this symposium.

Phenology

Growth Stages

The crop phenology components of the CERES models describe the changing allocation of dry-matter accumulation among plant organs during the course of crop growth. The growth of the crop

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Table 1. Growth stages used in CERES wheat and maize models and plant parts growing during each stage (in parentheses).

Stage	Wheat	Maize
7	Presowing	Presowing
8	Sowing to germination	Sowing to germination
		Germination to emergence (roots, leaves)
1	Emergence to terminal spikelet (roots, leaves)	Emergence to tassel initiation (roots, leaves)
2	Terminal spikelet to end of vegetative growth (roots, leaves, stems)	Tassel initiation to beginning of linear ear growth (exclusive of grain) (roots, leaves, stems)
3	End of vegetative growth to end of pre-anthesis ear growth (roots, leaves, stems, ears)	Linear ear growth to end of vegetative growth (roots, leaves, stem, ear)
4	End of pre-anthesis ear growth to beginning of linear grain fill (roots, stems)	End of vegetative growth to beginning of linear grain fill (stem, ear)
5	Linear grain fill (roots, stems, grain)	Linear grain fill (stem, grain)
6	End of grain fill to harvest	End of linear grain fill to physiological maturity

is divided into growth stages during which dry-matter partitioning into organs such as roots, leaves, stems, ears, and grain is relatively constant. For example, prior to tassel initiation in maize, all accumulating dry matter is partitioned between leaves and roots. However, from tassel initiation to the beginning of linear ear growth, roots, leaves, and the stem grow simultaneously. The growth stages used in the CERES models and the organs which can grow during each stage are described in Table 1.

Control of Phenology

Matching the phenology of the crop to the environment in which it grows is one of the most important aspects of matching crop requirements to the environment. If the phenological development of the crop is not correctly matched with environmental conditions, crop growth and yield will be adversely affected. For example, in drought-prone environments crop development must be completed during periods of adequate rainfall and soil water.

Both genotype and environment affect phenological development. Many studies have shown that crop development is very sensitive to temperature, and biological clocks based on accumulated heat units have long been used to predict crop development .In the CERES models phenological development is driven by accumulation of daily thermal time (DTT); however, in some genotypes the effects of DTT on phenological development are modified by vernalization (in wheat) and photoperiod.

Thermal Time

In the CERES models DTT is normally the difference between daily mean air (or crown) temperature and the base temperature (0°C for wheat and 8 or 11°C for maize). If the mean temperature is below the base temperature, DTT is 0. If the mean temperature is above a critical "optimum" temperature (29°C in wheat and 34°C in maize), DTT is reduced due to high-temperature stress.

In CERES-wheat, cumulative DTT required for linear grain fill (stage 5) is genotype-dependent. In CERES-maize, cumulative DTT for both linear grain fill (stage 5) and for the period from emergence to tassel initiation (stage 1) are genotype-dependent.

Under normal conditions grass leaf primordia are initiated at a constant rate in thermal time, and their initiation ceases when panicle primordia begin to form. Therefore, the number of leaves on a grass tiller is fixed at the end of stage 1. Leaf tips and ligules emerge from the whorl at a near-constant rate in thermal time. Therefore, the thermal time from tassel initiation until all leaves have completely emerged (end of vegetative growth) is determined by the number of leaves formed prior to panicle initiation. Thus, in the CERES maize model, cumulative DTT from tassel initiation to the end of vegetative growth (stages 2 plus 3) is a function of cumulative DTT in stage 1.

Another important genotypic variable related to thermal time in both CERES models is the cumulative DTT required to complete linear grain fill (stage 5). This variable affects the time, and hence the amount of dry matter accumulated during grain filling, and it can have an important effect on final grain yield.

Photoperiod

Most C_3 grasses are long-day plants in which panicle initiation and flowering are hastened by days longer (nights shorter) than a certain threshold. Most C_4 grasses are short-day plants in which flowering is hastened by short days. In CERES-maize, plants are assumed to have a juvenile phase in which phenology is insensitive to photoperiod. However, daylength can affect the number of calendar days between the end of the juvenile phase and tassel initiation. In photoperiod-sensitive cultivars, photoperiods longer than 12.5h lengthen the period from the end of the juvenile phase to panicle initiation. Since leaf primordia continue to be initiated during this period, long days also cause leaf number to increase in photoperiod-sensitive cultivars.

In CERES-wheat, daylengths shorter than 20 h slow the development of the crop during stage 1. The shorter the daylength, the slower phenological development occurs at a given temperature. As in CERES-maize, some genotypes are more sensitive to short daylengths than others. In general, the phenology of spring wheats is more sensitive to photoperiod than is that of winter wheats.

Vernalization

Winter wheat cultivars usually require prolonged exposure to cold temperatures (vernalization) for normal phenological development. On any day, maximum vernalization occurs at mean crown temperatures of 0 to 6°C. Vernalization is insignificant at temperatures below 0°C or above 15°C. For typical winter wheat cultivars, about 50 days of ideal vernalizing conditions are required for complete vernalization and normal phenological development; however, longer periods of non-optimal vernalizing temperature can also result in complete vernalization. If vernalization is incomplete, growth stage 1 is prolonged in the spring, and terminal spikelet formation is delayed. Spring wheats have a much lower vernalization requirement than winter wheats.

Growth

Dry-matter Production

In the CERES models potential dry-matter production of the crop is a linear function of intercepted, photosynthetically active radiation (PAR). For example, in wheat and maize plants, dry matter potentially increases at a rate of 2.9 and 3.4 g biomass per megajoule (MJ) of intercepted PAR, respectively. As crop biomass increases, the potential efficiency of conversion of intercepted PAR to dry matter decreases slightly due to increased maintenance respiration of the crop.

The percentage of incident PAR that is intercepted by the crop is a curvilinear function of leaf area (LAI). Over 90% of incident PAR is intercepted when LAI exceeds 3.

The actual rate of dry-matter production is usually less than the potential rate due to the effects of non-optimal temperatures or water stress. Since photosynthesis occurs only during the day, a weighted mean daytime temperature is calculated from the minimum and maximum temperatures. For wheat the optimum daytime temperature is 18°C; for maize it is 26°C. Water stress can reduce actual dry-matter production below the potential whenever crop extraction of soil water falls below the climatically driven potential transpiration rate of the crop.

Leaf Growth

Plant leaf area has an important effect on light interception and dry-matter production. The rate of leaf area expansion is one of the components of plant growth most sensitive to environmental stresses. For example, leaf growth is more sensitive than photosynthesis to drought stress. In addition, the optimum temperature for leaf growth is several degrees higher than that of photosynthesis. Thus, cool temperatures or moderate drought stresses often reduce expansion growth more than photosynthesis, and this causes non-structural carbohydrates to accumulate. The CERES models account for these plant responses by having different temperature and drought responses for photosynthesis and leaf growth.

The daily growth of plant leaf area in CERES models is the product of the following: the total width of expanding leaves on the plant, the maximum daily rate of extension growth of a leaf, a reduction factor for non-optimal temperatures, and a reduction factor for suboptimal soil water availability. In CERES-wheat and CERES-maize, the optimum temperatures for leaf growth are 21 °C and 29°C, respectively, 3°C greater than the optimum temperatures for photosynthesis. Soil water availability can limit leaf growth even before transpiration is reduced. Whenever transpiration on a day is greater than 0.67 of the potential total water absorption by the root system, leaf extension growth decreases.

Root Growth

Accumulating biomass is partitioned into shoots and roots. The proportion that is partitioned to roots affects the shoot: root ratio and the ability of the root system to supply the shoot with water and nutrients. The fraction of dry-matter production which is diverted to the root depends on the growth stage of the crop. The fraction partitioned to the roots usually declines as the plant develops, but it is sensitive to environmental factors such as drought stress and competition for light. Stresses such as drought, which reduce leaf expansion more than they reduce biomass accumulation, tend to increase the fraction partitioned to the root system. Stresses such as competition for light affect biomass accumulation more than expansion growth, and they tend to decrease the fraction of dry matter partitioned to the roots.

The total growth of roots on a day is determined by the amount of biomass translocated to the root system. A rooting preference factor is assigned to each soil layer. The preference factor decreases with depth and is sensitive to the soil water content of the layer. Thus, when soil water is adequate throughout the profile, root growth declines exponentially with depth. However, when a particular soil layer becomes quite dry, root growth in that layer decreases, but compensatory root growth normally occurs elsewhere in the profile.

Grain Growth

In CERES-wheat, the number of grains per ear is a linear function of stem weight at the end of pre-anthesis ear growth and a genotype-specific coefficient characterizing the relative sizes of the stem and ear. In CERES-maize, the number of grains per ear is determined from average biomass accumulation in growth stages 3 and 4. It is not genotype-specific.

The maximum growth rate of grains during stage 5 is determined by a genotype-specific coefficient. However, the rate is also limited by temperature and by the amount of carbohydrate which is available for grain growth. Most of the carbohydrate used during grain growth is provided by concurrent photosynthesis during linear grain fill, but a small percentage can be translocated from vegetative plant parts.

Leaf Senescence

In the CERES models leaf senescence is driven by crop development. Senescence is initially very slow, but it increases as the plant approaches physiological maturity. In addition to phenology, stresses can affect senescence. Thus, on any day, leaf senescence can be hastened by drought stress, competition for light, or cold temperature. In addition, in CERES-wheat, senescence is affected by the degree to which the crop has been hardened by previous exposure to cold temperatures. Unhardened crops are much more susceptible than hardened crops to low-temperature stresses.

Table 2. Processes or growth stages affected by genotype-specific coefficients in CERES wheat and maize models.

Crop	Process
Wheat	1. Sensitivity to daylength
	2. Sensitivity to vernalization
	3. Thermal time from beginning of linear grain fill to maturity
	4. Rate of vegetative expansion during stage 1
	5. Grain number determination
	6. Rate of grain fill
	7. Tiller number determination
	8. Relative winterhardiness
Maize	1. Sensitivity to daylength
	2. Thermal time from seedling emergence to end of juvenile phase
	3. Thermal time from end of vegetative growth to physiological maturity
	4. Rate of grain fill

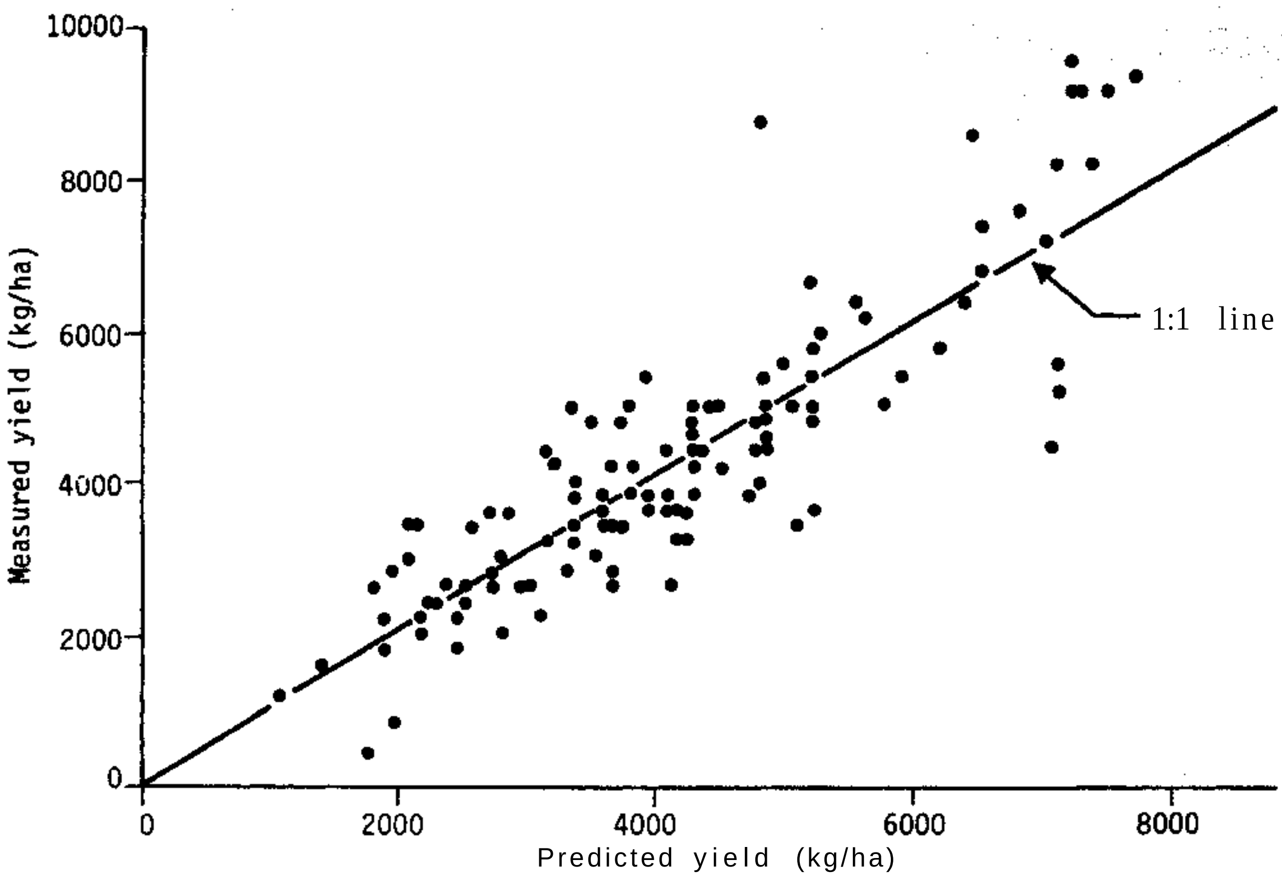

Figure 1. Preliminary test results from comparisons of measured and CERES-simulated growth, development, and yield of wheat.

Genotype-specific Coefficients

Several genotype-specific coefficients are used in the CERES models to quantify differences among cultivars in phenological development and growth (Table 2). These coefficients are available for several maize and wheat genotypes for which the models have been tested. For other cultivars, the coefficients must be deduced from dates of phenological events and detailed measurements of growth. However, these data can usually be obtained quite easily in one or more experiments, and the coefficients can be applied without further calibration in other experiments.

Minimum Data Sets

The simple CERES wheat and maize models are designed to run with a minimum of soil and climatic data. These data are summarized in Table 3. More data are needed to evaluate the accuracy of the various components of the model (Table 4). Daily climatic data are required, and these data may be taken from standard meteorological stations. Soil data should be taken in each layer of the soil to a depth at least 2 m or to a depth of bedrock.

Preliminary Test Results

The CERES models are still under development. They will not be published in final form until mid-1984. They are currently being tested with data sets from a wide variety of locations throughout the world, and preliminary documentation is available on request. Preliminary comparisons of measured and simulated wheat growth, development, and yield are given in Figure 1. In most cases, CERES-wheat gave reasonable estimates

Table 3. Minimum data set needed to run the CERES crop models.

Type of data	Data
Management	Cultivar name Planting date Plant population irrigation dates and amounts
Climate	Longitude and latitude Solar radiation (daily) Maximum and minimum air temperature (daily) Precipitation (daily)
Soil (by layer)	Initial soil water content Drained upper limit of soil water and lower limit of plant-extractable soil water; or 0.33 and 15-bar water contents, soil texture, and cation exchange capacity

Table 4. Minimum data set needed to evaluate CERES model predictions.

Type of data	Data
Soils	Soil water content of each layer several times during the season
Crop	Dates of emergence, anthesis, and physiological maturity Leaf area index several times during the season Shoot weight several times during the season Yield components

of crop behavior in these preliminary tests. The correlation coefficient (r) between observed and simulated yield (Figure 1) is 0.89.

Summary

The CERES wheat and maize models simulate crop growth and development from readily available soil and daily weather data. The models use genotype-specific coefficients to simulate differences among genotypes in duration of growth stages, sensitivity to vernalization (wheat) and photoperiod, and dry-matter partitioning. Weather inputs are daily maximum and minimum air temperatures, solar radiation, and precipitation. The soil water component of the model requires estimates of volumetric water content at the drained upper limit and the lower limit of plant-extractable water. A more complex version of each model is also available. The version simulates nitrogen dynamics and effects in the soil-plant system and it will be discussed in another paper at this symposium.

The Water and Nitrogen Components of the CERES Models

D.C. Godwin, C.A. Jones, J.T. Ritchie, P.LG. Vlek, and LJ.-Youngdahl*

Abstract

The CERES wheat and maize models, which simulate growth, phenology, water and nitrogen balance, and yield, are broadly described in an accompanying paper at this symposium. The CERES models incorporate a soil water balance component that includes calculations of surface runoff, evaporation, drainage, and plant water extraction. The soil water balance model operates on a layer-by-layer basis with the layer depths and storage characteristics as input parameters. The nitrogen component of the model describes leaching, upward movement of N with evaporation, mineralization, and immobilization of N associated with the decay of crop residue, nitrification of ammonium, denitrification, crop demand, and uptake of N. The manner in which crop water and nitrogen deficits affect crop growth and yield is also simulated.

Introduction

The CERES wheat and maize models share common components describing the soil water balance. A second version of each model is available that also describes nitrogen dynamics. The nitrogen routines have evolved as a result of a collaborative effort between the International Fertilizer Development Center, Muscle Shoals, Alabama, and the USDA-ARS Crop Systems Evaluation Unit (CSEU) at Temple, Texas.

In the companion paper (C.A. Jones et al. these Proceedings) a broad outline of the phenology and growth components of the CERES models is provided. The purpose of this paper is to describe the soil water and nitrogen components of the CERES models and their associated data requirements. In addition, brief details of model testing are included, together with an outline of some of the possible applications for the model.

Water Balance

The soil water component of the CERES model employs a multilayered, one-dimensional model. The number of layers and the thickness of each are specified by the user usually within the guidelines that the top layer is no more than 15 cm thick and that no individual layer is more than 30 cm thick. Profile depths considered are generally to the maximum depth of rooting or to 2 m.

Saturation (SAT) moisture content is the maximum water content that a layer can hold before drainage occurs, while the drained upper limit (DUL) is the maximum water content after drain-

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age occurs. Plants can extract water in the range of water contents between the DUL and a lower limit (LL). These three key levels of water availability for each layer are required inputs.

Runoff, Infiltration, and Drainage

When precipitation occurs, runoff is calculated on the basis of the amount of water already in the profile and a runoff coefficient. This coefficient is related to soil texture, surface properties, and slope, and it can be estimated from a soil description. The water that infiltrates moves through the profile by saturated and unsaturated flow. The model simulates this by utilizing a simple cascading system with the top layer filling to saturation and then draining to the layer below, which, in turn, drains to the layer below and so on until all infiltrating water has been accommodated. The rate at which water drains through the profile is limited by the slowest draining layer in the profile. This limit is termed "the whole profile drainage rate constant," and its value is supplied by the user. Values for this constant can be estimated from soil texture data. The nitrate leaching calculations in the nitrogen component of the model are dependent on this drainage submodel.

Evapotranspiration

Potential evapotranspiration in the model is calculated by using a modified Priestley-Taylor (1972) method, and the actual evaporation from the soil surface is estimated by the method of Ritchie (1972), Use of these methods for evaporation calculations reduces the climatic data requirements to a minimum of daily values of precipitation, maximum temperature, minimum temperature, and solar radiation.

Soil surface albedo is used in the soil evaporation calculations and is thus a required input. In practice a realistic value can be inferred from soil texture and color. As the crop leaf area develops, the combined surface albedo changes and hence affects both potential evapotranspiration and proportions of water lost from the plant and the soil. Actual soil evaporation (ES) is modeled as a two-stage process, with the first stage occurring when the only limit to ES is the amount of energy available at the soil surface. This stage continues until a soil-dependent upper limit of stage 1 evaporation (U) is reached. U is also a required input, which can be calculated from other/more generally available, soil properties. Stage 2 evaporation occurs when water becomes more limiting, and it is calculated as a declining function of the time since the beginning of stage 2.

After ES has been determined, the soil water balance is updated and any upward flow of water toward the soil surface is taken into account. This upward movement of water is used to determine the rate of upward movement of nitrate.

Plant Water Uptake and Soil Water Deficit Factors

As outlined by C.A. Jones et al. (these Proceedings), the CERES models have a dynamic root growth and distribution component. Knowledge of the root length distribution in the profile makes it possible to calculate a maximum water uptake from each layer in the soil when the prevailing water availability in each layer is also known. The actual amount of water taken up by the crop is the lesser of this potential root water uptake (TRWU) and the actual plant evaporative demand (EP). In many dryland cropping systems, the crop frequently has many roots in the dry upper part of the profile but has only a few roots at depth where the water supply is adequate. This method of water uptake calculation makes it possible to simulate these effects. This root and water distribution has marked effects on nutrient uptake, particularly if most of the nutrient supply is in the top part of the profile.

The ratio between water supply and demand in the profile (TRWU:EP) provides us with a powerful tool for manipulating plant growth. The ratio is termed "the soil water deficit factor" and is used to modify the rate of photosynthesis, tillering, leaf expansion, senescence, and the distribution of assimilates.

Nitrogen Components

The nitrogen components of the model simulate changes in the extractable nitrate and ammonium N in the soil on a layer-by-layer basis. The major N transformations described by the model are environmentally driven and thus have the potential to work in any location. Volatile ammonia losses from the soil, which may be significant under some circumstances, are not as yet described in the model, although some developmental work is in progress.

Mineralization and Immobilization

In the CERES models mineralization and immobilization of N are simulated by using a method based on that described by Seligman and van Keulen (1981). In this method, organic matter is partitioned into fresh organic matter and a stable organic or "humic" fraction. The model calculates the daily decay rate of these two fractions as a function of prevailing soil water, soil temperature, and N-availability conditions. The amount of organic matter present initially must thus be supplied as input data and can usually be approximated from the amount of crop residue present and its estimated C:N ratio. The stable organic fraction is estimated from soil organic carbon data, which must also be supplied by the user.

The N-mineralization rate is related to the decay rate of the two organic fractions. If the N required by this decay rate is greater than that released by the decay, net immobilization of N occurs. This can occur if a residue with a high C:N ratio is incorporated in the soil. The model maintains the stable organic matter pool with inputs coming from the decay of the fresh organic matter. Thus, the model is able to simulate the turnover of various types of crop residue in differing environments and on differing soils.

Nitrate Movement

Nitrate leaching is modeled as a function of the volume of water draining through each layer. The nitrate and water moving from a layer are added to the layer below, and the cascading system continues until a dry layer or the bottom of the profile is reached. The reverse process of upward movement of nitrate with evaporative loss of water and the associated nitrate movement with unsaturated flow are also modeled. The amount of nitrate flux in clays differs greatly from that in sands, principally because the amount of water which can drain relative to the total water is smaller in clays. The CERES models can readily simulate this difference.

N Uptake and Plant N

In the maize and wheat models, a relationship between critical N concentration in plant tissue and phenological age of the plants has been formulated for each species. Comparison of the actual concentration of plant N at a given point with this reference relationship provides an estimate of the relative N-deficiency status of the crop. Since the relationship is tied to phenological rather than chronological age of the crop plant, N status can be attained for differing cultivars growing at any location.

The plant N status is used to modify various growth and yield processes in a manner analogous to the soil water deficit factor. Grain N concentration and the rate of grain fill are also varied according to the plant N status.

Crop N demand is calculated as the amount of N required to restore the N concentration to the critical level, plus the amount required for any new growth that may occur. Potential uptake of ammonium-N and nitrate-N from each layer in the profile is calculated as a function of the concentration of the two ions in the soil, the water availability, and the root length density in that layer. The actual amount of N taken up from the profile is the lesser of this potential uptake integrated across the depth of rooting and the N demand.

As mentioned above, in dryland cropping systems the following conditions frequently apply: (1) there is an abundant N supply in the top of the profile, (2) the top of the profile is dry, (3) there is some N at depth, and (4) there is adequate water but only a few roots at depth. Through integration of the uptake calculations, as above, uptake from each layer can be realistically simulated.

Denitrification

Denitrification occurs when the oxygen supply in the soil is low and when there is sufficient nitrate and energy. The soil oxygen supply drops as the soil becomes wetter. Denitrification in the model commences when the soil moisture in a layer is at the DUL, and it increases linearly up to SAT. Soil temperature and the amount of soluble carbon associated with soil organic matter also influence the rate of denitrification. This rate is modeled as a simple first-order kinetic process.

Nitrification

The conversion of ammonium to nitrate is modeled as a simple one-step, first-order process.

Soil water availability and soil temperature influence the rate of nitrification. Under some conditions (such as after a long dry period) there may be a short lag in nitrification activity, This lag phase is determined from recent soil history in the model.

Fertilizer Nitrogen

Before N can be taken up by the crop, it must be in the soil solution in the form of either nitrate or ammonium ions. The model assumes instantaneous dissolution of fertilizer into these pools. The proportions going to each pool are dependent on the composition of the fertilizer. Ammoniacal fertilizers such as ammonium sulfate contribute to the ammonium pool, whereas nitrate fertilizers such as potassium nitrate contribute to the nitrate pool. Urea is assumed to contribute to the ammonium pool. To obtain this partitioning, the type of fertilizer used is a required input.

Routines describing fertilizer dissolution and urea hydrolysis are currently under development. These will make provision for the cases when there is a delay in fertilizer transformation to the plant-available forms. In association with this, further development work is concerned with simulating the gaseous losses of ammonia from the soil surface, which can be significant under certain circumstances.

The model is capable of examining the effects of fertilizer placement depth and the timing of fertilizer applications. The dates, rates, and depths of all fertilizer applications are required inputs.

Table 1. Soil water input data requirements for the CERES model.

A. For each layer
- Layer depth
- Lower limit of soil water availability[1]
- Drained upper limit of soil water availability[1]
- Saturation moisture content[1]
- Initial moisture content

B. For the whole profile
- Soil surface albedo, first-stage evaporation constant, soil runoff curve number, whole profile drainage rate constant.

1. This parameter can be estimated using soil texture, bulk density, and soil organic matter information.

Table 2. Soil nitrogen input data requirements for the CERES model.

A. For each layer
- Layer depth
- Initial extractable nitrate
- Initial extractable ammonium
- Bulk density
- PH

B. Crop residue information
- An estimate of the amount of crop residue present, its depth of incorporation, and its C:N ratio or state of decay

C. Fertilizer
- Fertilizer nitrogen date, rate, and depth of all applications and the type of fertilizer

Minimum Data Sets

The input data required for the water and nitrogen components of the CERES models are summarized in Tables 1 and 2. Additional requirements in the form of climatic, genetic, and management data are outlined in the companion paper. To test the water and nitrogen component of the model, additional data required are volumetric soil moisture content of the various layers at several times throughout the growing season. To test the nitrogen components, plant N and soil N in each layer measured at several times throughout the season would be required. To assist in further model development, root length density measurements taken at various times during the growing season would be beneficial. These data would only be required for model development and testing and are not required to run the model.

Preliminary Model Validation

Some preliminary testing of the model against data sets from the USA, Syria, Netherlands, Australia, and Canada indicates that the model generally gives reasonable predictions of both yield (Figure 1) and N uptake (Figure 2). The correlation coefficient between observed and predicted yield is 0.88 and between observed and predicted N uptake is 0.82. Further testing and development work is currently in progress on the nitrogen components.

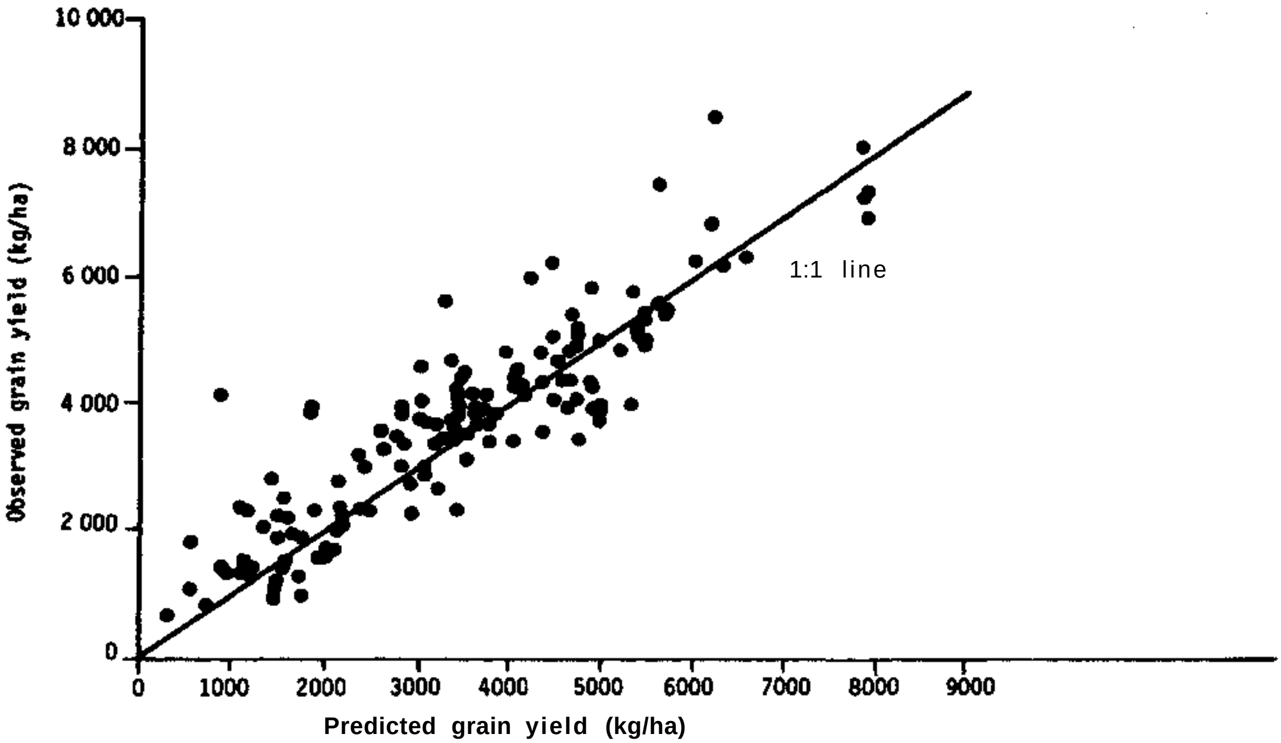

Figure 1. Validation of the wheat and maize yield model.

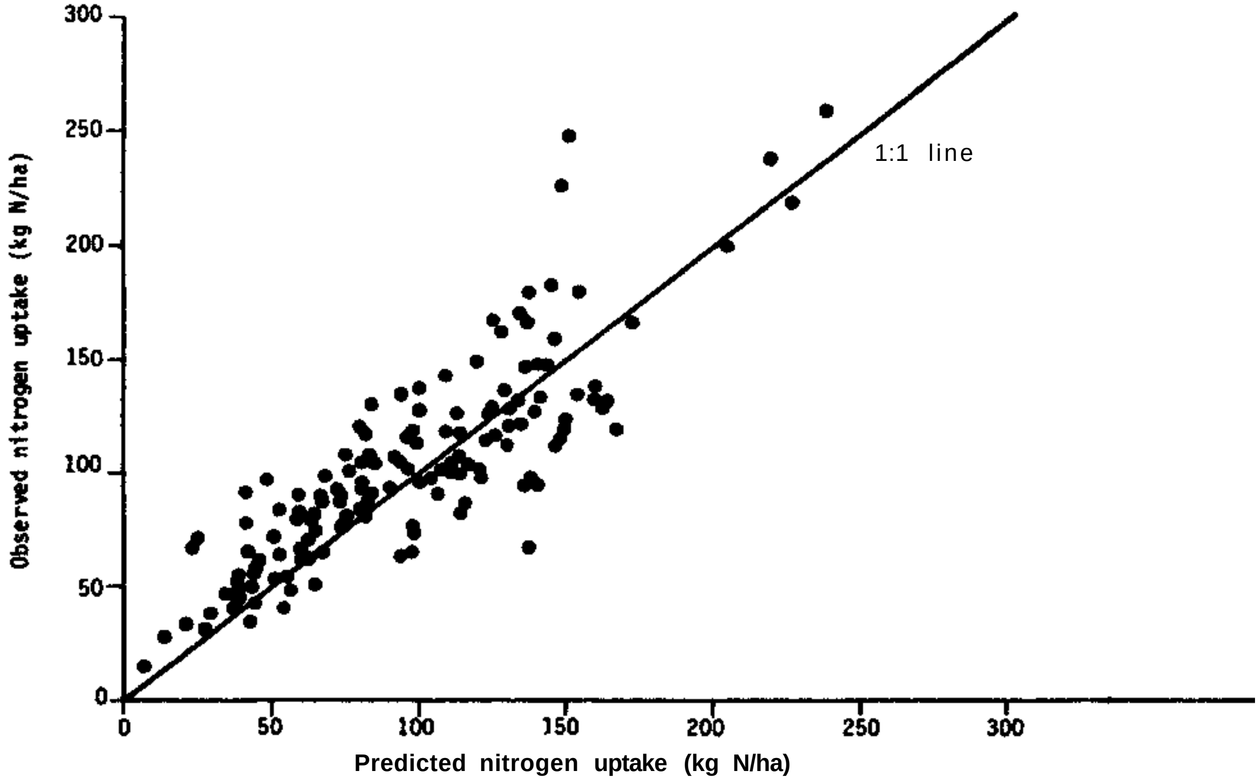

Figure 2. Validation of the nitrogen component of the CERES model.

Model Applications

Some possible model applications that may facilitate agrotechnology transfer are:

1. Identification of the physiological and phenological attributes of a cultivar needed to exploit to the maximum the climatic and soil environment to produce a higher yield.
2. Evaluation of various fertilizer strategies such as timing, rate, and depth of incorporation at a particular site.
3. Evaluation of irrigation and other agronomic strategies such as planting date and plant population.

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Heat Tolerance in Potato—an Explanatory Modeling Approach

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Abstract

Research at Cornell University and in other breeding programs has shown that useful levels of heat tolerance can be developed in the potato. The paper describes briefly the screening techniques developed to test for ability to tuberize under extremely unfavorable temperature conditions. This heat tolerance will be combined with resistance to various diseases and nematodes in one breeding population. The next step will be to breed and select heat-tolerant cultivars adapted to particular locations in the tropics. A quantitative simulation model is being constructed to aid in this task; field studies and controlled-environment experiments are also proposed. To supplement these, growth analyses on a set of six potato cultivars to be grown across a network of sites are also proposed.

Research at Cornell University under contract with the International Potato Center (CIP) is aimed at development of heat tolerance within populations of *Solanum tuberosum* sp *andigena.* Andigena types of potato are well suited to the cool temperatures and short photoperiods of the Andean highlands where the potato originated. Under long photoperiods and/or high temperatures, andigena potatoes tuberize poorly. Through recurrent selection within an andigena collection grown under long photoperiods, populations have been developed which will tuberize as well as the S. *tuberosum* sp *tuberosum* varieties normally grown in the temperate zone. We refer to these adapted populations as "neo-tuberosum."

A cutting technique has proved useful in screening for ability to tuberize under both long photoperiods and high temperatures (Ewing 1981). Plants to be screened are grown in a greenhouse under daily maximum temperatures of 40°C and minimum temperatures of 30°C. Photoperiods are maintained at 18 h. Tuberization on cuttings taken from plants grown under these extremely unfavorable conditions indicates that the clone possesses the ability to tuberize even at very high temperatures.

A second useful screening criterion for heat tolerance is the ability to produce total biomass at high temperatures. When combined with data on tuberization of cuttings, ratings for plant vigor in the hot greenhouse provide a reliable basis for selection of types that show heat tolerance in the field. According to regression analysis, tuberization on cuttings and vigor ratings of plants grown in the hot greenhouse were associated with 24% of the yield variation when plants of the same clones were grown in the field at San Ramon, Peru (Ewing et al. 1982). This was in spite of the presence in the field plots of a severe bacterial disease problem against which there had been no screening.

From our own results and from the progress in other breeding programs, we are convinced that useful levels of heat tolerance can be developed in the potato. We are now in the process of

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combining heat tolerance with resistance to various diseases and nematodes in one breeding population.

The next step will be breeding and selection of heat-tolerant cultivars adapted to particular locations in the tropics. This is an especially formidable task (Ewing and Keller 1982). The physiology of crop yield in the potato is complicated by the plasticity of the potato plant in its response to environmental changes. It is well known that cool temperatures and short photoperiods favor partitioning of dry matter to tubers. However, these conditions do not necessarily lead to the highest yields. Excessive tuberization early in the growing season will so restrict haulm and root growth that tuber yields, though early, will be low. Highest yields generally result from conditions that promote vigorous stem and leaf growth early in the season followed by strong induction to tuberize after a large canopy has been attained. Another complication is that the "sink" effect of developing tubers increases the net assimilation rate (Moorby and Milthorpe 1975). It is safe to predict that there are substantial genetic influences on all these interactions. With changes in climate and growing season from one part of the tropics to another, breeding and selection of heat-tolerant cultivars for each location could be an enormous task.

To make the job more feasible we are attempting to construct a quantitative simulation model as proposed by Moorby and Milthorpe (1975) for potato growth and development. Loomis et al. (1979) have reviewed the advantages of explanatory models. An explanatory model that incorporates cultivar differences in response to the effects of photoperiod and temperature should help create ideotypes for the tropics. It could help the breeder identify in a breeding population clones adapted to particular locations and growing seasons.

The model on which we are working was constructed by Ng and Loomis (unpublished). It is highly explanatory; that is, it describes the physiology of the potato in great detail. The model is hierarchical, describing the growth of potatoes at several levels—organ, whole plant, and community. This model was originally written to describe the growth and development of the Russet Burbank grown in Idaho, USA.

Environmental factors determine output from the model. Inputs to the model, on a daily basis, are: mean air temperature, mean dew point, total wind, and total radiation. The output is also dependent on the plant density, the latitude, and the crop emergence date. In addition, daylength is calculated from the latitude and time of year, and this is used by the model.

The program is structured in modules. Each module directs the simulated growth of a different plant part or process. There are modules for the growth of leaves, stems, branch leaves, branch stems, roots, and tubers. Other modules encompass photosynthesis, respiration, plant water, and community-level factors. Each of these modules is executed 24 times per simulated day.

One basic equation describes the growth of the plant parts:

$$GR = MRGR*W*f(AGE)*MIN(EA,\ ET,\ EW)$$

GR is the growth rate of the particular plant organ. MRGR is the maximum relative growth rate possible. W denotes the weight of the organ. The maximum rate is modified by several scaling factors that lie between 1.0 and 0.0. The first, f(AGE) is a function of the age of the organ. This "co-active" factor is followed by the "limiting" factors. These are the minimum values of the effect of assimilates (EA), temperature (ET), and water (EW). These values are determined from a function that describes the relationship between the factor (assimilates, temperature, and water) and the scaling factor.

Field studies are presently under way to provide data for modification of the model. Partitioning is controlled in the model by the simulated percent reserves in the plant, and little information is available on the actual reserve levels. In the present model, leaves get first priority for carbohydrate, stems second, and tubers last throughout the season. We are analyzing percent total nonstructural carbohydrates in stems, leaves, and tubers in three varieties on four harvest dates to improve this important model component. Likely improvements resulting from these data would be in adjustment of the priority relationships.

Even with these data, the partitioning function will be oversimplified, and would probably be inaccurate in a nontraditional environment. Data need to be collected that would allow modeling of the following interactions with partitioning: leaf number, organ age, temperature, photoperiod, and cultivar.

Other possible improvements are to incorporate the sink effect of tubers on photosynthesis and photosynthesis interactions with plant age, photoperiod, and cultivar.

In order to obtain information required for adapting the model to the tropics, we are planning experiments in the greenhouse and growth chamber to compare heat-tolerant and -sensitive clones at high and low temperatures with respect to: (1) net photosynthetic rates; (2) dark respiration rates; (3) tuberization of cuttings; (4) partitioning of total nonstructural carbohydrates; and (5) ^{14}C translocation.

To supplement the experiments under controlled environments we are proposing that growth analyses be carried out on a set of cultivars grown at a network of sites. Most of the sites would be in tropical locations, with a few in the temperate zone in order to obtain contrasting effects. The same set of six cultivars would be grown at each location, and standardized methods would be employed for periodic growth analyses. The goal at each site would be to make five harvests during the growing season to determine dry weights of leaves, stems, stolons, and tubers as well as leaf areas, numbers of stems and nodes, and stem lengths. A final harvest would be made for tuber yield. Simple meteorological data such as maximum and minimum temperatures, irradiance, and wind movement would be collected daily throughout the growing season. Other observations (soil characteristics, fertilization, irrigation, pest control, other cultural practices) would be recorded for future reference even though not included initially in the Cornell model.

Cultivars would consist of Desiree (European cultivar with wide adaptation and moderate heat tolerance), Norchip (early-maturing American cultivar with heat tolerance in greenhouse tests), Katahdin (American cultivar with broad adaptation to temperate conditions but low to moderate heat tolerance), LT-1 (heat-tolerant clone from CIP breeding program, selected for humid lowland tropics), and two heat-tolerant clones of neo-tuberosum from the Cornell contract with CIP.

The six cultivars are available in vitro at Cornell. They have been tested for freedom from PSTV viroid by DNA hybridization and PAGE and are free from known virus and bacterial diseases according to ELISA tests. Techniques have been developed to maintain these cultures under aseptic conditions, to multiply them at the rate of a 100-fold increase in plantlets per 6 weeks, and to mail them throughout the world as plantlets or "microtubers."

About 30 to 40 kg of seed tubers would be required for each cultivar per location. Provision of seed tubers to cooperators would depend upon the local situation. Some countries would have facilities and expertise to multiply their own seed tubers, starting from in vitro cultures supplied by Cornell or CIP. In other cases it would be necessary to ship in seed by air freight from an outside agency that would meet local quarantine restrictions. CIP has the experience to make these arrangements.

Data from each location would be published according to the wishes of the individual cooperators or in summarized form for more than one location if the individuals concerned preferred to do so. All of the data would be assembled at Cornell University and/or at CIP. The data would be used to improve and validate the model already under study at Cornell, but they would also be made available to anyone interested in receiving them.

The data should greatly aid our understanding of how cultivar differences are affected by photoperiod and temperature, especially if they contribute to the construction and validation of an explanatory model of growth and development. In addition to the long-range contributions toward development of cultivars adapted to the tropics, participants will have the opportunity to compare the performance of heat-tolerant clones under their local conditions and to compare their results with results in widely differing parts of the world.

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The EPIC Model and Its Application

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Abstract

EPIC (Erosion-Productivity Impact Calculator) is a comprehensive model developed to determine the relationship between soil erosion and soil productivity throughout the USA. It continuously simulates the processes involved, using a daily time step and readily available inputs. Since erosion can be a relatively slow process, the model is capable of simulating hundreds of years if necessary. EPIC is generally applicable, computationally efficient, and capable of computing the effects of management changes on outputs. EPIC is composed of (a) physically based components for simulating erosion, plant growth, and related processes and (b) economic components for assessing the cost of erosion, determining optimal management strategies, etc. The EPIC physical components include hydrology, weather simulation, erosion-sedimentation, nutrient cycling, plant growth, tillage, and soil temperature. Test results are reported for 12 sites in the continental USA and 13 sites in Hawaii, and model applications are used to demonstrate EPIC's usefulness in decision making.

Introduction

Accurate estimates of future soil productivity are essential in agricultural decision making and planning from the field scale to the national level. Soil erosion depletes soil productivity, but the relationship between erosion and productivity is not well defined. Until the relationship is adequately developed, selecting management strategies to maximize long-term crop production will be impossible.

The Soil and Water Resources Conservation Act (RCA) of the Congress of the United States requires a report by 1985 that establishes the current status of soil and water resources in the USA. One important aspect of these resources is the effect of erosion on long-term soil productivity. The National Soil Erosion-Soil Productivity Research Planning Committee documented what is known about the problem, identified what additional knowledge is needed, and outlined a research approach for solving the problem (Williams et al. 1981). One of the most urgent and important needs outlined in the research approach was the development of a mathematical model for simulating erosion, crop production, and related processes. This model will be used to determine the relationship between erosion and productivity for the USA. Thus, a national Agricultural Research Service (ARS) erosion-productivity modeling team[1] was organized and began developing the model during 1981. The model called EPIC (Erosion-Productivity Impact Calculator) is composed of physically based components for simulating erosion, plant growth, and related processes, and economic components for assessing the cost of erosion, determining optimal management strategies, etc.

[1]J.R. Williams, M.J. Shaffer, KG. Renard, G.R. Foster, J.M. Laflen, L. Lyles, C.A. Onstad, A.N. Sharpley, A.D. Nicks, C.A. Jones, C.W. Richardson, P.T. Dyke, K.R, Cooley, S.J. Smith.

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EPIC simulates the physical processes involved simultaneously and realistically using readily available inputs. Commonly used EPIC input data (weather, crop, tillage, and soil parameters) are available from a computer filing system assembled especially for applying EPIC throughout the USA. Since erosion can be a relatively slow process, EPIC is capable of simulating hundreds of years if necessary. EPIC is generally applicable, computationally efficient (operates on a daily time step), and capable of computing the effects of management changes on outputs.

The components of EPIC can be placed into eight major divisions for discussion—hydrology, weather, erosion, nutrients, plant growth, soil temperature, tillage, and economics. A detailed description of the EPIC components was given by Williams et al. (1982). A brief description of each of the eight components, results of limited testing, and sample applications are presented here.

Model Description

Although EPIC is a fairly comprehensive model, it was developed specifically for application to the erosion-productivity problem. Thus, user convenience was an important consideration in designing the model. The computer program contains 53 subroutines, although there are only 2700 FORTRAN statements. Since EPIC operates on a daily time step, computer cost for overnight turn around is only about $0.15 per year of simulation on an AMDAHL 470 computer. The model can be run on a variety of computers since storage requirements are only 210 K.

The drainage area considered by EPIC is generally small (~ 1 ha) because soils and management are assumed to be spatially homogeneous. In the vertical direction, however, the model is capable of working with any variation in soil properties—the soil profile is divided into a maximum of ten layers (the top layer thickness is set at 10 mm and all other layers may have variable thickness). When erosion occurs, the second layer thickness is reduced by the amount of the eroded thickness, and the top layer properties are adjusted by interpolation (according to how far it moves into the second layer). When the second layer thickness becomes zero, the top layer starts moving into the third layer, etc.

Hydrology

Surface Runoff

Surface runoff of daily rainfall is predicted using a procedure similar to the CREAMS runoff model, option one (Knisel 1980; Williams and Nicks 1982). Like the CREAMS model, runoff volume is estimated with a modification of the SCS curve number method (USDA Soil Conservation Service 1972). There are two differences between the CREAMS and EPIC daily runoff hydrology components: (1) EPIC accommodates variable soil layer thickness; and (2) EPIC includes a provision for estimating runoff from frozen soil.

Peak runoff rate predictions are based on a modification of the Rational Formula. The runoff coefficient is calculated as the ratio of runoff volume to rainfall. The rainfall intensity during the watershed time of concentration is estimated for each storm as a function of total rainfall using a stochastic technique. The watershed time of concentration is estimated using Manning's Formula considering both overland and channel flow.

Percolation

The percolation component of EPIC uses a storage routing technique combined with a crack-flow model to predict flow through each soil layer in the root zone. Once water percolates below the root zone, it is lost from the watershed (becomes groundwater or appears as return flow in downstream basins). The storage routing technique is based on travel time (a function of hydraulic conductivity) through a soil layer. Flow through a soil layer may be reduced by a saturated lower soil layer.

The crack-flow model allows percolation of infiltrated rainfall even though the soil water content is less than field capacity. When the soil is dry and cracked, infiltrated rainfall can flow through the cracks of a layer without becoming part of the layer's soil water. However, the portion that does become part of a layer's stored water cannot percolate until the storage exceeds field capacity.

Percolation is also affected by soil temperature. If the temperature in a particular layer is 0°C or below, no percolation is allowed from that layer. Water can, however, percolate into the layer if storage is available.

Since the 1-day time interval is relatively long for routing flow through soils, EPIC divides the water into 4 mm slugs for routing. This is necessary because the flow rates are dependent upon soil water content which is continuously changing. Also, by dividing the inflow into 4 mm slugs and routing each slug individually through all layers, the lower layer water content relationship is allowed to function.

Lateral Subsurface Flow

Lateral subsurface flow is calculated simultaneously-with percolation. Each 4 mm slug is given the opportunity to percolate first and then the remainder is subjected to the lateral flow function. Thus, lateral flow can occur when the storage in any layer exceeds field capacity after percolation. Like percolation, lateral flow is simulated with a travel time routing function.

Drainage

Underground drainage systems are treated as a modification to the natural lateral subsurface flow of the area. Simulation of a drainage system is accomplished by shortening the lateral flow travel time of the soil layer that contains the drainage system. The travel time for a drainage system depends upon the soil properties and the drain spacing.

Evapotranspi ration

The evapotranspi ration component of EPIC is Ritchie's ET model (Ritchie 1972). The model computes potential evaporation as a function of solar radiation, air temperature, and albedo. The albedo is evaluated by considering the soil, crop, and snow cover. The model computes soil and plant evaporation separately. Potential soil evaporation is estimated as a function of potential evaporation and leaf area index (area of plant leaves relative to the soil surface area). The first-stage soil evaporation is equal to the potential soil evaporation. Stage 2 soil evaporation is predicted with a square root function of time. Plant evaporation is estimated as a linear function of potential evaporation and leaf area index.

Irrigation

The EPIC user has the option to simulate dryland or irrigated agricultural areas. If irrigation is indicated, he must also specify the irrigation efficiency, a plant water stress level to start irrigation, and whether water is applied by sprinkler or down the furrows. When the user-specified stress level is reached, enough water is applied to bring the root zone up to field capacity plus enough to satisfy the amount lost if the application efficiency is less than one. The excess water applied to satisfy the specified efficiency becomes runoff and provides energy for erosion.

Snow Melt

The EPIC snow melt component is similar to that to that of the CREAMS model (Knisel 1980). If snow is present, it is melted on days when the maximum temperature exceeds 0°C, using a linear function of temperature. Melted snow is treated the same as rainfall for estimating runoff, percolation, etc.

Weather

The weather variables necessary for driving the EPIC model are precipitation, air temperature, solar radiation, and wind. If daily precipitation, air temperature, and solar radiation data are available, they can be input directly to EPIC. Rainfall and temperature data are available for many areas of the USA, but solar radiation and wind data are scarce. Even rainfall and temperature data are generally not adequate for the long-term EPIC simulations (50 years $^{+}$). Thus, EPIC provides options for simulating temperature and radiation given daily rainfall or for simulating rainfall as well as temperature and radiation. If wind erosion is to be estimated, daily wind velocity and direction are simulated.

Precipitation

The EPIC precipitation model developed by Nicks (1974) is a first-order Markov chain model. Thus the model must be provided as input monthly probabilities of receiving precipitation if the previous day was dry and monthly probabilities of receiving precipitation if the previous day was wet. Given the wet-dry state, the model determines stochastically if precipitation occurs or not.

When a precipitation event occurs, the amount is determined by generating from a skewed normal daily precipitation distribution. Inputs necessary to describe the skewed normal distribution for each month are the mean, standard deviation, and skew coefficient for daily precipitation. The amount of daily precipitation is partitioned between rainfall and snowfall using average daily air temperature.

Air Temperature and Solar Radiation

The temperature-radiation model developed by Richardson (1981) was selected for use in EPIC because it simulates temperature and radiation that exhibit proper correlation between one another and rainfall. The residuals of daily maximum and minimum temperature and solar radiation are generated from a multivariate normal distribution. Details of the multivariate generation model were described by Richardson (1981). The dependence structure of daily maximum temperature, minimum temperature, and solar radiation was described by Richardson (1982a).

Wind

The wind simulation model was developed by Richardson (1982b) for use in simulating wind erosion with EPIC. The two wind variables considered are average daily velocity and daily direction. Average daily wind velocity is generated from a two-parameter Gamma distribution. Wind direction expressed as radians from north in a clockwise direction is generated from an empirical distribution specific for each location

Erosion

Water

The water erosion component of EPIC uses a modification of the USLE (Wischmeier and Smith 1978) developed by Onstad and Foster (1975). The Onstad-Foster equation's energy factor is composed of both rainfall and runoff variables. In contrast, the USLE energy factor contains only rainfall variables.

The hydrology model supplies estimates of runoff volume and peak runoff rate. To estimate the daily rainfall energy in the absence of time-distributed rainfall, it is assumed that the rainfall rate is exponentially distributed. This allows for simple substitution of rainfall rates into the USLE equation for estimating rainfall energy. The fraction of rainfall that occurs during 0.5 h is simulated stochastically.

The crop management factor is evaluated with a function of above-ground biomass, crop residue on the surface, and the minimum factor for the crop. Other factors of the erosion equation are evaluated as described by Wischmeier and Smith (1978).

Wind

The Manhattan, Kansas, wind erosion equation (Woodruff and Siddoway 1965), was modified by Cole et al. (1982) for use in the EPIC model. The original equation computes average annual wind erosion as a function of soil erodibility, a climatic factor, soil ridge roughness, field length along the prevailing wind direction, and vegetative cover. The main modification to the model was converting from annual to daily predictions to interface with EPIC.

Two of the variables, the soil erodibility factor for wind erosion and the climatic factor, remain constant for each day of a year. The other variables, however, are subject to change from day to day. The ridge roughness is a function of a ridge height and ridge interval. Field length along the prevailing wind direction is calculated by considering the field dimensions and orientation and the wind direction. The vegetative cover equivalent factor is simulated daily as a function of standing live biomass, standing dead residue, and flat crop residue. Daily wind energy is estimated as a nonlinear function of daily wind velocity.

Nutrients

Nitrogen

The amount of $N0_3$-N in runoff is estimated by considering the top soil layer (10 mm thickness) only. The decrease in NO3-N concentration caused by water flowing through a soil layer can be simulated satisfactorily using an exponential function. The average concentration for a day can be obtained by integrating the exponential function to give NO3-N yield and dividing by volume of water leaving the layer (runoff, lateral flow, and percolation). Amounts of NO_3-N contained in runoff, lateral flow, and percolation are estimated as the products of the volume of water and the average concentration.

Leaching and lateral subsurface flow in lower layers are treated with the same approach used in the upper layer, except that surface runoff is not considered.

When water is evaporated from the soil, NO_3-N is moved upward into the top soil layer by mass flow. Thus, the total NO_3-N moved upward into the top layer by evaporation is the product of soil evaporation and NO3-N concentration of each layer to a maximum depth of 300 mm.

A loading function developed by McElroy et al. (1976) and modified by Williams and Hann (1978) for application to individual runoff events is used to estimate organic N loss. The loading function estimates the daily organic N runoff loss based on the concentration of organic N in the top soil layer, the sediment yield, and the enrichment ratio. The enrichment ratio is the concentration of organic N in the sediment divided by that of the soil. A two-parameter logarithmic function of sediment concentration is used to estimate enrichment ratios for each event.

Denitrification, one of the microbial processes, is a function of temperature and water content. Denitrification is only allowed to occur when the soil water content is 90% of saturation or greater. The denitrification rate is estimated using an exponential function involving temperature, organic carbon, and NO3-N.

The N mineralization model is a modification of the PAPRAN mineralization model (Seligman and van Keulen 1981). The model considers two sources of mineralization: fresh organic N associated with crop residue and microbial biomass and the stable organic N associated with the soil humus pool. The mineralization rate for fresh organic N is governed by C:N and C.P ratios, soil water, temperature, and the stage of residue decomposition. Mineralization from the stable organic N pool is estimated as a function of organic N weight, soil water, and temperature.

Like the mineralization model, the immobilization model is a modification of the PAPRAN model. Immobilization is a very important process in EPIC because it determines the residue decomposition rate and residue decomposition has an important effect on erosion. The daily amount of immobilization is computed by subtracting the amount of N contained in the crop residue from the amount assimilated by the microorganisms. Immobilization may be limited by N or P availability.

Crop use of N is estimated using a supply and demand approach. The daily crop N demand is estimated as the product of biomass growth and optimal N concentration in the plant. Optimal crop N concentration is a function of growth stage of the crop. Soil supply of N is assumed to be limited by mass flow of NO_3-N to the roots. Actual N uptake is the minimum of supply and demand.

Fixation of N is an important process for legumes. EPIC estimates fixation by adding N in an attempt to prevent N stress that constrains plant growth. Plant growth is limited by the minimum of four factors (N, P, water, and temperature) each day. If N is the active constraint, enough N (a maximum of 2 kg/ha per day) is added to the plant to make the N stress factor equal the next most constraining factor if possible. The amount of N added is attributed to fixation.

To estimate the N contribution from rainfall, EPIC uses an average rainfall N concentration for a location for all storms. The amount of N in rainfall is estimated as the product of rainfall amount and concentration.

EPIC provides two options for applying fertilizer. With the first option, the user specifies dates, rates, and depths of application of N and P. The second option is more automated—the only input required is a plant stress parameter. At planting time, the model takes a soil sample and applies up to 15 kg/ha of N fertilizer if needed. The model also applies enough P to bring the concentration of labile P in the top two layers up to the concentration level at the start of the simulation. There are two opportunities for applying additional N fertilizer during the growing season (at 25 and 50% of maturity). The amount of N applied at each of these two top dressings is determined by predicting the final crop biomass.

Phosphorus

The EPIC approach to estimating soluble P loss in surface runoff is based on the concept of partitioning pesticides into the solution and sediment phases as described by Leonard and Wauchope (Knisel 1980). Because P is mostly associated with the sediment phase, the soluble P runoff is predicted using labile P concentration in the top soil layer, runoff volume, and a partitioning factor.

Sediment transport of P is simulated with a loading function as described in organic N transport. The loading function estimates the daily sediment phase P loss in runoff based on P concentration in the top soil layer, sediment yield, and the enrichment ratio.

The P mineralization model developed by Jones, Cole, and Sharpley (C.A. Jones, C.V. Cole and A.N. Sharpley, 1982, A simplified soil phosphorus model, I. Documentation) is similar in structure to the N mineralization model. Mineralization from the fresh organic P pool is governed by C:N and C:P ratios, soil water, temperature, and the stage of residue decomposition. Mineralization from the stable organic P pool associated with humus is estimated as a function of organic P weight, labile P concentration, soil water, and temperature.

The P immobilization model also developed by Jones et al. (1982) is similar in structure to the N immobilization model. The daily amount of immobilization is computed by subtracting the amount of P contained in the crop residue from the amount assimilated by the microorganisms.

The mineral P model was developed by Jones et al. (1982). Mineral P is transferred among three pools: labile, active mineral, and stable mineral. When P fertilizer is applied, it is labile (available for plant use). However, it may be quickly transferred to the active mineral pool. Simultaneously, P flows from the active mineral pool back to the labile pool (usually at a much slower rate). Flow between the labile and active mineral pools is governed by temperature, soil water, a P sorption coefficient, and the amount of material in each pool. The P sorption coefficient is a function of chemical and physical soil properties. Flow between the active and stable mineral P pools is governed by the concentration of P in each pool and the P sorption coefficient.

Crop use of P is estimated with the supply and demand approach described in the N model. However, the P supply is predicted using an equation based on soil water, plant demand, a labile P factor, and root weight.

Soil Temperature

Daily average soil temperature is simulated at the center of each soil layer for use in nutrient cycling and hydrology. The temperature of the soil surface is estimated using daily maximum and minimum air temperature, solar radiation, and albedo for the day of interest plus the 4 days immediately preceding. Soil temperature is predicted for each layer using a function of damping depth, surface temperature, mean annual air temperature, and the amplitude of daily mean temperature. Damping depth is dependent upon bulk density and soil water.

Crop Growth Model

A single model is used in EPIC for simulating all the crops considered (corn, grain sorghum, wheat, barley, oats, sunflower, soybean, alfalfa, cotton, groundnut, and grasses). Of course, each crop has unique values for the model parameters. Energy interception is estimated with an equation based on solar radiation, daylight hours, and the crop's leaf area index. The potential increase in biomass for a day can be estimated by multiplying the amount of intercepted energy times a crop parameter for converting energy to biomass. The leaf area index, a function of biomass, is simulated with equations dependent upon the maximum leaf area index for the crop, the above-ground biomass, and a crop parameter that initiates leaf area index decline.

The daily fraction of the potential increase in biomass partitioned to yield is estimated as a function of accumulated heat units and the ratio of total biomass to crop yield under favorable growing conditions. Since most of the accumulating biomass is partitioned to yield late in the growing season, late-season stresses may reduce yields more than early-season stresses. Root growth and sloughing are simulated using a linear function of biomass and heat units.

The potential biomass is adjusted daily if one of the plant stress factors is less than 1.0 using the product of the minimum stress factor and the potential biomass. The water-stress factor is computed by considering supply and demand (the ratio of plant accessible water to potential plant evaporation). Roots are allowed to compensate for water deficits in certain layers by using more water in layers with adequate supplies.

The temperature stress factor is computed with a function dependent upon the daily average temperature, the optimal temperature, and the base temperature for the crop.

The N and P stress factors are based on the ratio of accumulated plant N and P to the optimal values. The stress factors vary nonlinearly from 1.0 at optimal N and P levels to 0.0 when N or P is half the optimal level.

Root growth in a layer is affected by soil water, soil texture, bulk density, temperature, aeration, and aluminum toxicity. Potential root growth is a function of soil water in a layer. It is then reduced with a stress factor which is the minimum of stresses due to soil texture and bulk density, temperature, aeration, and aluminum toxicity. The soil texture-bulk density relationship was developed by Jones (1983). The aeration factor is based on percent air-filled porosity. The temperature factor is based on soil temperature and crop-specific temperature response curves. The aluminum toxicity factor is based on percent aluminum saturation and a crop-specific aluminum susceptibility relationship.

Lime

EPIC simulates the use of lime to neutralize toxic levels of aluminum in the plow layer. Two sources of acidity are considered. KCl-extractable aluminum in the plow layer and the acidity associated with addition of ammonia-based fertilizers. The lime requirement due to KCl-extractable aluminum is estimated according to Kamprath (1970). All fertilizer N is assumed to be urea, ammonium nitrate, or anhydrous ammonium, all of which produce similar acidity when applied to the soil. When the sum of acidity due to extractable aluminum and fertilizer N sum to 4 tonnes lime/ha, the required amount of lime is added and incorporated into the plow layer.

Tillage

The EPIC tillage component was designed to mix nutrients and crop residue within the plow depth, simulate the change in bulk density, and convert standing residue to flat residue. Each tillage operation is assigned a mixing efficiency (0-1). Other functions of the tillage component include simulating row height and surface roughness.

There are three means of harvest in the EPIC model—(1) traditional harvest that removes seed, fiber, etc. (multiple harvests are allowed for crops like cotton); (2) hay harvest (may occur on any date the user specifies); and (3) no harvest (green manure crops, etc.). When hay is harvested, the yield is computed as a function of mowing height and crop height. Tillage operations convert standing residue to flat residue using an exponential function of tillage depth and mixing efficiency. When a tillage operation is performed, a fraction of the material (equal the mixing efficiency) is mixed uniformly within the plow depth. Also, the bulk density is reduced as a function of the mixing efficiency, the bulk density before tillage, and the undisturbed bulk density. After tillage, the bulk

Table 1. Comparisons of simulated and measured crop yields for sites in the continental USA.

State and County	No. of years	Crop	Yield (kg/ha)		Standard deviation	
			Measured	Simulated	Measured	Simulated
Iowa						
Monona	5	Corn	6996	7653	1110	1035
Monona	5	Oats	1755	2225	774	1000
Monona	10	Corn	6162	7325	1908	1895
Ringold	7	Corn	7270	7235	1702	798
Ringold	7	Soybeans	1910	2065	284	531
Ringold	10	Corn	6593	7095	1296	1075
Story	5	Corn	6664	7580	815	790
Story	5	Corn	6575	7265	922	1215
Story	5	Corn	6077	7250	1279	1210
Story	4	Corn	7033	7205	1010	1175
Missouri						
Boone	10	Corn	7833	7632	2077	1635
Ohio						
Coshocton	3	Corn	8399	7460	2665	2020

density returns to the undisturbed value at a rate dependent upon infiltration, tillage depth, and soil texture.

Model Tests

EPIC simulations have been performed on 150 test sites in the continental USA and 13 in Hawaii. Crop yield results of the simulations for 12 of the test sites from the continental USA are shown in Table 1. These 12 test sites were carefully conducted experiments that provided measured inputs for weather, management practices, and fertilizer rates. Table 1 contains both measured and simulated means and standard deviations of crop yields. It is important that simulation models produce frequency distributions that are similar to those of measured data. Close agreement between simulated and measured means and standard deviations indicates that the frequency distributions are similar. Generally, the simulated

Table 2. Comparison of measured and predicted corn yields for irrigated plots iin Hawaii with various N fertilizer rates.

Plot name	Measured/predicted yield (kg/ha) at N fertilizer rate (kg/ha) of					
	0	29	70	108	144	186
KALB B21	2655	4971	6441	7 059	7 622	8 169
	1848	3244	4558	5 439	6 455	7 527
IOLE E11	3202	5079	6638	7 439	6 957	7 176
	3102	4100	5200	6 365	7 287	8 404
IOLE 110	3723	3268	4076	5 580	6 409	6 600
	3115	3949	5196	6 681	7 590	7 919
KUK A21	3616	6499	6357	6 561	7 174	6 962
	3386	4294	5603	6 614	7 436	7 634
KUK A22	1733	3357	4190	4 457	4 673	4 549
	3672	4420	4929	5 186	5 245	5 296
KUK C11	4005	7358	7257	8 269	8 161	8 768
	3679	4460	5747	6818	7 832	8 825
KUK D11	3715	6293	7663	8 254	8 291	8 471
	3976	4735	5802	6 737	7 652	8 551
KUK D12	2867	5546	6889	7 766	7 892	8 828
	3118	4207	5396	6 654	7 763	8 870
MOL A10	6628	7953	9266	9 928	9 390	10 462
	6451	7712	8990	10 148	10 704	10918
MOL A11	2162	3833	4971	5 343	5 443	5 537
	2978	3670	4794	5 855	6 545	7 599
	N fertilizer rate (kg/ha)					
	0	32	83	129	174	225
HAL 822	891	2292	5339	6863	7815	8629
	2242	3610	4664	6003	7223	8320
KUK C12	3824	7249	8221	8984	9213	9262
	3428	4281	6200	7426	8569	9651
	N fertilizer rate (kg/ha)					
	0	27	63	95	127	163
MOL B10	2539	4983	6087	6985	8546	8773
	2214	2945	3835	4718	5606	6457

results compare closely with the measured values, although it is difficult to obtain accurate estimates of standard deviations with such short periods of record.

Table 2 shows results from 13 test sites in Hawaii. Data from each site included corn yield for one growing season, weather information, management practices, and fertilizer rates. Although it is not possible to estimate means and standard deviations with only 1 year's data, these sites provide an excellent test of EPIC's response to N fertilizer. The simulated yields generally agree fairly well with measured yields, although there is some discrepancy for some sites at low levels of N fertilizer. Overall, the test results appear satisfactory, particularly since the crop and all other model parameters remained constant for all tests shown in Tables 1 and 2.

Model Application

EPIC can be used to estimate the effects of varying one management practice (e.g., irrigation, fertilizer rate, or planting date) while holding all other practices constant. This simulation strategy can predict the effect of eliminating or reducing a single limiting factor. However, when one limiting factor is removed, others often replace it before yields increase dramatically. Thus, entirely new management strategies must often be developed to improve several components of the farming system. This approach has been used at ICRISAT in its development of new farming systems, and it can also be simulated with EPIC.

As an example of possible EPIC applications in technology transfer, four management strategies were simulated for the deep Vertisol at ICRISAT (Table 3). Soil chemical and physical characteristics were taken from ICRISAT (1981). Weather generator parameters were obtained from ICRISAT (1982), and crop growth was simulated over a 50-year period. The first management strategy is similar to a traditional system. Grain sorghum is planted in the postrainy season without fertilizer N or P (Table 3). In this system, N deficiency limited mean simulated grain sorghum yield to 547 kg/ha, which is similar to the 483 kg/ha mean yield at ICRISAT from 1976 to 1981 (ICRISAT 1981). When fertilizer N and P were added to the traditional system, N deficiency was eliminated and simulated grain sorghum yields approximately doubled. Similar responses were found at Sholapur and Bellary, India, on similar Vertisols (ICRISAT 1981). When N deficiency was eliminated, cool temperatures and water stress became the most important constraints on grain sorghum yield. To alleviate these stresses, the crop was planted in the rainy season when moisture and temperature limitations are not as great. In this case, maize was planted instead of grain sorghum because mold-resistant, humidity-tolerant sorghum germplasm is not available at ICRISAT (Kampen 1982). From 1976 to 1981, the improved maize-chickpea sequential system gave a mean maize yield of 3200 kg/ha (ICRISAT 1981). The simulated 50-year mean yield for this system was 3430 kg. Note also that rainy-season strategies reduced runoff and erosion—particularly when fertilizer was added (Table 3).

Thus, the EPIC simulations of the several management strategies for deep Vertisols at ICRISAT seem to be realistic. With additional testing and possible modification, EPIC could be used to predict the effects of management

Table 3. Comparisons of four simulated cropping systems on a deep Vertisol at ICRISAT (50-year means).

Crop	Season	Fertilizer (kg/ha) N	Fertilizer (kg/ha) P	Rainfall (mm)	Runoff (mm)	Soil loss (t/ha)	Yield (kg/ha) Dry matter	Yield (kg/ha) Grain
Grain sorghum	Postrainy	0	0	809	143	9.1	1450	547
Grain sorghum	Postrainy	45	25	809	101	4.9	3750	1370
Maize	Rainy	0	0	809	141	6.7	1830	673
Maize	Rainy	45	25	809	75	2.5	9200	3430

strategies on agricultural production throughout the tropics. Two factors currently limit the use of EPIC for this purpose: familiarity of the EPIC modeling team with soil, crop, and climatic cohditions in the tropics and availability of minimum data sets for model testing and validation. We hope that the participants in this symposium can help remove these limitations.

Conclusions

The EPIC model is operational and has produced reasonable results under a variety of climatic conditions, soil characteristics, and management practices.

More extensive testing is planned for EPIC. Although some components of the model like hydrology and erosion are based on accepted technology, other components will require rigorous testing for validation. The two components that will need testing most are crop growth and nutrients. This is true because these are newly developed and because they are extremely important to the success of the EPIC model.

EPIC has many potential uses beyond the RCA analysis including: (a) conservation policy studies; (b) program planning and evaluation; (c) project level planning and design; and (d) as a research tool.

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Base Data Collection and Analysis

Using Climatic Data for Estimating Representativeness and Testing Crop Simulation Models

C. Sakamoto, T. Phillips, and T. Hodges*

Abstract

The IBSNAT agrotechnology transfer program will involve processing large complex data sets that can be used to determine whether it is environmentally feasible to grow selected cultivars in areas where they had not been grown before. Potential agroclimatic tools are available which utilize simple data sets. It is suggested that these tools be used initially to provide, at minimum cost, a first approximation on the suitability of the growing area. Climatic and crop data can also be used with simulation models to complement other methods. All of these tools, however, will require a data set that is quality-controlled and structured in such a manner that data can be retrieved quickly and easily and analyzed cost-effectively. This paper presents suggestions to address these potential problems.

"Representativeness" as defined by Webster is "the characteristics of a scientific experiment that makes an adequate sample of the general case." In the context of the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) program, representativeness is illustrated as follows. Given (1) an experimental site with a known crop response and (2) a new area with similar edaphic and management characteristics as the experimental sites, is it possible for the crop to be successfully adapted at this new location with productivity similar to the experimental site? Because the soil-plant-atmosphere continuum interaction is very complex and response is highly variable under different environmental conditions, it is difficult to find perfect analogues. Therefore, to determine whether a cultivar can be successfully transferred, one must ask: to what degree can one expect the climatic conditions at the experimental site and the extended area to be similar?

In this paper we propose that information from simple climatic data analysis will help any technology transfer program. Climatic data are a valuable resource that can be used in identifying potential crop extension areas. Appropriate climatic data can be used to supplement information gained from crop simulation modeling and testing efforts. This paper will also discuss potential methods to deal with representativeness or similarity. In addition, experience gained at the Assessment and Information Services Center (formerly the Center for Environmental Assessment Services) in dealing with climatic data collection, management, and analysis will be discussed.

Methods

Description of the agroclimate for an area is a time-space data problem. The space domain can be illustrated from Figure 1. If we want to transfer the results of an experiment at station A to crop region R, we need to determine how similar R is to A. Ideally, it would be desirable to have identical types of observations at several locations, e.g., B, C, D. In reality, however, this is often not possible;

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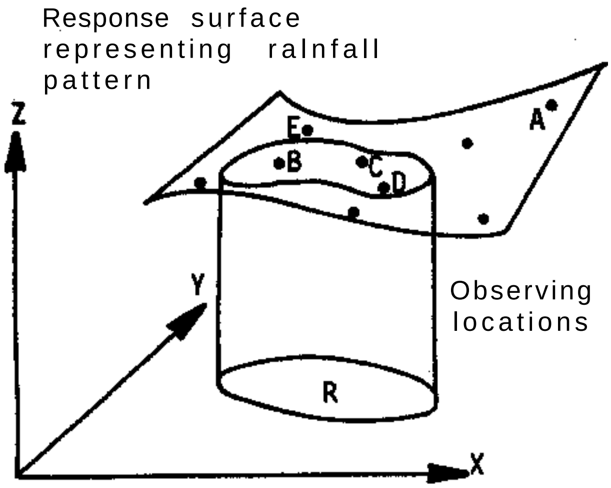

Figure 1. Illustration of the space domain of crop region R represented by station B, C, and D. A is an experimental site, the technology of which is to be transferred to R; E is a station outside the crop region.

frequently data outside the area of interest, such as E in Figure 1, may be available. This situation leads to a large degree of uncertainty in space.

The time problem is just as severe; records may be missing due to instrument malfunction, or contain errors due to calibration shifts, observer mistakes, station moves, etc. This leads, consequently, to a measure of uncertainty. Year-to-year variability in weather can cause large fluctuations in crop production. Therefore, the problem of representativeness from a user's view is a value judgment; it not only requires user inputs on criteria for crop adaptation but also requires decisions to determine the degree of risk involved and of the risk the user is willing to accept from atmospheric unknowns in the time-space domain.

This uncertainty requires a test criterion that involves the probability of a selected variable(s) reaching a threshold value. With many potential climatic factors, the practical approach is to select a forcing function or limiting variable that impacts differences or similarities. An example of this approach was reported by Williams (1983) in Canada. He developed an agroclimatic resource index (ACRI) utilizing the freeze-free growing season length. He judged this factor to be the most important constraint in land-use planning and climatic resource sensitivity analysis. In the semi-arid tropics, we might be concerned about the differences at two sites on a hill with similar amounts of rainfall. If one faced north and the other south, the energy distribution—and hence the soil water balance—may differ. Solar radiation may therefore be the limiting factor to be considered in the water balance.

Moisture availability may also be a limiting factor. Hargreaves (1981) proposed a simple moisture availability index (MAI) that has been used to assess land use for maize and sorghum in South America. MAI is defined as the ratio of PD to PET, where PD is the amount of rainfall associated with the 75% probability and PET the potential evapotranspiration. An index of 1.00 indicates that 75% of the time precipitation is nearly adequate for the crop water requirement. The example for Honduras (Figure 2) shows four possible areas for crop extension. At Atlantida in the north and Choluteca in the south, rainfall deficiency could occur but the major problem is excess rain. Comayagua is relatively dry; crop extension would not be economically feasible without irrigation. In the Guayape Valley, the MAI is near 1.00; the low probability of excess rain indicates this would be a feasible area for expansion based on climatic factors.

Another approach to address representativeness is illustrated by Figure 3. Gommes and Houssian (1982) classified areas in Tanzania for potential maize and sorghum production and estimated the likelihood of yield reduction due to water stress. The probability of precipitation exceeding the crop water requirement at specific growth stages was determined. Water consumption is computed by multiplying appropriate crop coefficients (Doorenbos and Pruitt 1977) by normal potential evapotranspiration (PET) calculated according to Penman and described by Frere and Popov (1979). The maximum crop coefficient K_m, when multiplied by PET, approximates the crop water requirement. A lower threshold crop coefficient value, K_i, is used to estimate a lower boundary of crop water consumption need. For Gommes and Houssian's study, this lower threshold was established at 0.5. When both water requirements in each month are compared with the frequency with which precipitation exceeds this crop requirement, different types of curves representing different probability levels evolve. The distribution is based on the assumption of an incomplete Gamma distribution, although other distributions could be used. The value judgment is, of course, the probability risk level that one is willing to take to develop new but

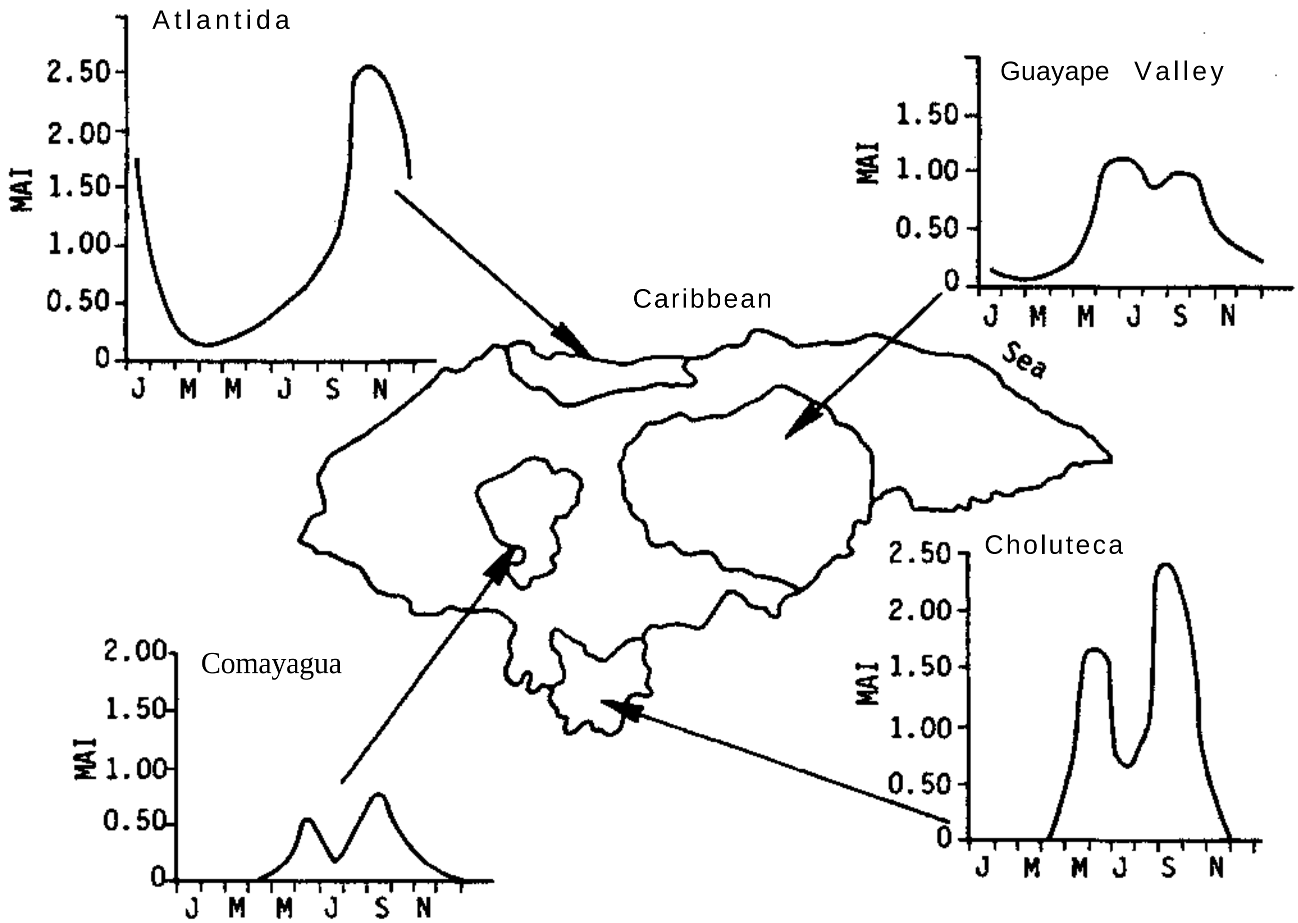

Figure 2. Moisture availability index (MAI) for four areas in Honduras (adapted from Hargreaves 1981).

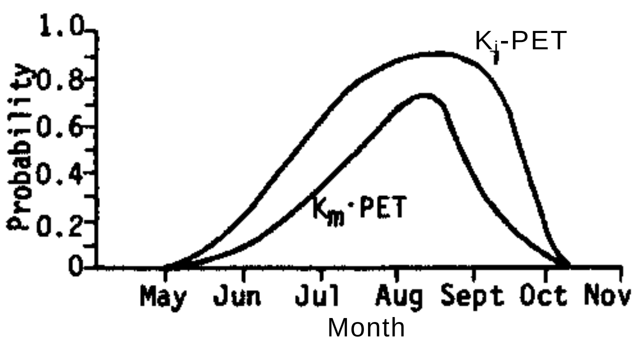

Figure 3. Probability of precipitation exceeding the maximum crop water requirement (K_m . PET) and the threshold crop water requirement (K_1. PET) (adapted from Gommes and Houssian 1982).

potentially productive land, A quantitative way to evaluate the similarity at two sites i and j is to consider the probability (P) difference of precipitation exceeding water requirements. This can be shown as G, the generalized distance:

$$G_{ij} = \quad (P_{ik} - P_{jk})^2 \; k = 1, n \qquad (1)$$

where k is the n number of probability months (12 months, times 4 crop coefficients). Values of selected levels of G can be used to cluster stations that are similar.

We have so far discussed the space-time variability issue and illustrated the use of key forcing functions to quantify representativeness. Because representativeness is a function of the time-space domain and the crop under consideration, it is also necessary to specify the significance of the variable at different times in the growth cycle of the plant. One method is to use a weighting scheme. One example of this approach is the Generalized Monsoon Index (Achutuni et al. 1982) which weights the seasonal water requirements. The largest weight is assigned to the time of greatest water need. The probability of receiving the required amount could be used as a representativeness criterion.

Nappo et al. (1982) suggest a criterion for an experimental site-to-area representativeness as follows:

$$\underline{P}r\{(q - q)^2 < \varphi^2\} = 0.80 \qquad (2)$$

This equation shows that there is an 80% probability that the experimental site variable q lies within ± φ of the extended area mean value q. If the variable q at an experimental site is normally distributed with variance a^2, the probability that it lies within one standard deviation of the mean is 68%. This can also be expressed as:

$$Pr\{(q - q)^2 \leq a_q^2\} = 0.68 \qquad (3)$$

If the variability of the extended area is greater than the variability of the experimental site, the extended area is not likely to be representative. Figure 4 illustrates this with the classical normal distribution; in all three cases the mean is identical but the standard deviation differs. One might conclude that A and B are similar, but C is unlike the other two.

What is the importance of this concept? There are two major points that need to be emphasized. First, a simple first-approximation approach to determine whether a germplasm can be extended to another area is to do a simple analysis with available data to determine representativeness. This can be followed by using simulation models to test possible scenarios, although the process is laborious. Second, users of simulation models may encounter missing data. Since most simulation models require daily climatological inputs, it is often necessary to estimate their values before a model is run. Software adjustments and assumptions could eliminate this problem, but in an experimental mode this is undesirable. Therefore, variables need to be simulated (estimated). Missing data applied for model applications at an extended area can be estimated by several methods, Sakamoto (1983) discussed several problems and methods associated with data application to crop weather models

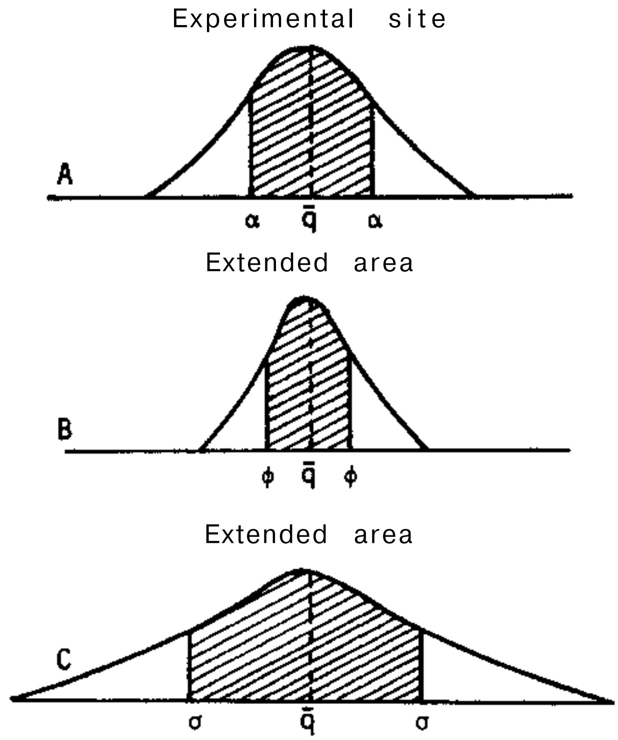

Figure 4. Illustration of three areas with identical mean (q) and different standard deviations.

It is important, when estimating missing data, to capture not only the seasonal oscillations, but also the daily variability that preserves the stochastic structure. Figures 5/6, and 7 illustrate this point. Figure 5 shows the seasonal distribution of simulated solar radiation by a method modified from Richardson (1981, 1982). This example follows the seasonal pattern very well, but does not provide the range and therefore the desired variability demonstrated by the observed data (Figure 6). Figure 7 is the result of another algorithm that attempts to incorporate this variability (Hodges 1983).

When testing a simulation model, it is desirable to do so with data for more than a "few" years. This was done for spring wheat in North Dakota using the model developed by Maas and Arkin (1980) (see Fig. 8). Note the distribution of the results with observed weather and a "changed weather.'" Testing a model through several years provides an indication of bias and the range of results. The distribution of yield should provide similar dispersion characteristics at the experimental site and at the extended area. If the shape of the distribution is similar, the two areas are likely to be representative of each other.

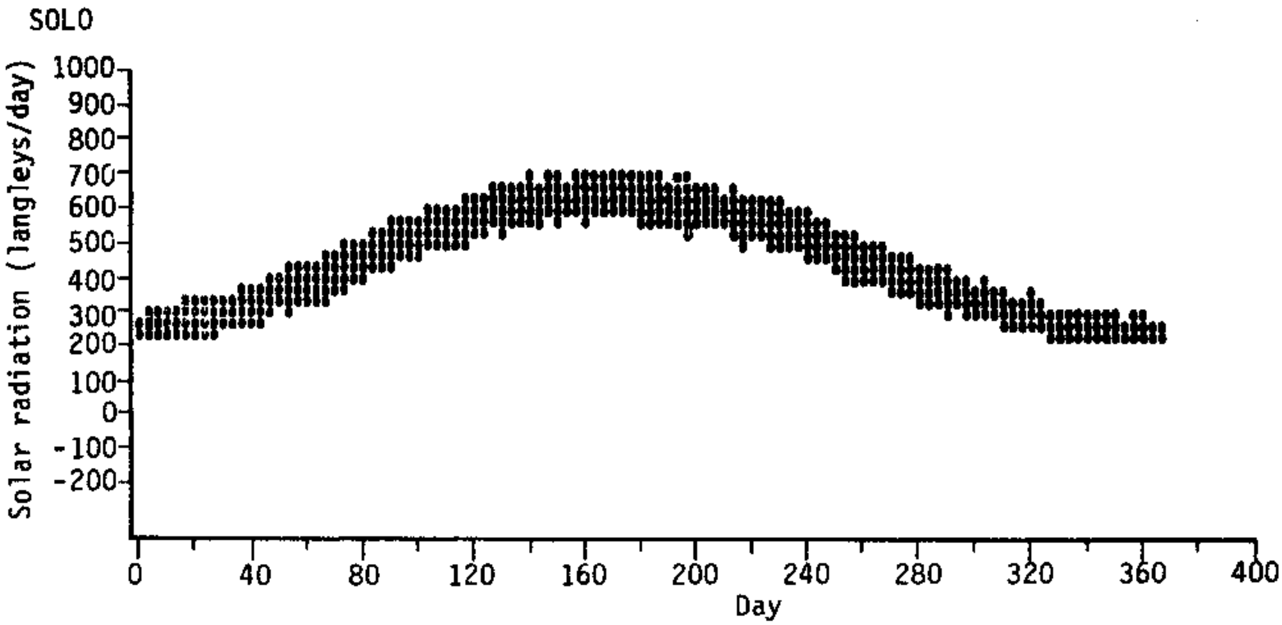

Figure 5. Seasonal distribution of simulated solar radiation by a modified method after Richardson (1981, 1982) at Oklahoma City, Okla, USA (1971-1972).

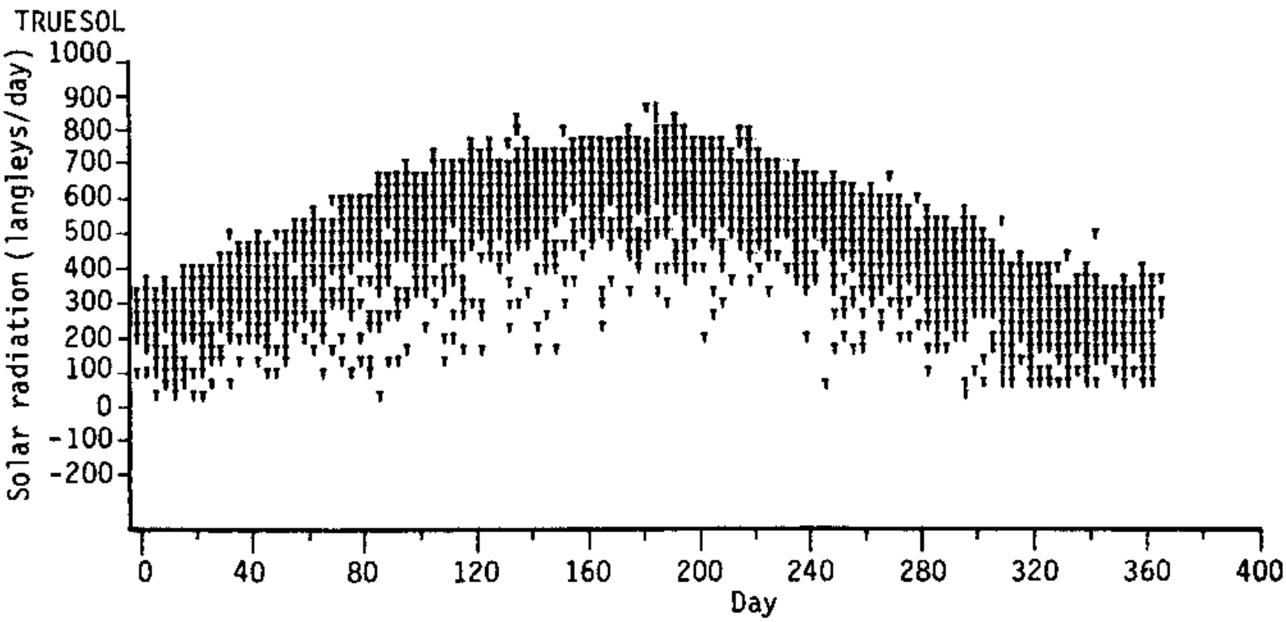

Figure 6. Observed distribution of solar radiation at Oklahoma City, Okla, USA (1971-1972).

There are other methods used to address the representativeness issue. An excellent discussion was presented by J.S. Russell (1980) at the International Workshop on the Agroclimatological Research Needs of the Semi-Arid Tropics held at ICRISAT He discussed the potential usefulness of pattern-analysis techniques in grouping similar climatic environments. Some of these tools were also used by French et al. (1982) to identify areas with similar crop response so that crop yield models developed at one area could be used for another similar area. In this study those variables

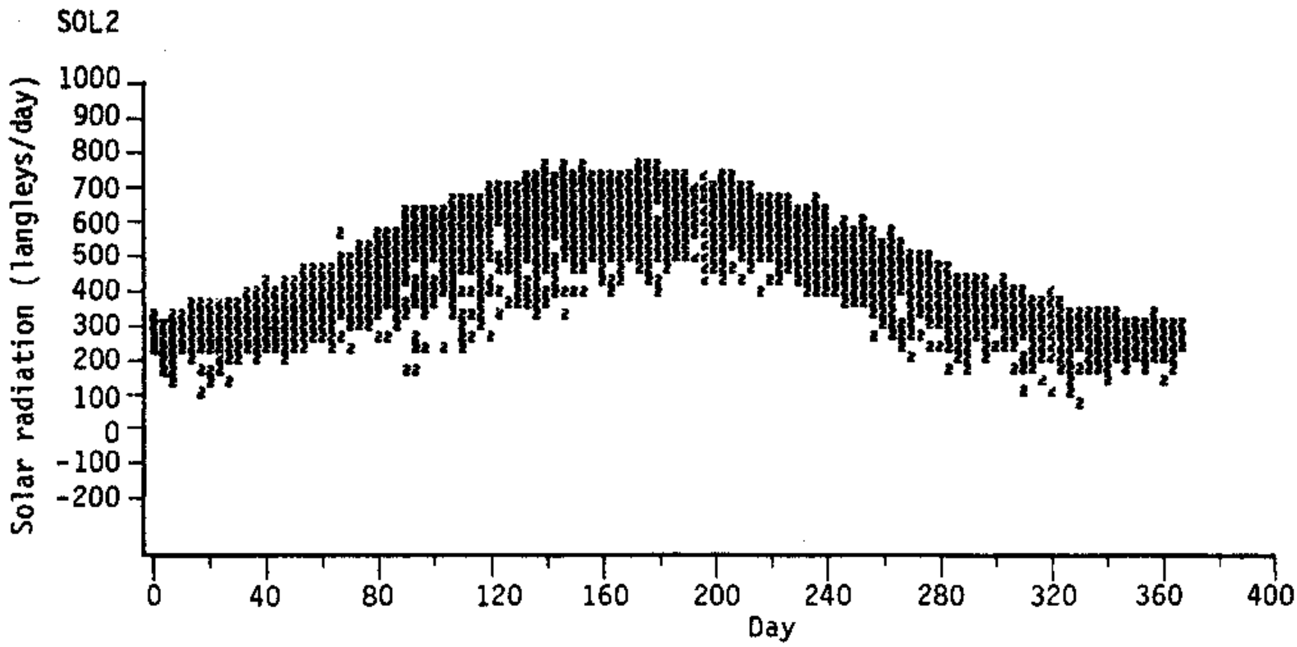

Figure 7. Seasonal distribution of simulated solar radiation (after Hodges et al. 1983) at Oklahoma City, Okla, USA (1971-1972).

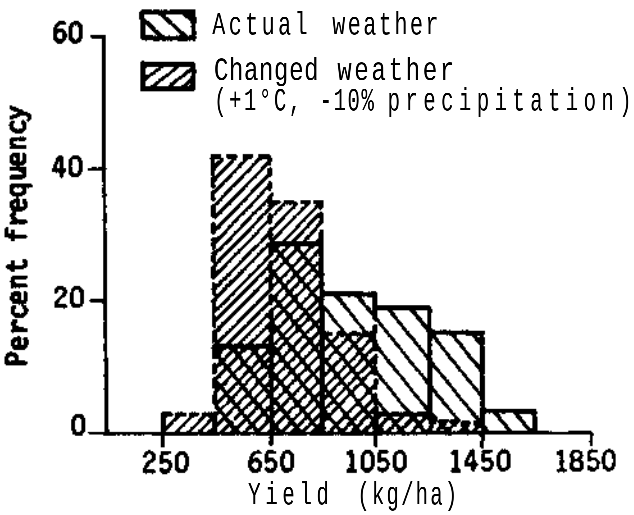

Figure 8. Distribution of spring wheat yield in North Dakota as determined by Maas and Arkins (1980) model for observed weather and "changed weather."

deemed significant to spring wheat in the USSR were compared with those in North Dakota and Minnesota (Fig. 9). Ward's minimum sum of squares hierarchical clustering technique was used. As monthly data were used, general classifications were sought. In spite of data limitations, the study demonstrated that with a carefully planned experiment, data for selected variables keyed on specific crop requirements and for specific growth stages can be useful for extension studies.

Program Design and Climatic Data Structure

Because of the time-space variability of meteorological elements, it may be necessary to run a crop simulation model sequentially over many years and many different locations. This permits a distribution analysis of the effects of different weather conditions or different location parameters. The sequential year analysis is often not considered during program development of a model.

In program development, the major objective of researchers is to validate relationships that are often based on experimental data. Therefore, in program design, it is advisable to consider input of climatic data (as well as agricultural data) from different sources, locations, or years. When the researcher has validated his model and is satis-

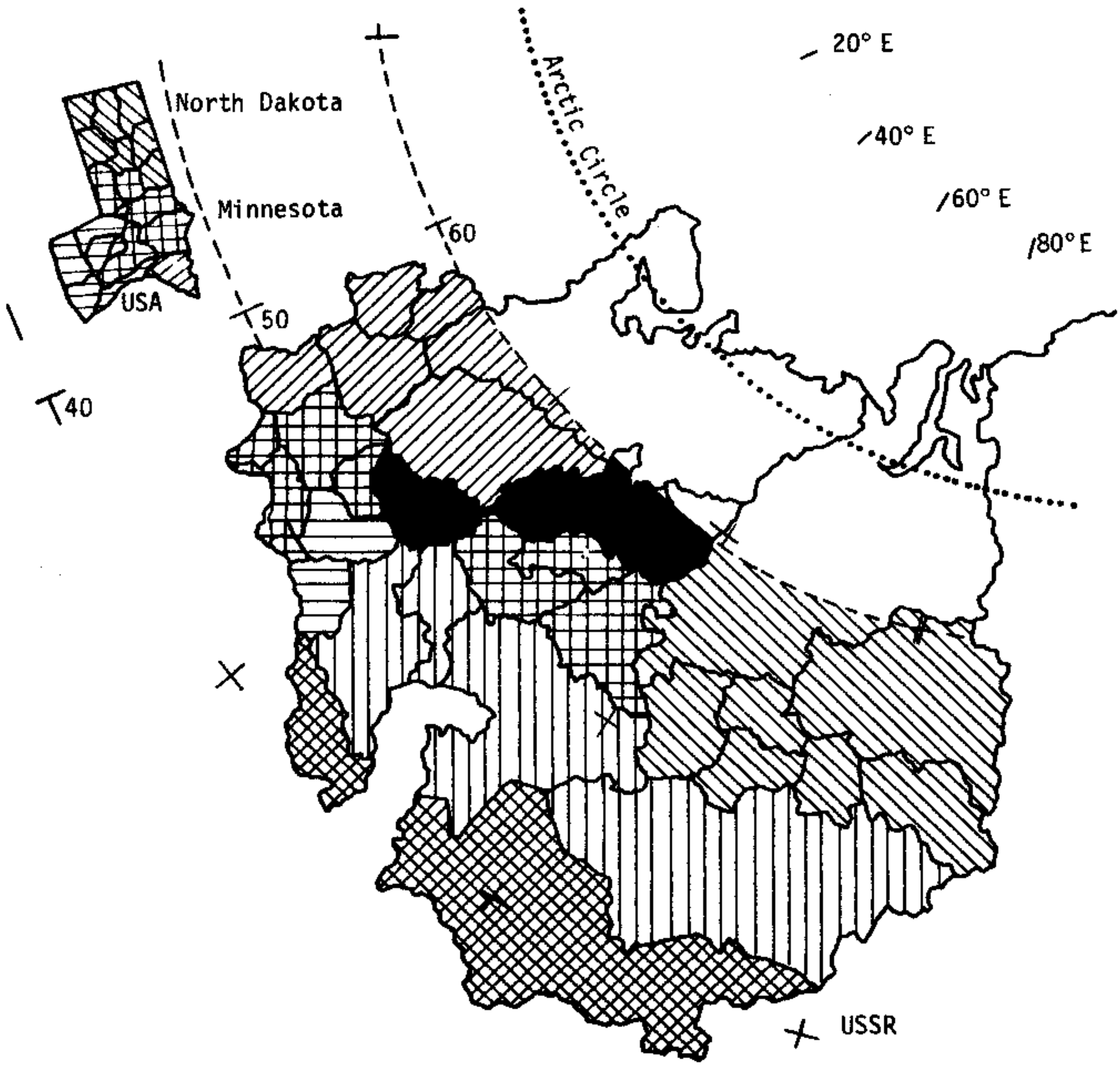

Figure 9. Areas with expected similar crop response in the USSR and in North Dakota and Minnesota, USA, as determined by a clustering technique. Similar hatched areas have similar defined environmental characteristics. (Source: French et al. 1982.)

fied, the model is ready for testing and can be run for several years and locations. Therefore in this testing mode it is designed to run as cheaply and quickly as possible on a particular computer. These are characteristics of what is considered an operational model in a test mode. The operational model has a fixed form, and may be run hundreds of times for many different locations. A developmental or experimental model may be changed almost every time it is run. It may be run on only one data set or on data of one type of structure. As changes are made in the model, it may grow into a "bowl of spaghetti*[1] design as shown in Figure 10. In this design there are many types of connections between different parts of the model and many variables are present throughout. An error in one section can become evident in another section which is only indirectly

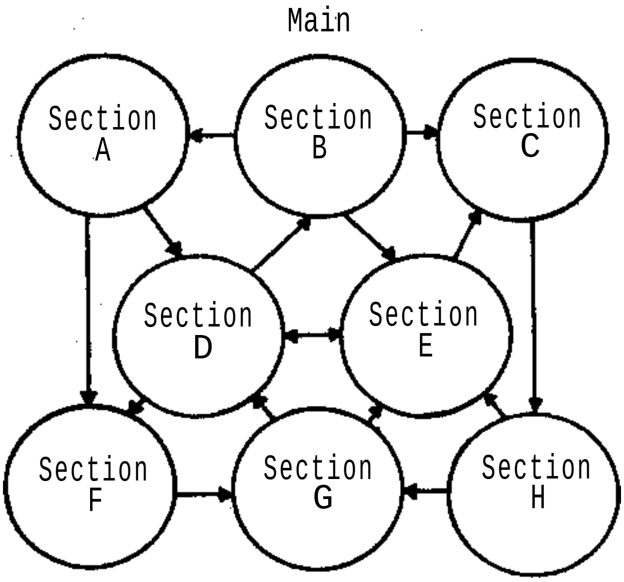

Figure 10. A "bowl of spaghetti' design for a simulation model.

connected to the first section. Also a change in one section may unexpectedly ripple through many distant sections and require additional changes throughout the model. With a modular or "top-down" structure, such "ripple" effects are eliminated or minimized. Figure 11 illustrates this type of design. Each module contains a single function or closely related group of functions and requires only a few specific variables. The modules are placed in a program library to be called as needed; each may be called by any model or program requiring its function(s). These modules are like "black boxes" or "plug-in, units" so that internal changes in one module do not affect others. Changing a module is very much like changing a light bulb or a battery; the whole appliance does not need to be rewired. When a model must be adapted for a new use, this type of design makes it relatively easy to anticipate what program changes will do to the overall operation of the model. Additionally, liberal use of comment cards thoroughout a program facilitates understanding of what a particular module is supposed to do

The modification and operation of simulation models will be greatly eased if data structure problems are considered a *priori* Experience at our Center has revealed that any projects involving climatic data require a major effort in organizing, quality controlling, and structuring..a database file into an efficient, manageable form. There are unique problems related to the meteorological field. Operational and experimental modeling projects will also have different data requirements.

When large, complex meteorological data bases are used, they usually must be stored on tape in some format. Format includes units of variables, field sizes, record length, file length or size, and sequence of time and space. The time and space sequences will vary depending upon the objective of the project. At our Center, we are using the data structure shown in Figure 12. Each record consists of one year of data for one location. Each record begins with location or weather station and year identifiers. This is followed by 366 daily values for each variable. (In leap years, 29 February is put at the end of the year and not used.) In a time sequence format (Figure 12) one file consists of all the years for one location. The next file has all the years for another location. This type of format is convenient for site analysis. In a space sequence format (Figure 12), a record consists of year and day identifiers, followed by values for ail locations for each variable. The next record will cover the next day. A file will consist of one or more complete years. Therefore, precipitation data for a particular day at several stations can be retrieved quickly. This type of data sequence is used for spatial analysis

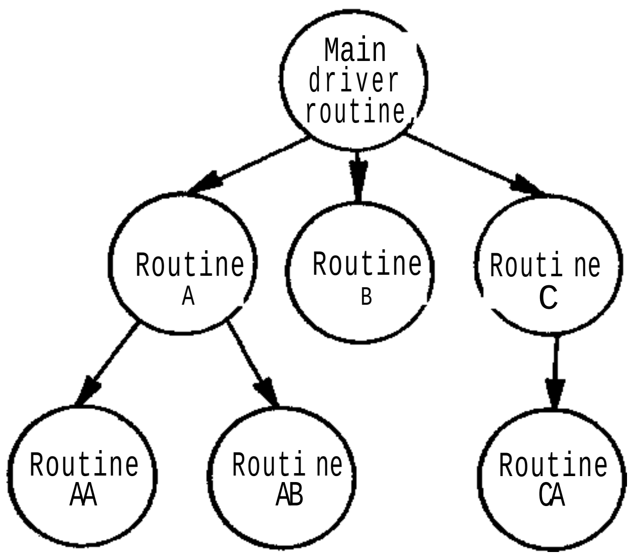

Figure 11.. A top-down structured design for a simulation model.

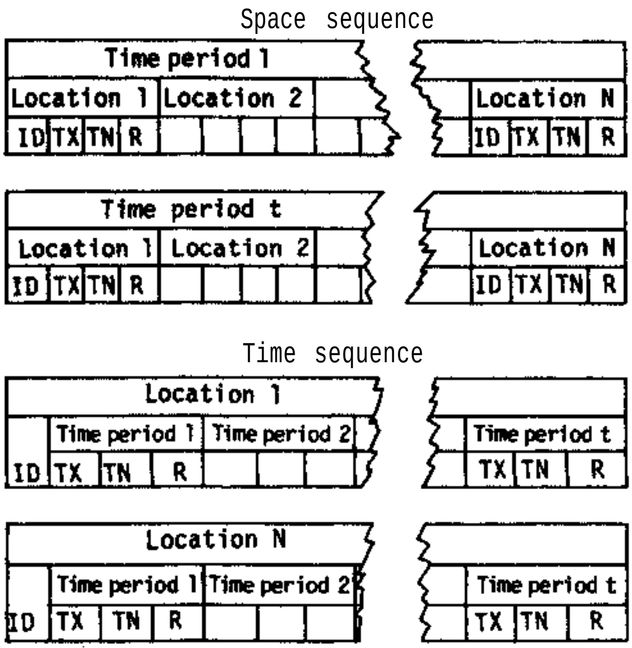

Figure 12. An example of a space and time sequence format.

of several sites at one pass and is applicable to regional or mesoscale studies.

Within each variable field, the number of characters per field needs to be standardized; units of the variable must consider possible signs, decimals, and missing values. The left field needs to be filled if signs are incorporated. Only positive bias should be used. A field for text comment is recommended, particularly if the data are to be used for research. Items on instrument calibration changes, site moves, instrument problems, station identification, etc., can be put in a separate file.

This process of data-base management (DBM) begins at the experimental site where observations are recorded. Decisions must be made as to who will process the data. For example, can it be sent to a central location? Missing data are best estimated at the experimental site. Following an agreed-upon schedule, the data set is sent to the central site for archiving in a standardized format. A backup copy should always be made with the system; a custodian of the data set is therefore a necessity. The custodian provides the focal point for the DBM system and provides a newsletter or information sheet that updates the data-base program for all users. Milestones, standardized documentation, software maintenance programs, problem areas, etc., can be included in the newsletter.

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Soil Data-base Management

Richard W. Arnold*

Abstract

Soil scientists observe, measure, and record information about many features, properties, and qualities of soils. A collection of such information is a soil data base. There are five major schemas for soil survey data bases: soil classification, pedon site characteristics, horizon or layer properties, soil mapping, and soil interpretations. The common element among the schema is the soil pedon. Pedons link to soil taxonomic units and soil map units. Soil taxonomic units are used for generic (interpretive) aggregation of soils data, and soil map units are used for geographic aggregation of soils data.

Because there is so much existing soils information, a system is needed to permit efficient and effective interaction of the data bases; such a management system (DBMS) is a computer program that allows linkage of and access to data bases. A DBMS to link and access soil and other land -resource data bases has not yet been developed or selected by USDA.

Soil survey data are currently being reviewed and depicted in logical data structures using the notions of entity attribute, relationship, relationship descriptor, and identifier Diagrams of soil data structures are difficult to prepare but important for selecting an appropriate DBMS.

Soils information is critical for a consistent land data base and a system that coordinates various kinds of resource data. Such a data base assists in technology transfer and evaluation of resource programs and policies. In the USA a nationally consistent agricultural data base may begin with land units that are combinations of capability class and subclass groups within major land resource areas (MLRA). These units combine a generic aggregation of land capability and a geographic aggregation of identified land areas. Other technical groupings of soil map units will permit different combinations of generic and geographic aggregations.

The effectiveness and efficiency of a network of scientists can be greatly enhanced by having available well-structured soil data and appropriate data base management systems.

Soil science includes several disciplines such as soil chemistry, soil physics, soil microbiology, soil fertility, soil classification, soil mineralogy, and soil survey. Scientists in each discipline observe, measure, and record information about features, properties, and qualities of soil and soil-related phenomena.

These data are commonly assembled in ways that permit the scientists to review and evaluate relationships. Such a collection of information is a *data base.* Historically, some information was recorded on forms and filed away, some was placed in. books, theses, and other publications. A lot of information was probably discarded or lost. As computers developed, so did the ways and means of storing and using data.

In soil science alone, there are hundreds, maybe thousands, of soil data bases. They differ in content, specificity, quality, format, accessibility, and utility. In the interest of using and sharing

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this information, there has been increasing attention given to the design of data bases and to the development of management systems so that more people have better access to more kinds of data. This promotes applications of existing information to questions or problems of interest. The proliferation of computer equipment and computer programs that permit the interaction of data bases has often fragmented the efforts for innovative transfer of ideas and technology.

For national, regional, and global analyses of resource programs and policies, a consistent data-base program for coordinating data collection and data management is essential.

Soil Survey Data Bases

Soil survey organizations observe, measure, identify, and classify specific kinds of soils based on both field and laboratory examinations. In addition, landscapes are delineated on maps and the dominant kinds of soil components are identified, described, and named as soil map units. The soil map units are interpreted for their known or expected behavioral responses when used for various purposes under stated conditions of management. The key to all of these activities is the establishment and use of a common soil classification system. Appropriate classes of soils and procedures for identifying their geographic location provide a framework for data systems and a geographic basis for linkages with other data sets. The National Cooperative Soil Survey of the USA develops and maintains many soil data bases to accomplish its goal of providing information about the kind, extent, and quality of soil resources in the nation. Soil data bases can be grouped into five schema (Figure 1)[1]. The common element among the schema is the soil pedon which is a small volume of the earth's mantle used as the basis for sampling and describing soils. Site features associated with a particular pedon are functionally related and constitute a pedon site characteristic schema. The horizons and layers within a pedon are described and often sampled for laboratory analyses to determine their properties. These functionally related data are described by a pedon layer properties schema. Each pedon is also related to a soil classification system through a soil classification schema.

[1] Gordon L. Decker, USDA, Soil Conservation Service, Washington, DC, USA, personal communication.

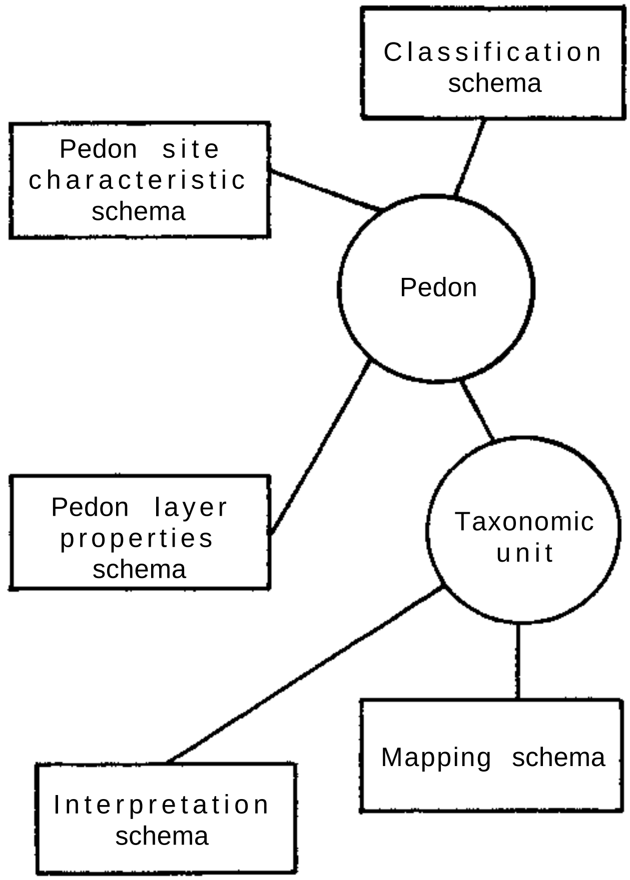

Figure 1. Major schema relating soil data sets.

Geographic representations of soils in landscapes are tied to soil property data by the taxonomic class of the dominant pedons in a delineation of a soil map unit. Geographic information is related to other soil information through a soil mapping schema, and the soil map unit interpretations are provided in a soil interpretation schema.

Soil Classification Schema

So/7 Taxonomy (USDA SCS 1975) is the soil classification system used in the USA. It is a hierarchal system with six categories. The structure of the system and its mnemonic nomenclature permit classes in the higher four categories to be easily identified by a name code or value code.

For example, a member of the order category is a Mollisol (Fig. 2). One class at the suborder level is an Usto//; one Ustoll at the great group level is an Argiusfo//, and one subgroup of Argiustoll is an

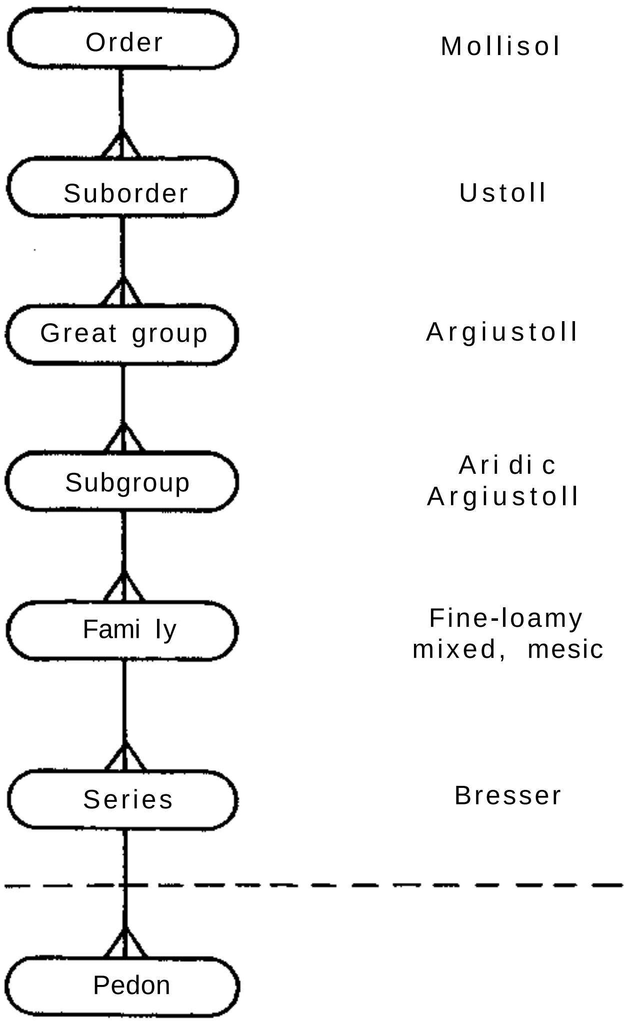

Figure 2. Overview of the hierarchal structure of *Soil Taxonomy,* a soil classification schema.

Aridic *Argiustoll.* A code can identify the category and the individual taxon easily in this hierarchal system.

The next lower category is the family (Fig. 2) whose name is supplied by classes of two or more properties. The most common family name indicates particle size, mineralogy, and temperature class identifiers, for example, the fine-loamy, mixed, mesic family of Aridic Argiustolls.

Members of the lowest category, soil series, are recognized by their constituent pedons. Individual soil series have local place names, usually geographic, that do not connote any soil properties.

A soil series is the lowest taxonomic unit used to identify and name soils in the U.S. classification system. Pedons do not receive individual names but can be uniquely identified by geographic location, series name, and sample number.

Pedon Site Schema

Many features of a site can be recorded where a pedon is described or sampled (Fig. 3). Identifiers may specify field and laboratory numbers as well as kind of pedon. Attributes of location include geographic divisions such as the major land resource area, watershed, state, county, and latitude and longitude.

Physiographic features include landforms, relief, and general physiography. Environmental features refer mainly to temperature and precipitation data. They are often linked to time—when and for what duration samples were collected or laboratory analyses were made.

Other properties of a pedon are grouped as slope features, parent material and underlying materials, water table, various site classes, and control sections within a pedon. Sampling and description of a pedon are usually done by layers or horizons; therefore, the pedon is the common link to those data. In the current schema for pedon site characteristics there are 22 major groups of characteristics, each of which may be considered as a data base related to a single pedon.

Layer Properties Schema

The data of layers is the largest schema in the structure of soil data bases. It is also the most complex because of the many kinds of information that are recorded. There are field data of a soil's morphology, laboratory characterization data that differ by type of analysis and kind of property, mineralogical data of various fractions, and data on engineering properties.

To record the morphological features observed in the field, a pedon coding system and form were developed that provide standard terms and codes for features and distributions. Other formats are used to record and store laboratory data. The horizons or layers of a pedon provide the link to these extensive data bases;

Many characteristics are reported by particle size within a layer. For example, nitrogen, organic carbon, and extractable iron may be provided for several size separates. Soil color of a layer, identified by Munsell notations of the hue, value, and chroma; is rather complex. It may be specific

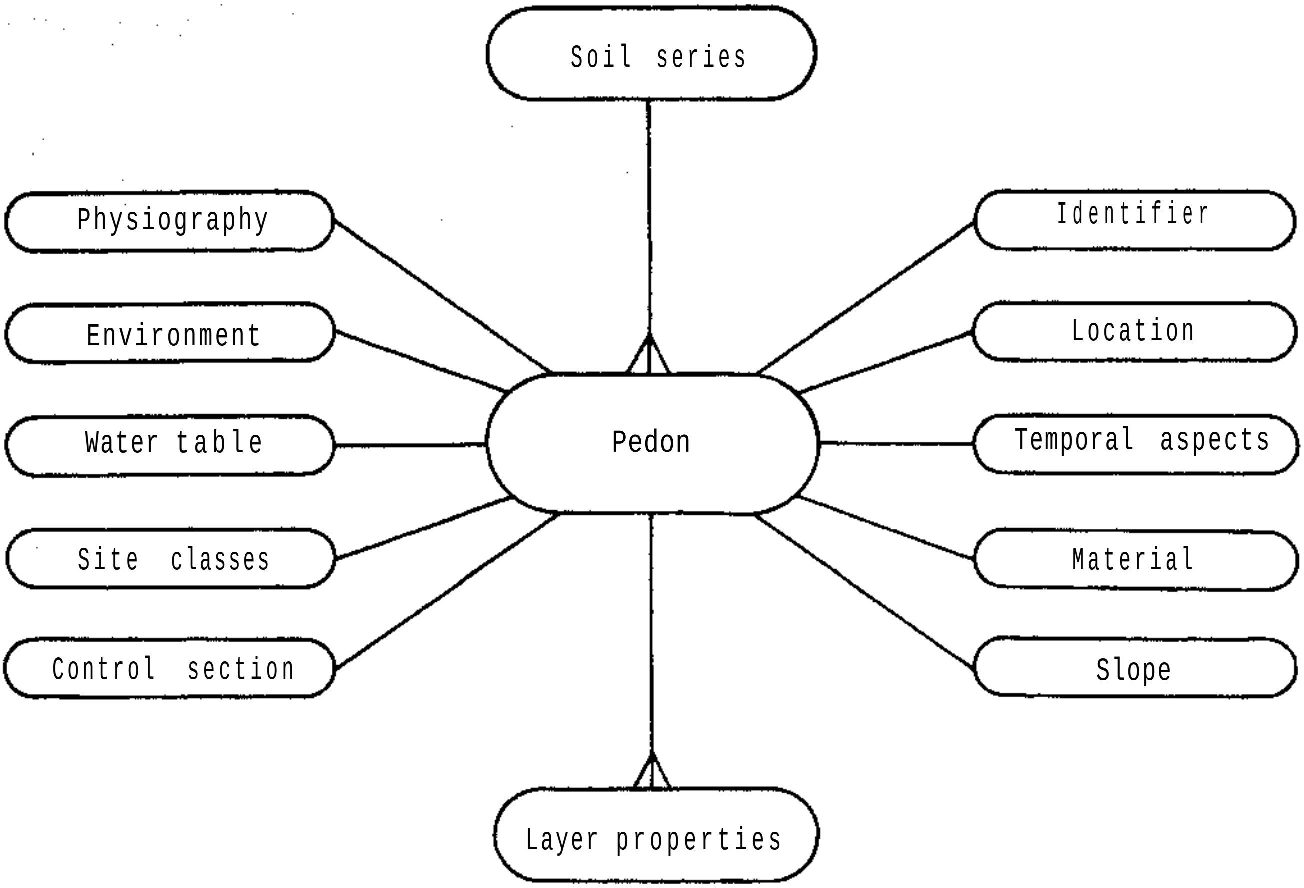

Figure 3. Schema for general relationships of site characterization for a soil pedon.

to the matrix and a proportion of the matrix, it may be for a broken ped or for material that is crushed and rubbed, and for a specified moisture condition.

Obviously a schema relating all this information must be carefully prepared if efficient and effective use is to be made of the numerous data bases related to soil layers.

Subschema were initially developed for field data, laboratory characterization data, mineralogical data, and highway engineering test data. As these became better understood, an attempt has been made to interrelate them into an overall schema for soil layer data. At present we recognize 35 major features of a layer, many of which link to three to five other attributes.

Soil Mapping Schema

Soil maps show the location, distribution, extent, and kinds of soils in an area. This geographic representation enables the joining of many data bases: census, land cover, land use, and other natural resource information.

Soil mapping is tied to the soil classification system through pedons that are members of a taxonomic class (Fig. 4). In the USA the most widely used taxonomic unit is the soil series, partly because it provides the most precise soil information and partly because of the historical precedent for making relatively large-scale maps. Even where series are not identified, the pedon is the link to higher category taxa such as the family or great group.

Soil map units consist of one or more taxonomic components because the scale of mapping is not large enough to reflect the variability in a landscape segment. In addition to identifying the soils, the map unit name provides information important for use and management, such as slope, amount of stoniness, degree of erosion, and other features not used to classify the kinds of soils. Such features are called phases. They modify the taxonomic units to provide for more

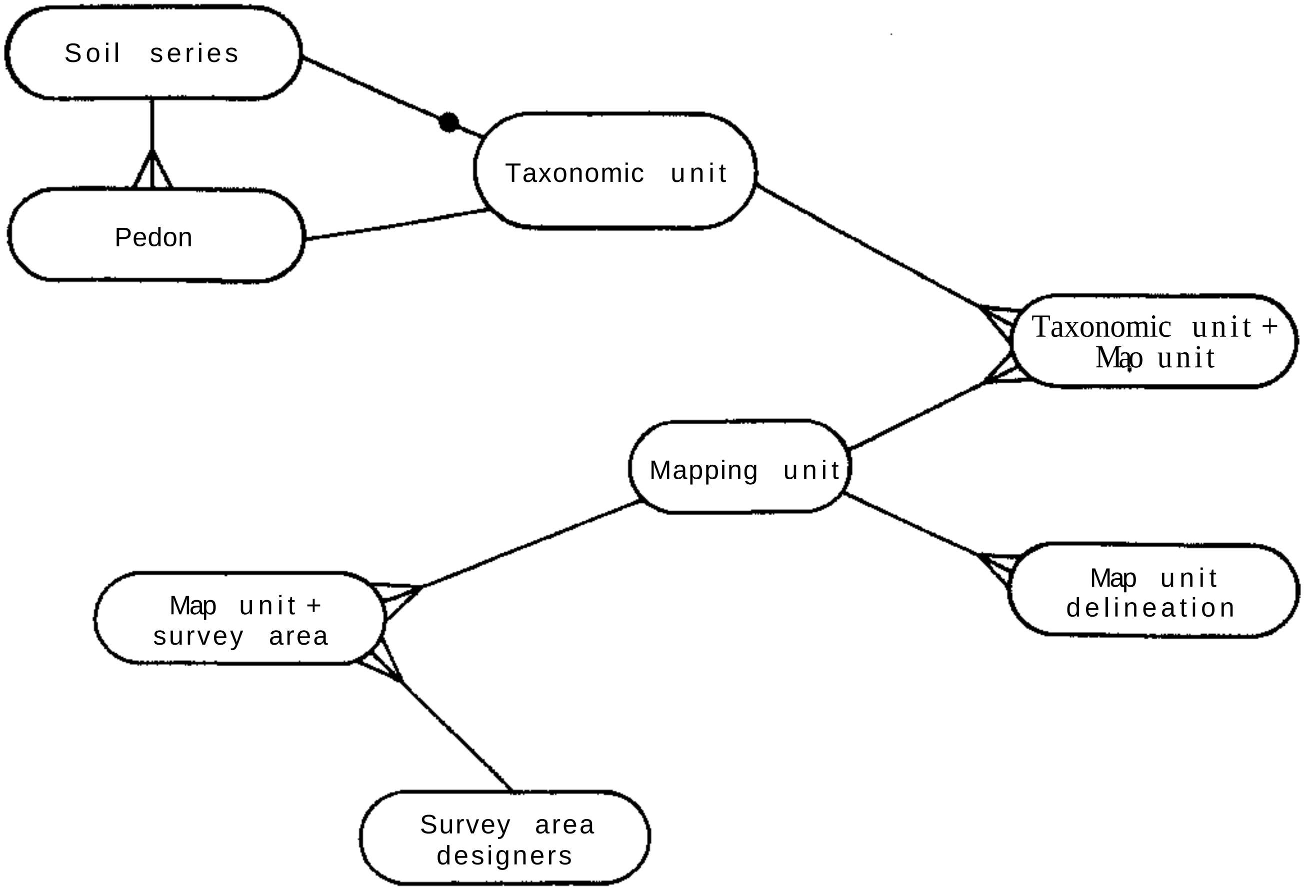

Figure 4. Schema showing general relationships in soil mapping.

homogeneity in the soil map unit than would be possible if only the taxonomic units were used. A soil map unit consists of the delineated areas that are identified by the same symbol and name. The delineations differ in size, shape, and relative location. At the present time in the USA, there are about 12 000 series, perhaps nearly 100 000 soil map units, and millions of delineations on soil maps. A map unit use file enables us to keep track of the numbers and names of map units, where they have been mapped, and the extent of each map unit. In the future, this map unit file will become important in evaluating geographic relationships as non-soil data bases are related to soils.

Soil Interpretation Schema

Users of soil data bases who are not soil scientists generally are more familiar and more interested in soil interpretations for specific purposes than in the many attributes that compose the data bases.

The link to other data bases is from the map unit through the taxonomic units that are its components (Fig. 5). Most interpretations are for a phased taxon, alone or in combination with others, depending on the kind of map unit and the specific interpretation.

The soil interpretation records are currently the largest existing data base of the soil survey with about 30 000 records. Each record contains a brief narrative soil description, classification, estimated physical and chemical information, interpretations for crops, pasture, range, wildlife and such items as sanitary facilities and building and recreation development.

Guidelines for evaluating the limitations of each soil map unit and estimating ratings for use of the soil are provided through the *National Soils Handbook* and other publications of the National Cooperative Soil Survey. Some of the guidelines and procedures have been programmed to assist in cross-checking data entries; however, soil interpretation records are still maintained and used as a separate data base rather than the interpretations being generated as needed.

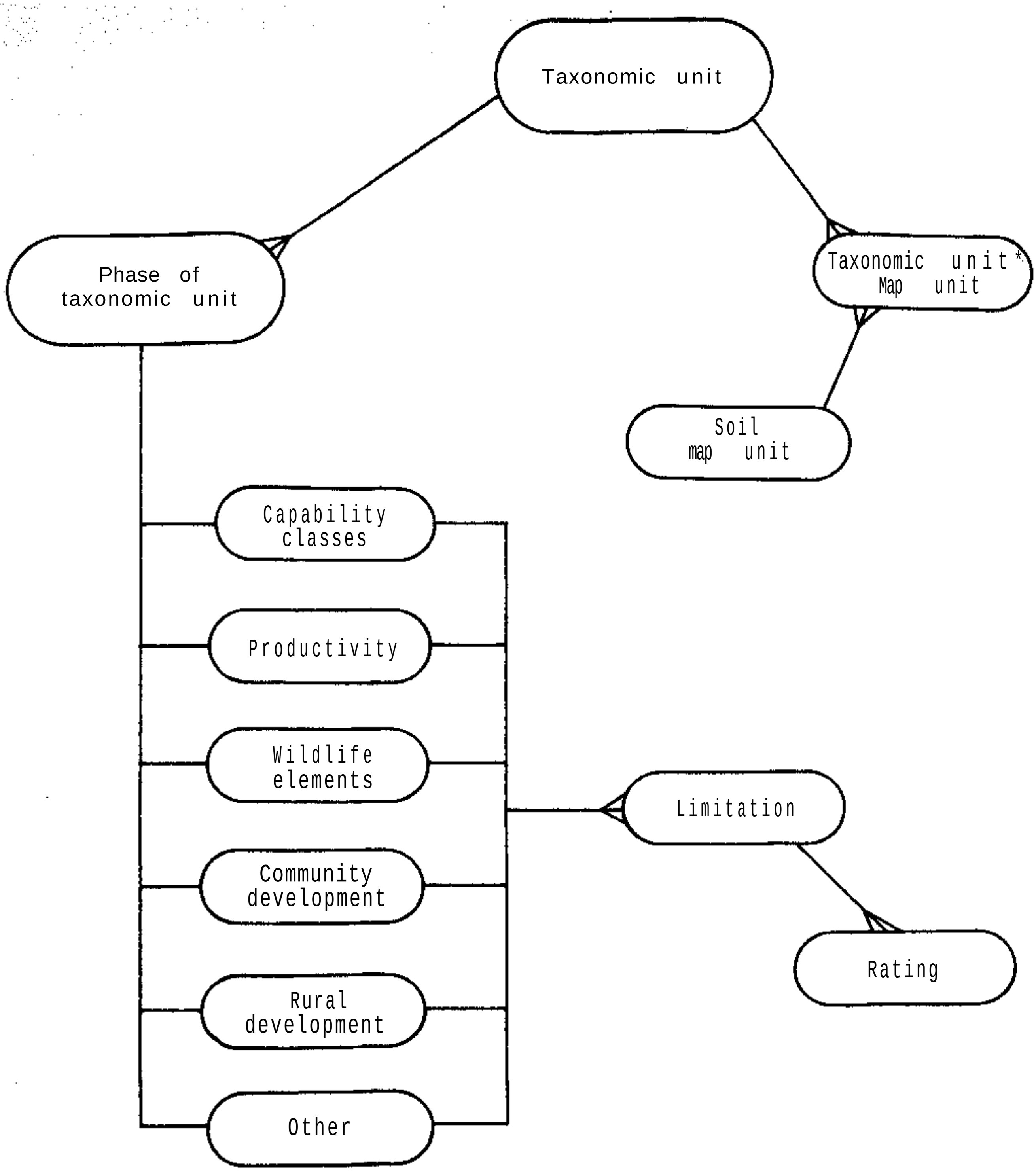

Figure 5. Schema showing general relationships for soil interpretations.

Data-base Management

As a data base is being developed, the number of its potential users and uses is not always known. The pedon data base of the Soil Conservation Service has two parts: one consists of the morphological descriptions of soils; the other, of the laboratory characterization of soil samples. There are also records of soil classification, soil map units, and of soil interpretations. The publisbed soil maps and reports constitute yet another record of important soils information. Some soil maps have been digitized and form another data base.

The master data bases, and often their subsets, generally use different formats to structure their contents. Redundancy has been built in, primarily by recording locational features, classification names, symbols, selected interpretations, and so forth. There are many opportunities for error due to typographical mistakes in recording or copying of the information and entering it in the computer. In some instances, the difference of only one letter in a name may lead to a mismatch of records, even when the data refer to the same pedon.

Given the vast amount of soils data and the increased interest of new users in examining more kinds of data relationships, a system is needed to permit data bases to interact efficiently and effectively.

Data-base Management System

A data-base management system (DBMS) is a computer software program that allows access to a data base or a set of data bases. It is analogous to a library with closed stacks to which only the librarian has access.

If there is no need to share data, or a simple solution is sufficient, then a complex DBMS may not be necessary. Sometimes it is thought that sensitive data accessible through a DBMS will not be secure or overhead costs of a system will be too high relative to the hardware. Some people believe that the conversion costs of integrating data bases will be too high, or that the system will require too many personnel to maintain and operate it.

There are, however, as many or more reasons why a data-base management system should be considered. A good system provides for independence of data and for sharing the data among various applications without interfering with each other. Multiple entry of names or locations can be reduced. Only those redundancies that improve efficiency need be retained. Because duplication of individual data bases is controlled, there are fewer opportunities for inconsistencies between them. For access to the data, a DBMS requires proper data formats and names. These permit standards to be enforced and contribute to the integrity of the information.

Data Models

There are three major data models that represent schemata or outlines: relational, hierarchic, and network. The schemata illustrated in this paper are mostly relational: the data bases consist of sets of relations that can be presented in tabular form. For example, a table of physical property values by horizons of a pedon is a familiar way of presenting such information.

The soil classification system has a hierarchal structure and is more easily presented in that form than as a table.

Until the various soil data bases are organized as a logical data structure, it is not prudent to suggest which model for a DBMS will be most satisfactory.

Logical Data Structure

The types of data in a data base are depicted by a logical data structure (LDS) (Fig. 6). There are five notions in a structure: entity, attribute, relationship, relationship descriptor, and identifier.

An entity is a group of objects about which information is maintained. A soil series, pedon, slope, location, and layer are entities. An entity is described by its attributes (name, number, size, etc.) and by its relationships with other entities. An attribute is a single-valued descriptor of one entity. For example, a pedon has only one sample number.

A relationship between two entities can be one to one, or one to more than one. A single series has many pedons (one to many), but a single pedon can belong to only one soil series (one to one). Whether the relationship is stated, or inferred from the names of the entities involved (soil series, pedon), it describes the linkage of two entities.

Attributes and relationships each have values that serve as identifiers for members of an entity. There are primary and secondary identifiers. For example, slope may be identified by a percent value and by a slope class code. Within a series, there may be several pedons with the same slope but only one slope for any given pedon. Therefore, pedon-slope entities are identified by their relationship and also by their attributes.

In the LDS diagrams in Figure 6 (as well as in Figs. 2 to 5), entities are shown by ovals and relationships are lines connecting entities. Where multiple instances of one entity are related to the

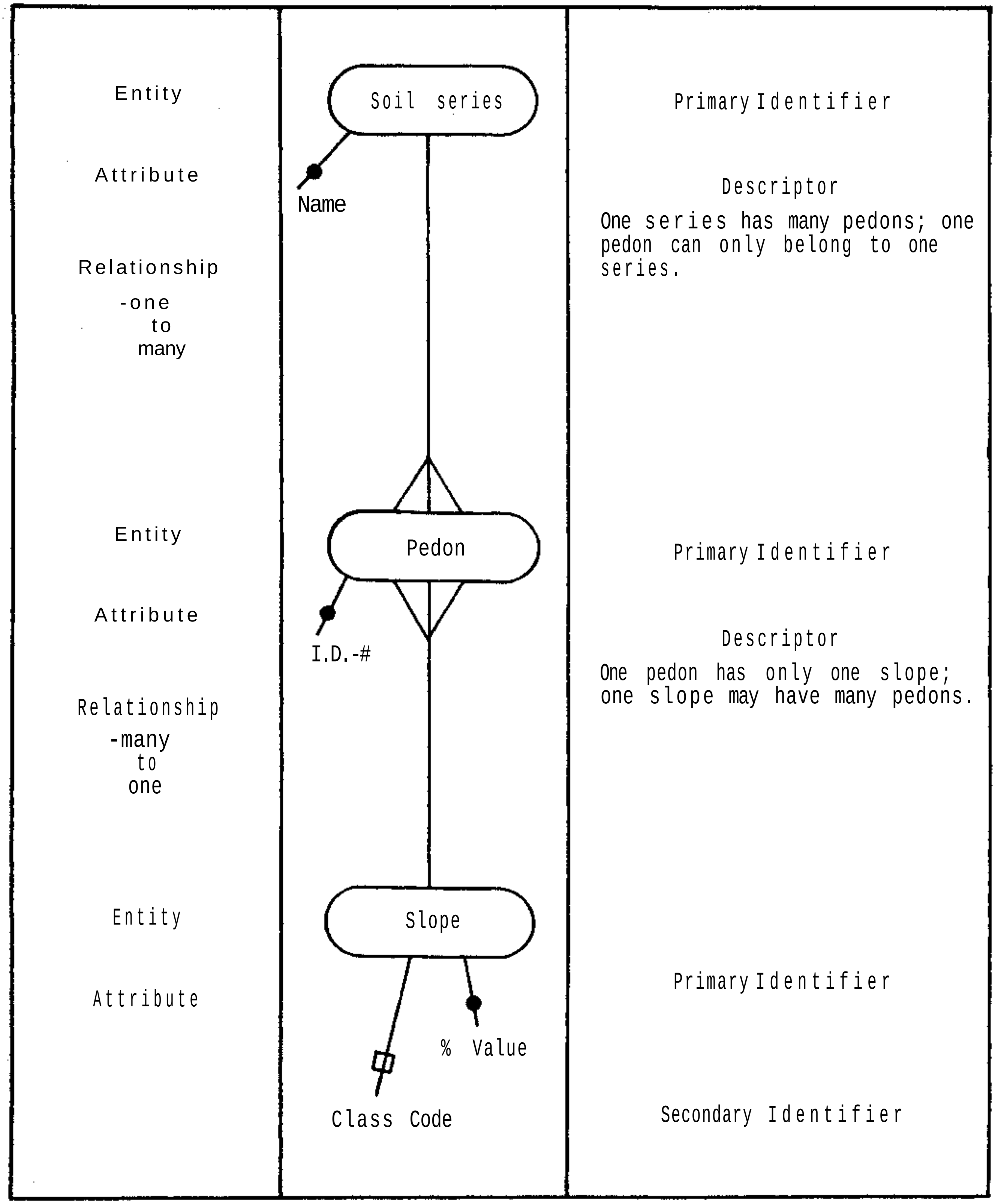

Figure 6. Illustration of logical data structure notion for soils.

same other entities (as pedons to series), they are indicated by a crow's foot or branching of the line. Relationships are implied by the names of the connected entities and by the type of line connecting them.

Primary identifiers are shown as dots and secondary identifiers are shown as squares (Fig. 6). The identifiers refer to either an attribute or a relationship.

Diagramming a logical data structure of a soil data base is quite complex; however, it is very useful in selecting or designing a data-base management system that will be efficient and effective. The current diagram of a pedon schema has about 50 entities, 60 major relationships, and at least five direct attributes. As this data structure is reviewed, it is likely that other entities and relationships will be identified.

When an acceptable set of data is available, it is stored in a format that can be easily used by the DBMS. Because different computer software and hardware systems have been used for soil data bases, the testing and evaluation of a DBMS are crucial.

In some data bases, voids will occur because the parameter values have been modified or added to without an updating of all files. A process for obtaining and filling these data voids is needed for optimal use. With the broad spectrum of information available, it is important to define data items and develop a data dictionary. New formats for storing data may be needed to make interactive systems compatible with each other and allow users additional access to the data bases.

The USDA SCS currently uses many data-base management systems but they access only limited data bases or have limited interactive capability. Care in planning and data formatting is a must if the network of users is to become a reality. Coordination and standardization become increasingly important for the users' satisfaction with any data-base management system.

A Consistent Data Base for Land

Land is a continuum of the earth's natural attributes. Land classification, therefore, is a systematic division of those attributes into preconceived units. In the Department of Agriculture our major concern is with agricultural attributes of land.

A consistent data base has several important features,[2]

1. It must provide a level of detail sufficiently homogeneous to permit reliable predictions of resource behavior under stated conditions for specific purposes.
2. It must be hierarchical so that detailed information can be systematically generalized with a minimum loss of accuracy.
3. It must identify the geographic location of resource units.
4. It must contain as many common identifiers as necessary to access and use the various data sets in the scheme.

Detailed soil map units may represent the ultimate level of detail for predictions of resource behavior. In the USA, soil units on maps at scales of about 1:20 000 are commonly phases of soil series or their combinations. In most places these map units correspond to areas that differ in performance. Information about soils may be grouped generically by common sets of attributes such as those in the soil classification schema. It can also be grouped by any of the soil interpretation groupings illustrated in Figure 5. There is no concern for geographic aggregation when information is grouped in a generic manner.

Grouping soils information by geographic association is necessary, however, if relationships with demographic data bases are to be evaluated. Very few political boundaries or census tracts correspond to natural elements of landscapes; consequently, many generalizations must be made. Geographic aggregation increases the heterogeneity of the data and often masks larger scale relationships between data sets.

Analysts are faced with the problem of providing data linkages at the lowest level of reliability of the weakest data set or at the lowest level of acceptable boundary approximations between data sets. The first is a generic problem and the second is a geographic problem.

Searching for a Solution

A consistent data base that coordinates different kinds of resource data can be used to improve technology transfer and to evaluate resource programs and policies.

[2] John W. Putman. USDA, Economic Research Service, Washington, DC, USA, personal communication

In many parts of the world, land is divided into capability groups such as provided by the USDA Land Capability System (Klingebiel and Montgomery 1961). Eight land classes are combined with four subclass elements to provide 29 class/subclass combinations. This system creates interpretive groupings for agricultural purposes based on the degree of hazard or limitation for sustainable production.

For additional evaluation the class/subclass groups (Fig. 7) may be linked with yields of crops, which in turn may be linked with specified management practices and their associated costs. The level of detail depends on availability of data and interests of the evaluator. A somewhat similar scheme is provided by the United Nations Food and Agriculture Organization (FAO) Land Evaluation System (FAO 1976). Both systems are generic aggregations and do not define geographic areas.

Soil surveys and land resource inventories provide maps locating and identifying geographic areas of limited variability. Soils information may be aggregated by survey areas, by political jurisdictions, and by major land resource areas (MLRA).

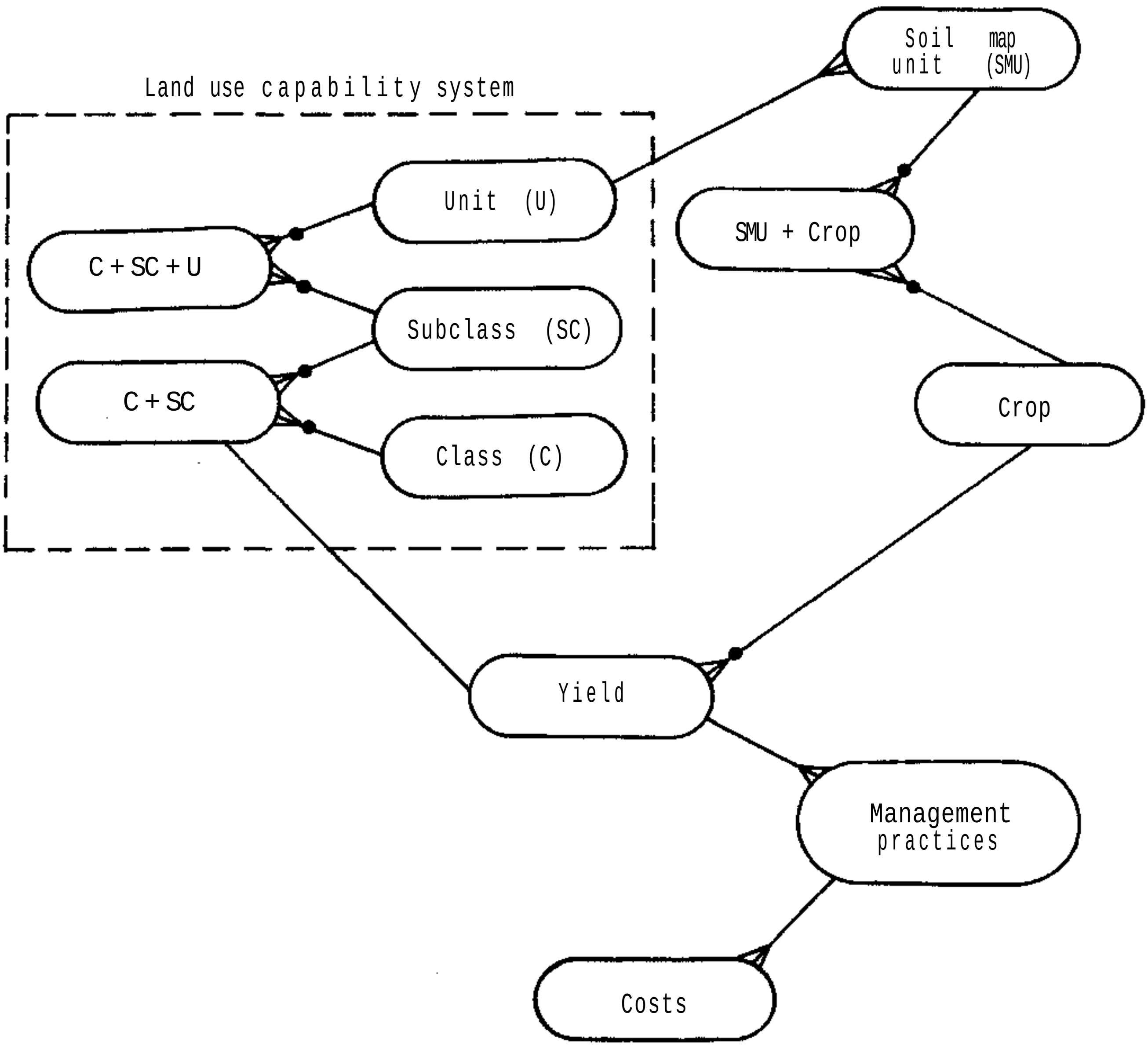

Figure 7. Structure of data for initial land evaluation.

An MLRA is described as a geographic area of land characterized by particular patterns of soils, climate, water resources, land use, and types of farming (USDA SCS 1981). Another type of land division is provided by the FAO agroecological zones which describe areas of similar crop potential (FAO 1978). A combination of soils information into land units (Fig. 8) may be feasible for relatively large land areas. One such geographic integrator is a major land resource area and one generic (interpretive) integrator is a land capability class/subclass group. Although land-use capability groups are scattered throughout an MLRA they do permit statements about kinds

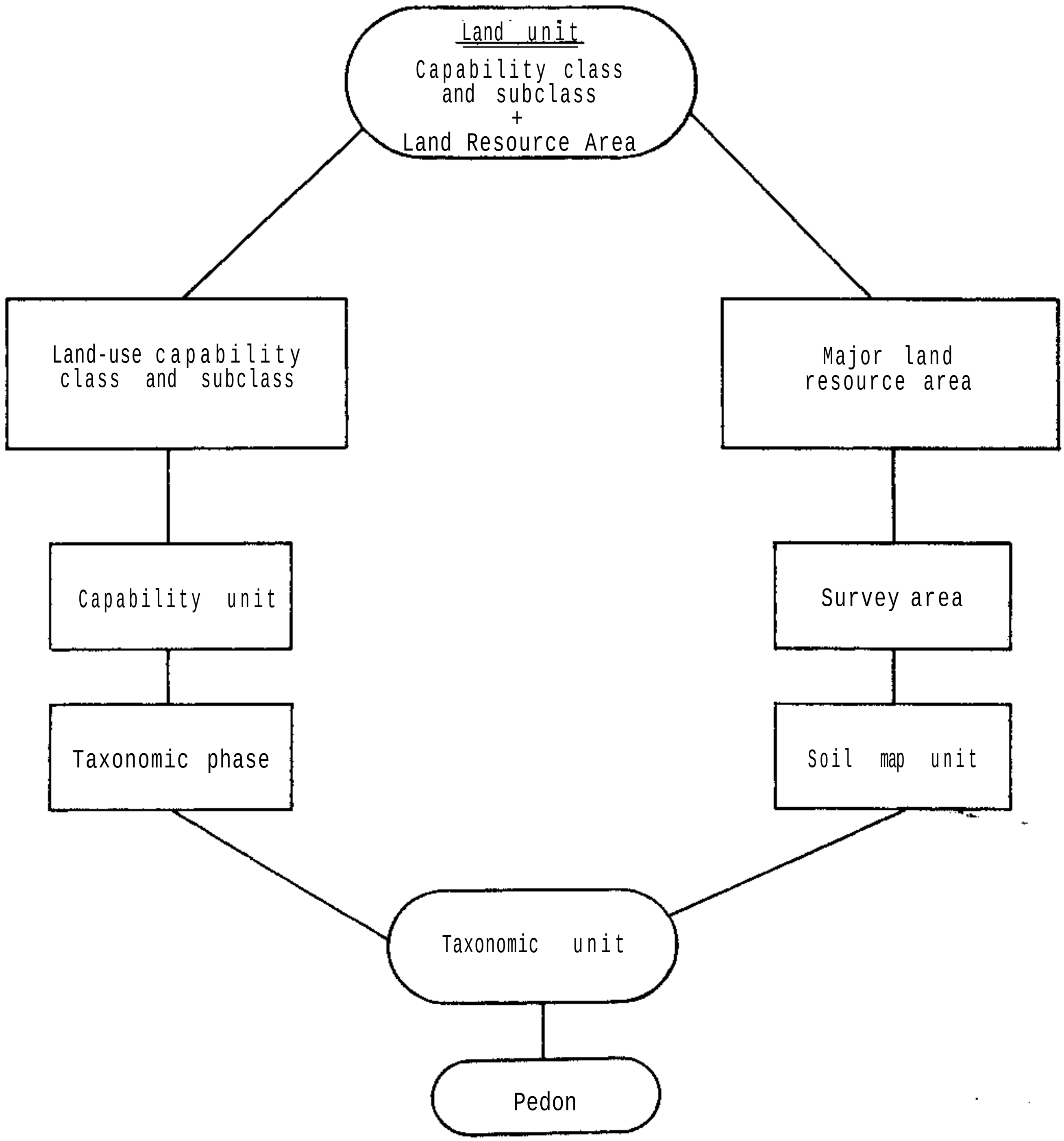

Figure 8. Aggregation of soils information to provide land resource units.

and amounts of similar resources in an area. An analogous situation exists for land utilization types within agroecological zones of the FAO system.

Concluding Comments

The growth of soil science and its disciplines has given rise to large, cumbersome data bases. Some have been lost and others are fragmental in location and in format. The potential users of data bases far outnumber those scientists who have contributed to the development of the data bases.

In soil survey there are five general data bases. Classification places the knowledge of pedons in a hierarchal structure. Pedons have site characteristics and for their constituent horizons and layers there are data on physical, chemical, mineralogical, and biological features. Soil maps form a geographic data base and soil interpretation records for the map units of a soil survey make up the fifth data base.

The usefulness of this information depends largely on developing a logical data structure of the existing soil data bases. It is a task worthy of our best efforts.

Hundreds of properties of soils are measured. In addition soil maps are prepared for many land areas. Grouping the information generically and geographically involves two different approaches and processes. Both products are important in linking other data bases with soil data bases. More attention should be given to better integrating the two kinds of data sets and on ways to present and evaluate the results.

In searching for improved soil data-base management, a system (a computer program) must be devised or selected that can effectively provide different users access to well-structured data bases. We are at the threshold of new adventures; we have much to learn about our own data, and much to share with each other.

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The Organization of Agronomic Experiment Data for Crop Modeling

Daniel Wallach*

Abstract

Data-base organization for crop modeling has largely been a neglected subject, though in fact it determines in large part the ease of model development, of model evolution, and of the exchange of data and models. A data-base structure is suggested here that consists of a series of relations, or tables, which contain, for each agronomic experiment, data concerning the experimental site, the experimental set-up, management practices, plant data and soil data. (It is assumed that meteorological data and soil properties data will also be part of the data base, but they are not considered explicitly). Each line of a table contains only a single type of data, the type being indicated by a code. Separate tables contain information about each of the data types that can occur in the data base. This structure is very flexible, in that any number of new types of data can be added without necessitating any reorganization of the data base. It facilitates the checking of new data, since information concerning reasonable data values is contained in the data base, and it is to a large extent self-documented, as quite detailed definitions of the data types are also included in the data base.

Introduction

The rapid development of crop modeling research in recent years has not been accompanied by supporting work on data organization for modeling, a subject that has been largely neglected. This may not be too serious as long as only a few data are involved in a modeling activity, but data organization becomes critical when large amounts of data, multiple uses of the data, and exchanges of data and models are considered, which often happens in modeling work.

Very generally, a data base for crop modeling contains data from various agronomic experiments. But exactly which data, and how they should be organized, depends on the probable uses to which they will be put. Basically, two uses are likely. First, the data base will be interrogated, either to aid in model development or independently of any particular model. For example, from a wheat experiment data base one might want the average of leaf weight per unit leaf area up to anthesis. More complicated questions might involve combinations of different types of data, such as plant and meteorological data. For example, what is the average of the number of degree days from one particular development stage to another?

The second major use of the data base will be to provide input data for crop simulation models. Obviously, the base must contain the data necessary for running a model for the conditions of each experiment. Typically, this includes meteorological data, soil properties, information about planting and crop management (irrigation, fertilization, etc.), and initial soil conditions. But some models may also use plant and soil data from the simulation time period as input, and it is useful to

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International Crops Research Institute for the Semi-Arid Tropics. 1984 Proceedings of the International Symposium on Minimum Data Sets for Agrotechnology Transfer, 21-26 March 1983, ICRISAT Center, India, Patancheru, A P. 502 324, India: ICRISAT.

have such data available for comparison with model predictions.

It is now possible to suggest the basic features desirable in a data base for crop simulation modeling. First, the data base should include not only the typical driving variables for models, but plant and soil data from each experiment as well. It should not be built specifically for a particular model, but rather to contain as wide a range of data as possible. The more complete the data base, the more valuable it is as a repository of crop information. Also, models and their data requirements have a tendency to evolve fairly rapidly, so a model-specific data base would quickiy become obsolete. Furthermore, the exchange of data and models between locations could be extremely advantageous, and such exchanges would be greatly facilitated if the same basic data organization were used at the different locations. This again requires that the data base contain a wide range of data, and not only data required for a particular application.

Regardless of the range of data originally foreseen for the data base, it must be assumed that with time new types, or even entire new categories, of data will be added to the base. For example, new measurement techniques may make new types of data commonly available (e.g. rooting densities). Or it may be decided to interface a crop model with insect models, necessitating the addition of insect population data to the base. The data base and the data management system should be designed in such a way that new types of data can be added without necessitating the rewriting of existing management programs or crop models.

Maintenance of the data base should be convenient and simple, even at the expense of some inefficiency in terms of computing time. For the foreseeable future, data-base maintenance will be done by modeling groups that will not generally be able to devote many resources to it. In any case, data-base maintenance is not expected to pose a difficult problem, since the data base will probably be very nonvolatile. Data will be added only intermittently and will rarely be deleted. Also, even fairly long delays between receiving data and adding it to the data base will probably be well tolerated.

A high level of integrity must be maintained; lengthy calculations will be based on the data and these cannot be redone because the data were in error. Therefore, the data should be checked as thoroughly as possible at the time of addition to the data base, and this should be done automatically.

The data base should of course be as efficient as possible in terms of storage space and retrieval times. For example, meteorological data should not be stored with each experiment. This would lead to an unacceptable level of redundancy, since many experiments may be associated with the same meteorological data and it would be too costly, in terms of computing time, to search a file sequentially every time a data record is required. However, some inefficiency in data retrieval may be acceptable, as long as data retrieval time remains small compared with the overall execution time of the models.

The purpose of this contribution is to suggest a data-base organization for crop modeling consistent with the above considerations. The data management programs that would be necessary or useful with this data organization will also be briefly discussed.

The proposed data-base organization is the outgrowth of previous work in organizing cotton data for a DEC PDP 11/70 computer (Wallach et al. 1980) and wheat data for an AMDAHL 470v/6.

Data Organization

The data considered here are those that (a) define an agronomic experiment (location, crop, planting date, etc.); (b) describe management practices during the experiment (irrigation, fertilization, etc.); (c) detail crop data from the experiment (e.g. LAI at various times); and (d) give soil data from the experiment (e.g. soil water content in various soil layers at various times). Data on meteorological conditions and soil properties should of course be included in the data base, but the organization of these warrants separate treatment and is not considered here.

Table 1 presents the suggested logical structure of the data. The actual physical structure of the data may be somewhat different (see below). The representation in Table 1 takes the form of a number of relations between data items, or atttributes. The word outside the parentheses is the name of the relation, and the words inside are the names of the attributes. Compound names are joined by hyphens. The relations indicate how the data could be organized into two dimensional tables. The columns of the tables would be

Table 1. Logical representation of an agronomic data base.

(1) FIELD (FIELD-NUMBER, FIELD-DESCRIPTION-CODE. FIELD-DESCRIPTION-NAME. FIELD-DESCRIPTION-VALUE)

(2) EXPERIMENT (EXP-NUMBER. EXP-DESCRIPTION-CODE, EXP-DESCRIPTION-NAME, EXP-DESCRIPTION-VALUE)

(3) MANAGEMENT (EXP-NUMBER. MGT-CODE. DATE. AMOUNT, METHOD-OF-APPLICATION, PRODUCT)

(4) PLANT-DATA (EXP-NUMBER DATE. PLANT-DATUM-CODE, REPLICATE. VALUE)

(5) SOIL-DATA (EXP-NUMBER, DATE. SOIL-DATUM-CODE. REPLICATE. CM-TO-TOP-OF-LAYER, CM-TO-BOTTOM-OF-LAYER, VALUE)

(6) FIELD-DATA-TYPES (FIELD-DESCRIPTON-CODE. FIELD-NAME-MEANING, FIELD-VALUE-MEANING)

(7) EXPERIMENT-DATA-TYPES (EXP-DESCRIPTION-CODE. EXP-NAME-MEANING, EXP-VALUE-MEANING)

(8) MANAGEMENT-DATA-TYPES (MGT-CODE, MGT-CODE-MEANING.MGT-MINIMUM-VALUE, MGT-MAXIMUM-VALUE)

(9) PLANT-DATA-TYPES (PLANT-DATUM-CODE, PLANT-DATUM-CLASS. PLANT-CODE-MEANING, PLANT-MINIMUM-VALUE, PLANT-MAXIMUM-VALUE)

(10) PHENOLOGY-DATA-TYPES (PHENOLOGY-CODE, PHENOLOGY-CODE-MEANING, PHENOLOGY-ORDER, REFERENCE-STAGE, PHENOLOGY-MINIMUM-DAYS, PHENOLOGY-MAXIMUM-DAYS)

(11) PLANT-DATA-EQUATIONS (EQUATION-NUMBER, CODE CALCULATED, CODE-FIRST-OPERAND, OPERATOR, CODE-SECOND-OPERAND, CONVERSION-FACTOR)

(12) SOIL-DATA-TYPES (SOIL-DATUM-CODE. SOIL-CODE-MEANING, SOIL-MINIMUM-VALUE, SOIL-MAXIMUM-VALUE)

labeled by the attribute names of the relation, and each row would represent data for a different entity.

The FIELD relation contains those attributes of a field that are invariant over time. An instance of the table corresponding to the FIELD relation is shown in Table 2. Each row, or tuple, contains the field identifier number, a code that indicates what data are represented in the tuple, and a name or a value. The identifier number plus the code are called the key of the tuple, since those two values together uniquely identify a tuple. In Table 1, the key attributes in each relation are underlined.

The FIELD-DATA-TYPES relation describes what data are associated with each code value in the FIELD relation. An instance of a FIELD-DATA-TYPES table is shown in Table 3. This table shows that in the FIELD table, the name following a code value of 1 is the farm name, the name following a code value of 2 is the field name, the values following codes 3 and 4 are respectively the latitude and longitude of the field, and the name following code 5 is the soil name. Returning now to Table 2, it can be seen that the tuples for field number 1 indicate that the name of the farm is Temple, the name of the field is ARS NW, the field location is 31.0° latitude and 97.2° longitude, and the soil is Houston Black Clay. The advantage to representing only a single field attribute per tuple is that it is then easy to add other attributes (e.g., slope) to the field description. The descriptions of the new attributes are added to the FIELD-DATA-TYPES table, and then values associated with the new attributes can be included in the FIELD table, in exactly the same way as the previous attributes. If, on the other hand, all the attributes of a field were contained in a single tuple, a major reorganization of the data might be required to add new attributes. (Leaving free space in the tuple would delay, but not solve, the problem).

In the EXPERIMENT, MANAGEMENT, PLANT-DATA and FIELD-DATA tables as well, each tuple contains only one kind of data, the kind being indicated by a code value. Information concerning the data types themselves is contained in separate tables. For example, the EXPERIMENT-DATA-TYPES table describes the types of data contained in the EXPERIMENT table.

The EXPERIMENT relation contains those attributes of an experimental field that can vary from crop to crop. The example of EXPERiMENT-DATA-TYPES table (Table 4) shows which attributes might be included here. Where applicable, units are specified in Table 4 in order to define the meaning of the data as precisely as possible. (The notation "YYYYMMDD" after sowing date indicates that the date is to be entered as four digits for the year, two for the month, and two for the day. All dates are represented in this form). Data codes 8 and 9 refer to information about the previous and following crops. The information is necessary for example to run a model for a

Table 2. An example of a FIELD table.

FIELD-NUMBER	FIELD-DESCRIPTION-CODE	FIELD-DESCRIPTION-NAME	FIELD-DESCRIPTION-VALUE
1	1	TEMPLE	
1	2	ARS NW	
1	3		31.0
1	4		97.2
1	5	HOUSTON BLACK CLAY	
2	1	OAHU SUGAR CO.	
2	2	120	
2	3		21.3
2	4		158.0
2	5	WAHIAWA	

Table 3. An example of a FIELD-DATA-TYPES table.

FIELD-DESCRIPTION-CODE	FIELD-NAME-MEANING	FIELD-VALUE-MEANING
1	FARM NAME	
2	FIELD NAME	
3		LATITUDE
4		LONGITUDE
5	SOIL NAME	

sequence of crops in a given field. Data types 8 and 9 need not be present for every experiment. For example, if the previous crop is unknown for a given experiment, data type 8 will not appear in the EXPERIMENT table for that experiment. It is also possible that the previous crop is known, but that data for that crop are in the data base. In that case, there will be a tuple for data type 8, but the previous experiment number will be marked as missing. In general, not all possible codes will appear for each experiment, and within a given tuple, attribute values may be missing.

The MANAGEMENT table contains information about the management of the crop, including tillage, irrigation, fertilization, application of herbicide and insecticide, defoliation, harvesting, etc. The types of data are described in the MANAGEMENT-DATA-TYPES table (not shown). This latter table also contains reasonable minimum and maximum values associated with an intervention, where applicable. For example, for sprinkler irrigation of cotton, the amount of water provided is generally in the range 40 to 150 mm. Specifying these limits makes it possible to check new inputs to ensure that the data are reasonable, and to issue a warning if they are not.

Table 4. An example of an EXPERIMENT-DATA-TYPES table.

EXP-DESCRIPTION-CODE	EXP-NAME-MEANING	EXP-VALUE-MEANING
1	TREATMENT NAME	
2	CROP NAME	
3	VARIETY NAME	
4		SOWING DATE (YYYYMMDD)
5		SOWING DEPTH (MM)
6		ROW SPACING (CM)
7		PLANTING DENSITY (PLANTS/M**2)
8	PREVIOUS CROP NAME	PREVIOUS EXPERIMENT NUMBER
9	FOLLOWING CROP NAME	FOLLOWING EXPERIMENT NUMBER
10	METEORO-LOGICAL STATION NAME	DISTANCE TO MET STATION (KM)

The PLANT-DATA table contains the results of plant measurements. The data which can be entered are described in the PLANT-DATA-

TYPES table. An instance of this table for wheat is shown in Table 5. This table shows the general class of each datum (1 refers to phenological data, 2 to harvest data, and 3 to plant data before harvest), describes the datum as exactly as possible, and contains reasonable minimum and maximum values for each datum, for use in checking new data. Phenology data are handled somewhat differently from the other data. A code of 1 in the PLANT-DATA table indicates that the tuple contains phenology data. The date attribute in the tuple specifies the date at which a particular stage was reached, and the identity of the stage is indicated by a code in the VALUE column. The explanations of the codes are given in the PHENOLOGY-DATA-TYPES table (Table 6), which also contains information for checking new phenology data. First, each stage is assigned an

Table 5. An example of a PLANT-DATA-TYPES table, applicable to wheat.

PLANT-DATUM-CODE	PLANT-DATUM-CLASS	PLANT-CODE-MEANING	PLANT-M1NIMUM-VALUE	PLANT-MAXIMUM-VALUE
1	1	PHENOLOGICAL STAGE	1.	8.
2	2	GRAIN DM. (G/M**2) AT HARVEST	50.	1000
3	2	COMBINE YIELD DM. (G/M**2) AT HARVEST	50.	1 000.
4	2	STRAW D.M. (G/M**2) AT HARVEST	50.	1 000
5	2	GRAIN + STRAW D.M. (G/M**2) AT HARVEST	100.	2 000.
6	2	PLANTS/M**2 AT HARVEST	25.	400.
7	2	HEADS/M**2 AT HARVEST	25.	1 500.
8	2	GRAINS/M**2 AT HARVEST	1000.	200 000.
9	2	HEADS/PLANT AT HARVEST	1.	30.
10	2	SPIKELETS/HEAD AT HARVEST	5.	30.
11	2	GRAINS/HEAD AT HARVEST	5.	150.
12	2	GRAINS/SPIKELET AT HARVEST	1.	6.
13	2	GRAIN D.M. (MG/GRAIN) AT HARVEST	10.	70
14	2	PLANT HEIGHT (CM) AT HARVEST	30.	150.
15	3	PLANTS/M**2	25.	400.
16	3	LAI (LAMINA ONLY)	0.	15.
17	3	LIVE SHOOTS (INCLUDING MAIN SHOOT)/M**2	25.	2 500.
18	3	HEADS/M**2	25.	1 500.
19	3	LEAF+SHOOT D.M. (G/M**2)	0.	2 000,
20	3	HEAD D.M. (G/M**2)	0.	2 000.
21	3	ABOVEGROUND D.M. (G/M**2)	0.	4 000.
22	3	GREEN LEAVES/M**2	1.	2 000.
23	3	LIVE SHOOTS (INCLUDING MAIN SHOOT)/PLANT	1.	30.
24	3	HEADS/PLANT	1.	30.
25	3	GREEN LEAVES/PLANT	0.	50.
26	3	GREEN LEAVES ON MAIN SHOOT	0.	5.
27	3	HEAD D.M. (G/HEAD)	0.	4.
28	3	GRAIN D.M. (G/HEAD)	0.	150.
29	3	GRAIN D.M. (MG/GRAIN)	0.	70.
30	3	PLANT HEIGHT (CM)	0.	150.
31	3	CUMULATIVE FULLY EXTENDED MAIN SHOOT LEAVES	0.	20.
32	3	CUMULATIVE EMERGED MAIN SHOOT LEAVES	1.	20.
33	3	LAI (ALL GREEN AREA)	0.	15.

Table 6. An example of a PHENOLOGY-DATA-TYPES table, applicable to wheat.

PHENOLOGY CODE	PHENOLOGY-CODE-MEANING	PHENOLOGY-ORDER	REFERENCE-STAGE	PHENOLOGY-MINIMUM-DAYS	PHENOLOGY-MAXIMUM-DAYS
1	PLANTING	100			
2	EMERGENCE (YYYYMMDD)	200	1	4	60
3	DOUBLE RIDGES (YYYYMMDD)	300	2	15	200
4	TERMINAL SPIKELET (YYYYMMDD)	400	3	5	30
5	FIRST NODE (YYYYMMDD)	500	4	0	7
6	HEADING	600	5	10	40
7	ANTHESIS	700	6	0	14
8	PHYSIOLOGICAL MATURITY	800	7	12	70

Table 7. The PLANT-DATA-EQUATIONS table associated with the PLANT-DATA-TYPES of Table 5.

EQUATION-NUMBER	CODE-CALCULATED	CODE-FIRST-OPERAND	OPERATOR	CODE-SECOND-OPERAND	CONVERSION-FACTOR
1	2	5	–	4	1.
2	2	13	*	8	.001
3	4	5	–	2	1.
4	5	2	+	4	1.
5	6	7	/	9	1.
6	7	9	/	6	1.
7	7	8	/	11	1.
8	8	11	*	7	1.
9	8	2	/	13	1000.
10	9	7	/	6	1.
11	10	11	/	12	1.
12	11	12	*	10	1.
13	11	8	/	7	1.
14	12	11	/	10	1.
15	13	2	/	8	1000.
16	15	17	/	23	1.
17	15	18	/	24	1.
18	15	22	/	25	1.
19	17	23	*	15	1.
20	18	24	*	15	1.
21	18	20	/	27	1.
22	19	21	–	20	1.
23	20	21	–	19	1.
24	20	27	*	18	1.
25	21	19	+	20	1.
26	22	25	*	15	1.
27	23	17	/	15	1.
28	24	18	/	15	1.
29	25	22	/	15	1.
30	27	20	/	18	1.

order indicating the normal sequence of developmental stages. (The orders in Table 6 are in the same sequence as the phenology codes, but this need not remain true as additional phenologicai stages are appended to the table). In addition, for each stage a reasonable minimum and maximum time since some previous stage (the reference stage) may be specified.

The PLANT-DATA relation includes a replicate number, making it possible (though not obligatory) to include separately the results of each replicate in a replicated experiment. This is necessary if statistical analyses are to be performed on the data. It may also be of interest for modeling work to know the standard deviations as well as averages of the data.

The plant data described in Table 5 ar not all independent. For example, grains/m^2 at harvest (code 8) = grains/head at harvest (code 11) * heads/m^2 at harvest (code 7). In some experiments only grains/m^2 may be reported, in others the more detailed information per head may be reported. In the latter case it is desirable to calculate grains/m^2, in order to obtain a standardized set of data for all experiments. In general, additional data values should be derived from the reported data wherever possible. The information contained in the PLANT-DATA-CALCULATIONS table (Table 7) makes this possible. This table includes all ternary relations among data types. Equation 8 in the table, for example, is the relation mentioned above mentioned for calculating grains/m^2. The conversion factor converts the result of the calculation to the correct units for the calculated data. All possible derivations of plant data, including those involving more than two operands, can be obtained by making a series of passes through the PLANT-DATA-EQUATIONS table. The process can be ended when no new data values are calculated in a pass.

The SOIL-DATA table contains the results of soil measurements by layer, including soil moisture, nutrients, etc. The descriptions of the types of data which can be entered here are contained in the SOIL-DATA-TYPES table (not shown).

The data structure shown in Table 1 is in what is known as third normal form. This type of structure is recommended for data bases because it is "easy to implement and to use," and because it allows the data base to "grow and evolve naturally" (Martin 1977).

The problem that arises in considering the physical organization of the data base is that on the one hand the data files should be exchangeable between locations/which in practice means they should have a simple, standard form; on the other hand, for computational efficiency, the physical data organization should be adapted to each particular installation. This problem can be resolved by having two sets of data files, an exchange set in simple form for exchange, and a computation set adapted to the installation for use in calculations.

Each exchange file should contain all the data from one experiment, organized as shown in Table 8. In addition, there should be separate exchange files corresponding to each of the relations 1 and 6 to 12 of Table 1, which contain data independent of any particular experiment.

The computation files on the other hand will each correspond to a relation in Table 1. The PLANT-DATA file then, for example, will contain the data from all experiments. The records in each file will contain the attributes of the corresponding relation in Table 1, plus free space for expansion, plus pointers to related data. Most important in the physical representation is the method used for finding particular data. For example, one might want the latitude of a parti-

Table 8. An example of an exchange file for data from an agronomic experiment.

RECORD TO INDICATE START OF EXPERIMENT DESCRIPTION

ANY NUMBER OF EXPERIMENT DESCRIPTION RECORDS
EACH CONTAINS THE ATTRIBUTES SHOWN IN TBL 1

RECORD TO INDICATE END OF EXPERIMENT DESCRIPTION

ANY NUMBER OF MANAGEMENT RECORDS
EACH CONTAINS THE ATTRIBUTES SHOWN IN TBL1

RECORD TO INDICATE END OF MANAGEMENT RECORDS

ANY NUMBER OF PLANT DATA RECORDS
EACH CONTAINS THE ATTRIBUTES SHOWN IN TBL. 1

RECORD TO INDICATE END OF PLANT DATA

ANY NUMBER OF SOIL DATA RECORDS
EACH CONTAINS THE ATTRIBUTES SHOWN IN TBL. 1

RECORD TO INDICATE END OF DATA FOR THIS EXPERIMENT cular field from the FIELD file, or the first plant data record for a particular field in the PLANT-DATA file. Various techniques for facilitating data retrieval may be used (direct access files with or without indices, pointers, etc.), but the choice of techniques will depend on the hardware at each location.

Data Treatment Programs

The most basic programs required are those for adding data to the base and for correcting previously entered data. One possibility is to have a set of programs that allow the data in the computational files to be entered or corrected interactively. These programs should check the data at the time of input, print out warning messages for suspicious data (e.g. development stages out of normal order), reject impossible data (e.g., nonexistent dates, or undefined codes), and calculate additional plant data values where possible. It is also necessary to be able to use exchange files as described above as input and to output exchange files.

An alternative, simpler scheme is to permit input of experimental data only in the form of exchange files. When data from a new experiment are received, a corresponding exchange file is prepared, and an input and checking program is used to transfer the data to the computational files. If errors are found subsequently in the exchange file—for example, as a result of warnings issued by the input and checking program—the exchange file is corrected and the program rerun. The program then treats all the data anew, automatically replacing incorrect values in the computational files with the new values. The inefficiency of this procedure is probably not very serious. Once data has been transferred to the computational files the exchange files can be kept as a backup. The input and correction of data not related to a particular experiment is simpler than handling experimental data, and so the programs to handle these data can easily be designed to handle either entire file or single records.

A second group of programs is required for output of selected portions of the data in convenient format.

A third group of programs is required for data retrieval. Particularly for modeling work, a standard group of subroutines for data retrieval should be defined. All dependence of a modelon a particular physical data organization should be contained in these subroutines. Then the model could be transported easily between locations, a change of data organization requiring simply the exchange of the previous standard subroutines for those of the new location.

Conclusions

The data organization described above can be applied to any crop. It is very flexible, in that new types of data can be added without necessitaing any reorganization of the data base. New categories of data (e.g. insect populations) would give rise to additonal relations like those in Table 1, but would not affect existing relations. However, subroutines would have to be added or modified to input and retrieve the new data, and additional pointers would be necessary to link the new data to other related data. The proposed data organization facilitates the checking of new data by including in the data base reasonable upper and lower bounds on data values. Also, the data base is to a large extent self-documented, since it contains quite detailed definitions of the data types handled.

It would be very advantageous if a standard organization for agronomic data were widely adopted, since this would greatly facilitate the exchange of both crop data and crop models. The proposed data organization could fill this role, since its flexibility makes it appropriate for a wide range of applications, including but not limited to, crop modeling projects.

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A Proposed Design of General Agriculture Systems for Expediting Technology Transfer

Paul T. Dyke*

Abstract

World population is over 4 billion and is expected to exceed 6.5 billion by the year 2000 Even today, it is estimated that one-third of the world goes to bed hungry.

This paper outlines a methodology and proposes a plan of work that will lead to an operational system capable of addressing a wide variety of research, food production, and food policy questions.

The objectives specify the creation of four major subsystems of simulation models: (1) physical, (2) economic, (3) political, and (4) sociological. A network must be established which enlists the cooperation of the many research centers that have agreed to collect a "minimum" set of critical data. These data must be assembled into a comprehensive research data base designed to aid in the development and testing of agricultural simulation models as well as to provide for the exchange of information among cooperators.

Information coming from the simulation system will provide feedback to research centers about kinds of additional research needed to understand better the processes of food and fiber production.

A second data base and network must be established for the users of the analytical system. The data base will include resource inventories (soil, water, labor, etc.) and information on climate, plant genetics, insects and diseases, cropping practices, costs, markets, and other information necessary to drive the simulation system for various geographic regions of the world. Besides the cooperating research centers, the user network will also encompass many other users such as farm advisors, project analysts, other plant breeders, regional planners, and agricultural policy analysts. This network will be designed to promote the distribution and rapid adoption of research and technology information at the producer level.

The resulting cooperative network and analytical system would provide a mechanism to reduce the cost and increase the speed at which scientific technology is developed, packaged, transferred, and implemented within the geographical, political, and sociological boundaries suited to it.

Introduction

Current world population is estimated to be over 4 billion; by the year 2000 it will top 6.5 billion. Even today, it is estimated that one-third of the world goes to bed hungry. Numerous reports, including the *Global 2000 Report to the President* (GEQ 1980), point out the critical nature of the time period from 1980 until 2000, which, as the Global 2000 report suggests, will play a major role in determining the level at which the world's resources can feed the population.

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International Crops Research Institute for the Semi-Arid Tropics. 1984. Proceedings of the International Symposium on Minimum Data Sets for Agrotechnology Transfer, 21-26 March 1983, ICRISAT Center, India. Pataneheru, A.P. 502 324, India: ICRISAT.

While there is no question about increase in demand for food, the agricultural scientific community is debating if, in fact, world resources will be able to meet this demand. We must do some rapid reassessment of how we do business if we are to meet this challenge. We must critically evaluate our tools of research, discard ineffective ones, and get on with the developing, testing, assembling, and full-scale utilizing of those that will give us the most use in the shortest time period.[1]

This paper is an attempt to address this challenge to action. It is intended to be more than a mere description of a methodology: it is a proposed plan of work. My hope is that the "plan of work" coming from this meeting will lead to more than a demonstration or prototype, embracing a plan for creating an operational system capable of addressing a wide variety of research, food production, and food policy questions.

The presentations that you have already heard point out that this task is well under way in the USA and other countries. By bringing together a forum of scientists such as we have assembled here, we hope procedures can be developed, a network of communication established, and a spirit of cooperation fostered that will provide research data and scientific expertise from all parts of the world to reduce the time gap between technological development and client usage.

Program Objectives and Philosophy for an Acceptable Design

The objectives outlined here are my interpretation of what is involved in creating a viable technology transfer network. The philosophy presented is intended to suggest the need for ground rules to be followed as research is designed, analytical components of submodels developed, and data collected. Hopefully, this will stimulate discussion to establish some set of ground rules based on sound methodology leading to the objective. As you will note, the objectives are divided into means and ends.

[1]I am not proposing the elimination of basic research, I am advocating the more extensive use of new research technology in addressing research questions—foe they basic or applied. The scientific research community is not immune to the classical problem of technology adoption

Objectives

Objectives—Means

It is first necessary to develop:

A. A subsystem of simulation models based on the principles of the physical sciences. The relational models must be sufficiently general to simulate crop growth and natural processes equally well for all geographic locations.

B. A subsystem of economic models capable of assessing the economic impact of various agricultural production, research, and policy management decisions in various sociological and political environments.

C. A subsystem of policy models capable of addressing risk analysis and probability of success for evaluating alternative food and fiber policies of a political entity. The system must take into consideration the quantity and quality of the natural and human resources within a political jurisdiction.

D. A subsystem of sociological models whereby the physical, economic, and political submodels can be made sensitive to the various sociological environments existing within the given geographic area of study.

E. A list of the research and data needed to create these subsystems.

It is also necessary to:

F. Establish a network of cooperation and communications to design and carry out experiments and to assemble, process, and disseminate to all cooperators the research information and data needed to develop and test these subsystems.

G. Develop the linkages among the physical, economic, political, and sociological subsystems to allow for the recursive and/or simultaneous interaction of the various subsystems with each other.

H. Develop a comprehensive list of the data needed to "drive" the linked subsystems and a list of the potential sources and methods of obtaining the needed data.

I. Establish a network of cooperation and communication to collect the data needed to drive the large-scale, operational, analytical system.

J. Garry out the assembling, processing, and organizing of the data bases needed for the operational system.

K. Provide a network of cooperation and communication to make the linked analytical system and supporting data bases available to many management levels and geographic locations. At one extreme, the analytical capabilities of the network should provide a management tool useful to those addressing specific problems; for example, farm advisors, plant breeders, and other researchers. At the other extreme, the integrating capabilities of the system should also be such as to help economic and policy analysts assess the impact of policies when addressing national, regional, and international types of questions about food and fiber production.

L. Provide the training, documentation, network access, technical support, and model relocation capabilities necessary to assure that all cooperators can effectively use the analytical capabilities of the system for addressing their specific questions and problems.

Objective—End

The ultimate objective is to reduce the cost and increase the speed at which scientific technology is developed, packaged, transferred, and implemented within the geographical, political, and sociological boundaries suited to it. A specific technology would be adopted if its use would enhance or stabilize food and fiber production, thereby improving the well-being of the members of that society.

A clear distinction must be maintained between means and ends. Only the last objective defines the ends. Any activity or any combination of activities that does not lead us toward the final objective is superficial and leaves our labors barren.

Philosophy

The developmental environment must stimulate input of, and cooperation among, many disciplines and geographic locations if it is to be accepted and used as a technology transfer tool.

In order to do this, the methodology must be acceptable to physical scientists, economists, political scientists/and sociologists.

Acceptability

To be acceptable to physical scientists, all components must have physical meaning and simulate physical relationships.

To be acceptable to economists, all components must have economic importance and must be balanced in an economic sense (i.e.; attention to component parts must be in proportion to the impact on output variables—yield, etc.). Attention must be given to production, storage, transportation, and other marketing costs; Seasonal demands and supplies must enter into the decision framework.

To be acceptable to political scientists, the components must be sensitive to the following considerations: resources ownership (property rights), political institutions (water rights, political boundaries, zoning, land use, etc.), governmental authority to implement change, impact on other agricultural and nonagricultural governmental policies and programs, technological stability under changing political environments, and translation of desirable technology recommendations into policy programs (governmental cost, legislative acceptability, etc.).

To be acceptable to sociologists, the system must be sensitive to the following social conditions: the distribution of resource ownership (farm size and tenure), the skill levels of the farm managers and agricultural advisors, the traditional roles of members of society, the current mode of operation and management (crops, crop rotations, working patterns, capital funding, etc.), the eating customs of consumers (seasonal foods, religious restrictions, holidays, etc.), and the general social preferences of a particular society.

Links

Tangible identifiable links must be clearly shown between physical processes, economic analyses, political alternatives, and social acceptability:

- Physical information must be convertible into economic information or a social welfare function.
- Economic information and social and policy decisions must be convertible into changes in the input mix of the physical resources.

The Systems Concept

To fit into a systems context, all information must be reducible to quantifiable numbers or logical tables which can be handled mathematically and logically, and can be stored in a logical data base.

The integrated system should built in modules so that it: (i) allows any and all parts to be dynamically upgradable, (ii) allows parallel development of components by many diverse

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The integrated system should built in modules so that it: (i) allows any and all parts to be dynamically upgradable, (ii) allows parallel development of components by many diverse disciplines and researchers, (iii) facilitates documentation, and (iv) facilitates component testing.

All components must run on a unit-time concept (i.e., daily, seasonal, etc.). These values are calculated for each time step and updated at the end of each time period. The new values become the beginning conditions for the next unit of time.

Geographic coverage should be a function of the data input into the model, not the model itself, (i.e., the same model is used for a farmer's field or for a geographic region; the difference is in the input data driving the model).

The modules should be built using as much available information as possible from existing research and scientific literature. Gains in knowledge will be used to build new modules to replace existing ones when improvements become available.

New experiments must be designed so as to address general principles, independent of geographic locations (i.e., results of experiments must hold for other climates, soils, and geographic conditions different from those where the experiment was conducted.)

The system should be constructed to allow a one-season or multi-season environment. Outputs can either single value or stochastic (expected value, standard deviation, etc.).

Inputs required for a module should be obtainable in an operational cost-effective environment. Data sources and data instruments must be identified and procedures for their use must be documented.

A concerted effort should be made to minimize input data requirements. Modules should be built to generate "default" data when actual data are not available.

Conclusion

The objectives listed are not intended to be all-inclusive; they are guidelines for developing a system that is cohesive and widely applicable.

Agricultural Production

Before discussing ways to meet specific objectives, I feel it is useful to review the agricultural production processes and their relationship to one another.

Component Parts

Agricultural production can be grouped into the following three categories: the resources or inputs, the relationships or processes, and the products or outputs.

Resources

Resources can be segmented into natural resources, capital resources, and human resources. The natural resources encompass: (1) the soil and its related properties, including location; (2) the climate, including sunshine, precipitation, irrigation water, wind, and temperature; and (3) the genetic pool of plant materials. The capital resources will include all the machinery and equipment, land forming, artificial drainage, irrigation equipment, seed, fertilizer, herbicides, insecticides, fungicides, and other external capital brought onto land. The human resources can be defined as labor, management, and social knowledge.

Management decisions as to crop rotations, tillage practices, irrigation schedules, fertilizer and pesticide applications, planting and harvesting dates, crop varieties, livestock grazing practices, and numerous other decisions all affect the growth of the plant and, therefore, the output. The management decisions in turn are influenced by economic conditions, institutional policies, and social preferences. The resources available to create the resource mix are frequently controlled by institutional constraints (e.g., pesticide bans, land ownership, etc.) or previous public and private investments in developmental research and basic industries (e.g., plant breeding, equipment design, irrigation water supplies, etc.).

Processes

The processes are the complex relationships and interactions that take place in an ecological and economic environment, including the interdependence among the living and nonliving, organic and inorganic, and/or the physical, economic, and social. Relational processes attempt to explain how the various resources respond when combined in predetermined resource mixes. For our purposes, we will divide the processes into three groups: the physiological processes within a given plant; the physical processes influencing the plant but external to it;

and the economic, social, and political processes that determine the kind and amount of resources available to the plant.

Products

The outputs of the production process are determined by how the process uses the inputs available to it. Outputs can be grouped in many ways such as economic and noneconomic, market and nonmarket.

Some products are both economic noneconomic. Plants exchange carbon dioxide and oxygen. In most cases this is a noneconomic output. It becomes economic only when the carbon dioxide-oxygen balance reaches a level where yield or other economic outputs are affected.

Products can have economic value and enter the decision process but not be a part of the formal market. For example, a crop will produce grain which will be sold in the market. It will also produce biomass above and below ground. Above-ground residues may be used for livestock feed or may be left to reduce soil erosion. Below-ground biomass will affect water infiltration and soil nutrients. Crop residues may affect water runoff which may carry toxic materials into the streams. All these products (grain, straw, roots, and toxic materials) have economic impact, but only the grain enters the marketplace.

The Whole

These processes are recursive. Output from one process and/or time period becomes input (either beneficial or detrimental) to many other processes either in the current or a later time period.

Each part of the production process contains all three components: input, relationship, and output. Even items previously defined as inputs, such as soil or climate, have their own internal processes, which may be simulated at some level on the input-output pyramid.Once this continuum is realized, the distinction between data and processes becomes relative. By reflecting on this logic, one comes to appreciate the immense momentum created by exploiting concepts like "default data," when default data are, in fact, output from the simulation of other physical and economic processes.

Resources in Agricultural Production

Natural Resources

The ancient Greeks thought of the basic natural elements as fire, air, water, and earth—the building blocks of life. Although we have learned a great deal more about the universe since Aristotle, these general divisions are still appropriate. Fire gives both light and heat. Air contains the gases needed by both plant and animal life. Water transports heat, nutrients, and other compounds to and away from the life tissue, thereby giving genetic materials the mobility to divide and grow. The earth stores and allocates nutrients, water, and heat, in addition to providing a stable medium to support the roots and bodies of plants and animal life. When the genetic memories and life processes are added to the above, all of the natural inputs used in plant growth and reproduction are included somewhere in the list.

It is, of course, impossible to address all of the interacting relationships among these inputs. There process submodels will concern themselves with a small number of the more economically important ones. As experience and knowledge are gained, and as the economic significance of inputs can be better tested, new links will be formed and old ones severed.

Climate. The prevailing opinion among scientists associated with plant process modeling is that daily maximum and minimum air temperatures, precipitation, and solar radiation constitute the minimum inputs needed to represent climatic factors. Some debate exists as to the economic importance of wind and relative humidity. Wind data are needed to address problems of wind erosion and are used in the current version of the EPIC model for the purpose. Associated information needed is: longitude and latitude of the location, date of observation, and possibly the elevation. Further research may show that soil and canopy temperatures are important influences on plant processes. As is currently done in EPIC, these will probably be estimated using air temperatures and a process submodel.

Soils. Because of the complex nature of soil, it is difficult to identify that set of soil properties adequate for input into process models. Only a tentative list of the important soil resources will be given here.

The general consensus among soil scientists is that soil properties should be identified and maintained by soil layer. Economically important soil properties are: taxonomic classification, drained upper limit, wilting point, plant-available water, thickness, bulk density, particle size or soil texture, soil albedo, organic matter, organic carbons, natural sources of soil nutrients (N, P, and K), pH, percent slope, slope length, porosity, infiltration rate, compaction characteristics, $CaCO_3$, O_2 content, drainage characteristics, salinity, Al toxicity, cation exchange capacity, and hydraulic conductivity.

Pool of genetic memories. The last of the natural resources to be discussed is the gene pool. It is properly named in that this raw natural resource is much like a pool. Through breeding, individual memories can be moved with some degree of success from one location to another. A useful concept is illustrated when one separates the raw genetic memories from the package (seed). Seed more nearly belongs in the next section, on capital resources. As will be discussed later, an intended use of the integrated network is to assist plant breeders in designing economically viable packages of genetic memories.

Scientists have identified many of these genetic memories; many more have never been observed, much less recorded. This is the least quantified of all the natural resources. Banks of genetic plant and animal material are being selected and maintained for various purposes; for example, the plant and crop germplasm banks maintained by the Food and Agriculture Organization (FAO) and the drought- and disease-tolerance germplasm banks of the International Rice Research Institute (IRRI). Many plant introduction stations have collections of a wide diversity of genetic memories. Numerous sperm and egg banks exist for preserving and managing animal germplasm. However, the effective distribution and use of these rich pools of natural resources are severely limited by the organization and qualification of the life characteristics locked in these genetic templates.

We need a comprehensive, definitive system of quantifying and storing genetic information on plant and animal adaptability to environmental conditions. Such a bank of economically important plants around the world has been started by James A. Duke (1978). However, much more quantification and detail are needed to provide the coefficients for the process models under consideration at this symposium. Although the taxonomic name and classification are precisely descriptive labels, they contain little information on individual genes. About all one can hope for at this stage is some quantifiable observable aggregate effects of many genes in a crop species or cultivar.

Capital Resources

Capital resources are natural and human resources that have been stored in time and moved in location. Machinery, fertilizer, pesticide, etc., are nothing more than labor and technology (knowledge) stored inside some natural resources packaged into small units, assembled into various combinations, and moved to a location where they provide an economic benefit. Capital resources frequently provide cost savings because they allow mixes of natural and human resources that would not otherwise be available. The most common examples of capital resources are machinery and equipment, but other examples include: drainage, irrigation (wells, pipes, ditches, equipment, delivered water, etc.), fertilizer pesticide, biocontrol technology, improved seed (new cultivars, hybrids, and species crosses such as triticales or sorghum-sudan crosses), and soil conditioners.

It is frequently difficult to distinguish between capital resources and naturally occurring resources once they have been introduced into the resource mix (e.g., nutrients, seed, water, etc.). It is sufficient to say that the distinction is important only because extra energy and costs are incurred in making these resources a part of the resource pool.

Certain soil and land-use modification practices are also packages of capital resources: land forming (terracing, leveling), deep plowing (subsoiling), salt removal, soil sterilization, texture modification (rock picking, pulverizing, etc.), and removal of shrubs, trees, and grasses. These practices differ from other "management" practices only in frequency of application and cost.

Human Resources

Human resources fall into three overlapping categories: labor, management, and social knowledge. No definitive attempt will be made to draw clear lines between them. In all three areas it is possible to store and transport these human resources in the form of capital resources.

Labor. Labor is of two types: physical and mental. We will restrict labor to mental or physical activities performed by the entrepreneur or any individual whose services are employed by the entrepreneur. Mental labor is very near management. To avoid noneconomic distinctions, mental labor can be defined as all mental activity, other than management, performed by the entrepreneur or an employee.

Management. Management is the process of assimilating all available information and formulating from it the combinations of resources to use in the production process.

Social knowledge. Social knowledge is the past labor and management held in the public domain. This is frequently stored in capital resources. Neither the entrepreneur nor the employee need understand, or even be aware of, what social knowledge is stored in a capital resource. However, the more he understands of how the end result will affect his operation, the better will be his management decisions.

Many questions dealing with the social conscience must be addressed by using social knowledge to look at the impact of resource mixes on members of our present and future societies, domestic and worldwide. Sometimes social knowledge must be used by policy makers to alter the resources available to the production process. This again is one of the primary purposes of an integrated analytical system—to assist in this type of policy analysis.

Management Practices

For each simulation scenario a management practice must be implemented and a resource mix chosen. A resource mix can be defined as one unique combination of natural, capital, and human resources chosen from all available combinations of resources. A management practice is the use of a resource mix in a production process.

Technology

Agricultural technology and its transfer encompass the entire agricultural production process. Any first-time recombinations of inputs, alterations of processes, and increase in beneficial (or reduction in detrimental) products can be considerable technological advancement. These first-time events do not have to be, and generally are not, economically more cost effective (cheaper) than established production procedures; however, some of them will eventually become a cost-effective, accepted procedure in the production processes. Others will not. Again, the end objective of this integrated analytical system is to improve the probability of developing cost-effective technology and to identify more rapidly where and with what resource combinations this technology can be matched.

Program Implementation

Agency and Country Cooperation

As J. R. Williams and C. A. Jones (these Proceedings) have described, the U.S. Department of Agriculture (USDA) has already developed operational versions of plant process models (EPIC, CERES, etc.). In addition, the Agricultural Research Service (ARS) is committed to the further development of a production management model (ALMANAC). The Economic Research Service (ERS) and Soil Conservation Service (SCS), also within the USDA, are currently using EPIC for its designed purpose—that of evaluating the influence of national policy programs on the long-term availability of the natural resources within the boundaries of the USA.

USAID, IBSNAT, SMSS, and ICRISAT have organized this symposium to plan for international cooperation in improving the transfer of technology to tropical agricultural areas. I feel the linking of the USAID objectives, as expressed in the IBSNAT and SMSS program, with the ongoing basic development of USDA's process models into an integrated agricultural system is a natural symbiotic relationship. A system like the one described above would provide all participants with a whole of greater value than the sum of the parts. I wish to encourage each agency represented here and each scientist present to give serious consideration to what he and his agency could contribute to this cooperative effort.

For those of you here who choose to participate, most would contribute to objectives, A, E, F, K, L, and possibly I. Other cooperators must be enlisted to help attain the remaining objectives.

Objectives A, E, and F--as the most crucial and urgent—are the ones that have been addressed at this symposium. Methodology for reaching the remaining objectives, although critical, cannot be fully designed until more information on the physical processes has been assimilated.

C. A. Jones and J. R. Williams have discussed what is needed to develop the physical sciences subsystem. This process will require a host of new field, greenhouse, phytotron, and laboratory experiments using innovative experimental designs. Many of our traditional experimental designs will not provide the answers, because they are not addressing the questions asked by an "integrated system simulation design." Much is known, but more must be discovered, about the growth habits of economically important crops. Close working relationships between experimentalists and modelers must be maintained if objective A is to be realized.

The list of research and minimum data sets has been addressed by Henry Nix. Mutual agreement on this subject is critical if research from differing locations is to be pooled.

Goro Uehara has addressed and, I am sure, will continue to press onward, the establishment and operation of the cooperative communications network for the exchange of information.

Daniel Wallach has presented a data-base management system designed to assemble, process, and report experimental data for use in model development and testing.

We already have experience in linking economic subsystems with process models. EPIC is providing input information into the U.S. National Linear Programming Model for use in national resource policy analysis. Other economic techniques which should become a part of the economic subsystem include: further use of linear programming, input-output models for tracing secondary impacts of technological change throughout other sectors of an economy and society, international trade and comparative advantage models, farmer income and income stability models, crop budget (currently a part of EPIC), benefit-cost analysis, and numerous other economic linkages which are possible and desirable.

Objectives H, I, and J are identical to the work carried out to make EPIC operational on a national basis in the USA. This large-scale production system is operational. The integrated EPIC system is being used on 191 geographic regions, 10 crops, and approximately 3000 unique soils in the USA. Although the general objectives are identified, the data needed for an internationally linked system will be somewhat different and greatly expanded.

The National Linear Programming Model is being used as a policy tool in the USA. However, much more attention must be given to developing the contents and structures of objectives C and D.

The problems and methodology needed to achieve a user network are similar to those for a scientist network. However, this network of communication must be available for use by many more managers and locations. More thought and work are needed to develop the most cost-effective way to achieve this objective.

Uses of an Integrated Technology Transfer System

The uses of a comprehensive integrated system like the one described above are numerous and far-reaching. The following section will be used to provide a sampling of the kinds of management questions that can be addressed with such a tool. For convenience, they are grouped into four types—questions on: (1) farm management, (2) plant breeding, (3) crop introduction, and (4) agricultural policy.

Farm Management

Today's farm managers must make complex decisions based on a wide array of questions; for example:

1. What planting schedule would provide the greatest potential yields, given a certain crop and geographic location?
2. What particular crop rotation and schedule will best (a) stabilize income, given a minimum level; (b) maximize income?
3. What would be the most effective way to use: irrigation water, fertilizer, pesticide, herbicide?
4. Given the initial soil type, soil moisture, and planting date, what crop variety would be best for a given year?
5. What probable profit and income variations could be expected under dryland versus irrigated production?

At every step the manager must weigh the physical (soil and weather) and economic risks and costs against the relative value or the potential profits from adopting a particular practice, whether deep-plowing, other tillage, liming, or alternative planting schedules or cropping patterns such as double versus single cropping. He must also know what a situation will look like several days or weeks later, given present conditions of soil moisture, nutrients, and plant size.

Plant Breeding

Like farm managers, plant breeders must have information that will aid them to make complex decisions based on the probable impact of a breeding program. For instance:
1. What would be the optimum combinations of plant genetic characteristics for a given climate and soil for (a) low-energy agriculture, using legumes in rotation, limiting fertilizer applications, and using minimum tillage, animal power, and no added inputs such as irrigation, insecticides, or herbicides; (b) high-energy agriculture?
2. What would be the economic impact of a cultivar with a 0.1 wider pH tolerance?
3. What would be the economic impact of developing a cultivar with an extended grain-filling period?
4. Given four dominant soils in a geographic area: (a) should a separate cultivar be developed for each or can a single cultivar be developed with enough adaptability to do well on most soils in the area? (b) What environmental influences limit yield on these soils: pH, salt, daylength. water, heat? (c) What would be the probable payoff of four or more cultivars in improved yield or income stability when compared with one or two?

The breeder must also have information that will enable him to determine how a proposed new crop cultivar will compare with those already in use and over what area worldwide the new cultivar could be grown.

What geographic locations would best suit a cultivar with a given combination of genetic parameters? What are the best gemplasm sources for breeding a cultivar with, for example, a particular sensitivity to daylength, high salt tolerance, etc.?

Crop Introduction Analysis

An integrated system such as the one proposed will have considerable utility in analyzing crop introduction potential. Such analysis must consider such questions as:

1. What crops can be grown effectiely in this area in addition to those currently grown?
2. How much area is suited to a given crop and where is this area located in relation to processing units and size?
3. How well is the crop suited to the growing season in a particular area: (a) How long does the crop need to mature? (b) How much of the harvesting can be staggered? (c) What planting dates and harvest schedule will most effectively utilize processing facilities in the area?
4. How well is the cultivar suited to the soil type?
5. What potential disease and pest problems can be expected with this crop?
6. What rate of erosion should be expected after the land has been opened or the new crop introduced?
7. If the new crop is introduced: (a) What will the soil look like after 10, 20, or 50 years? (b) What would be the projected income profits and distribution at a given time in the future?

Policy Questions

Numerous agricultural questions can be addressed with a system in which technological information can be expeditiously transferred, such as: questions on food policy, food-crop production and soil management, and agricultural marketing.

Food Policy

1. What kind of program can be designed to stabilize food production in a country?
2. How can food policy programs be integrated for a nation?

Crop Production and Soil Management

1. What is the cheapest way to control erosion?
2. If we change the pH or salt content of a soil, what will be the impact on yields and production in this region?
3. How many hectares of what crops can be irrigated with a proposed reservoir?
4. What is the best way to allow for surface or subsurface drainage?

Agricultural Marketing

1. What are the best locations for the processing units, given soils and climatic information on a region?

2. Where should roads, rails, etc., be located to best utilize the agricultural production potential of a region?

Conclusion

In the hands of the proper decision makers an analytical tool capable of addressing similar types of questions could substantially expedite the adoption and diffusion of agricultural scientific technology. The scientists and administrators at this symposium have the technical capability to build and implement such a system. What we do with this opportunity will, in one way or another, affect food and fiber production around the world.

Summary

This paper describes a methodology and a plan for implementing an operational analytical system to address a wide range of research, food production, and food policy questions. The creation of four major subsystems of simulation models—denoted "physical," "economic," "political,[1]', and "sociological"—is specified in the objectives. These require "minimum" data sets of critical data from research centers and other locations around the world. The minimum data sets assembled will form a comprehensive data base that will serve both as input for testing simulation models and as a pool of data to be used among cooperators. Simultaneously, there is the need to build a second data base for the users of the analytical system. The potential users of this data base are the cooperating research centers as well as farm advisors, project analysts, plant breeders, regional planners, and agricultural policy analysts. The user data base will need to include the resource, climatic, genetic, insect and disease, cost, cropping practice, and market information necessary to drive the simulation models. Together the data bases and the data transfer system will provide a means to effectively and efficiently market technologies across geographical, political, and sociological boundaries.

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Minimum Set of Benchmark Sites

Characteristics of Cooperators' Research Sites

Goro Uehara*

Abstract

Twenty potential cooperators have expressed interest in joining the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT). On an average each cooperator has offered five potential sites for conducting IBSNAT research. Based on personal knowledge and data from questionnaires, the network of research stations includes the Aquic, Udic, Ustic, Xeric, and Aridic soil moisture regimes and thermic, hyperthermic, isohyperthermic, isothermic, and isomesic temperature regimes.

The most common combinations of soil temperature and soil moisture regimes are the isohyperthermic-udic and isohyperthermic-ustic. Variations in edaphic factors add a third and large dimension to the range in characteristics of the IBSNAT's agroenvironments. Some common crops currently being studied in the network are cassava, cocoyam, beans, groundnut, maize, pigeonpea, pasture grass, potato, rice, sorghum, soybean, wheat, and yam. Potato and wheat are concentrated in the cool (isothermic), high elevation zone, and sorghum, pigeonpea, and groundnut are researched in the warm (isohyperthermic), seasonally dry (Ustic) environments.

Our aim is to select from this set of potential research sites, a minimum number of benchmark sites to generate data for the development and validation of a general agricultural management model for agrotechnology transfer.

A definition of a benchmark site and the characteristics of a research network consisting of a minimum number of benchmark sites is expected to be an output of this symposium.

To assess the range of agroenvironments covered by the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT), 20 cooperating countries were asked to complete and return questionnaires (see Annexure 1) on the characteristics of likely IBSNAT experimental sites. Complete or partial information on 36 research stations from five countries was available at the time of this writing; personal knowledge and reports from other regions have been used to make up for the missing information.

Figure 1 shows the global distribution of IBSNAT cooperators, and Figure 2 shows the distribution of IBSNAT cooperators who have indicated willingness to contribute resources and space for field experiments. Each point in Figure 2 represents at least one experimental site and in most cases several. The initial response to our questionnaire averaged five research sites per country. It is therefore likely that some 100 potential IBSNAT research sites exist among the 20 countries identified in Figure 2.

In a paper to follow, Dr. Hari Eswaran will present some ideas on the minimum set of benchmark research sites. The participants of the symposium will also be asked to identify the minimum set of crops, reach agreement on the characteristics of the minimum set of benchmark sites, and provide guidance on the minimum data set to collect from each type of experiment. We

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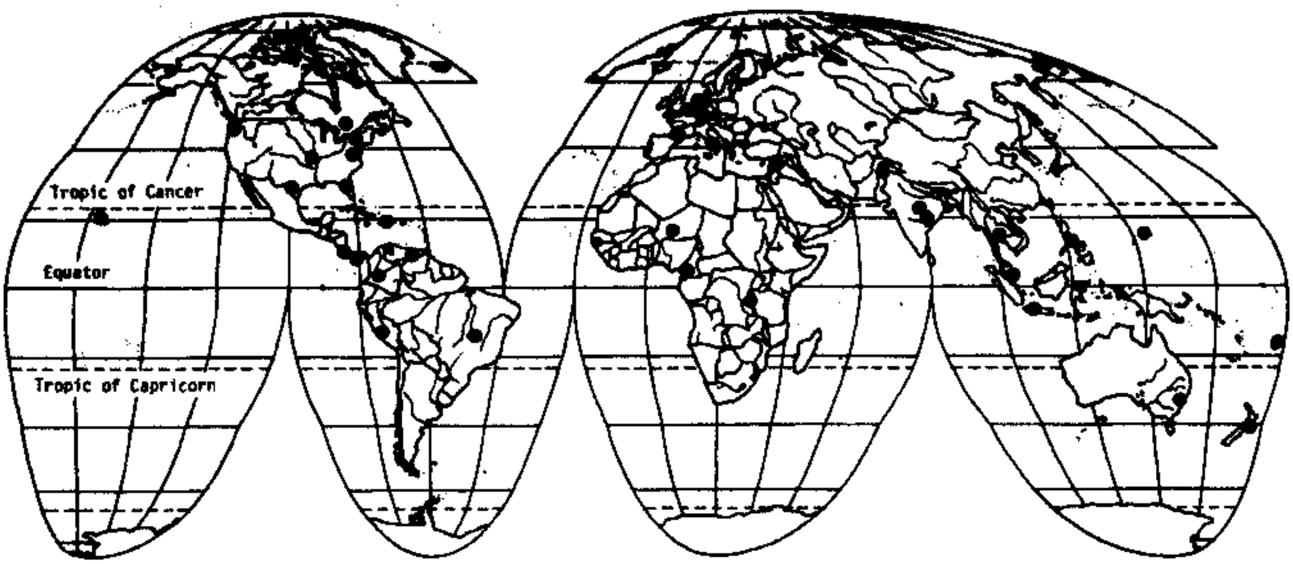

Figure 1. Global distribution of IBSNAT cooperators.

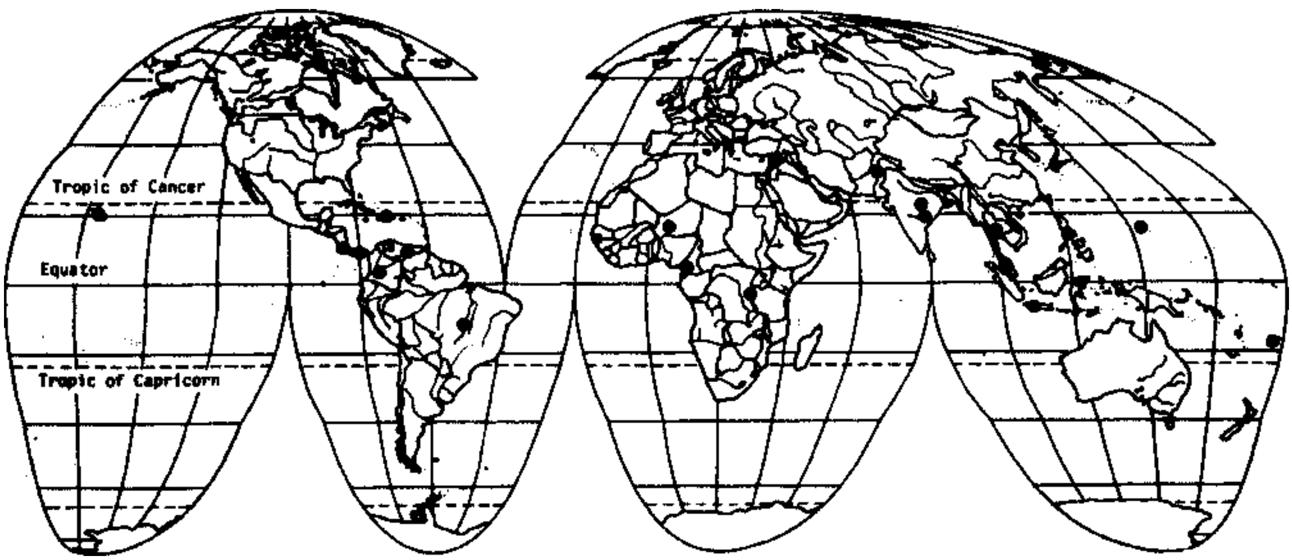

Figure 2. Network of IBSNAT cooperators' experimental sites.

expect that the minimum data set needed to adequately describe a cropping system will be determined by the requirements of the crop and the characteristics of the land on which the crop is grown.

An important task of IBSNAT therefore is to develop the means to match crop requirements to land characteristics so that crop performance can be predicted in new environments. Since crop performance is affected by the number and magnitude of mismatches between crop requirements and land characteristics, it is crucial for agrotechnology transfer that IBSNAT identify the minimum data set needed to match crops to land.

The purpose of this paper is to summarize for the participants of this symposium, the range of IBSNAT agroenvironments available for research. Our aim is to identify the minimum number of benchmark sites necessary to achieve IBSNAT's goal. We wish to achieve balance in the kinds of land characteristics at each research site by avoiding too many sites with similar characteristics. IBSNAT will use Soil Taxonomy as a means to define the soil and climate of each research location.

Soils

In the description of the benchmark sites, three of the ten soil orders in Soil Taxonomy are frequently mentioned: Ultisols, Alfisols, and Inceptisols. Four are less frequently but commonly mentioned: Oxisols, Vertisols, Aridisols, and Entisols. The remaining three are rarely mentioned: Histosols, Spodosols, and Mollisols. Although it is probably not necessary to have every soil order represented in IBSNAT, it might be desirable to have a range of benchmark soils from the orders Ultisol, Oxisol, Vertisol, Inceptisol, Alfisol, Andisol, and Entisol.

Moisture Regimes

Soil Taxonomy stratifies soil moisture regimes into five taxa. Aquic for the poorly drained or hydromorphic soils, Udic for the well-drained soils that occur under humid environments; Ustic and Xeric for soils in the semi-arid climates; and Aridic or Torric for soils in desert environments. The Ustic moisture regime corresponds to semi-arid environments in which the rainy season corresponds to the growing seasons; the Xeric moisture regime corresponds to semi-arid environments in which the rain falls in the cold winter months. "Xeric" has approximately the same meaning as "Mediterranean climate."

All moisture regimes are represented in IBSNAT but the Udic and Ustic predominate.

Temperature Regimes

Soil Taxonomy recognizes eight soil temperature classes as shown in Table 1. Soil temperature regimes having the iso- prefix generally occur in the intertropical region. Since most of the benchmark sites occur in the tropics, the soil temperature regimes are mostly iso- regimes. Some hyperthermic temperature regimes will be encountered in Pakistan, and thermic regimes in the Middle East and North African experimental sites under the jurisdiction of the Arab Center for the Study of Arid Zones and Drylands (ACSAD), which is the only cooperator with experimental sites that have Xeric moisture regimes.

Crops

The major crops cultivated at the benchmark sites are beans, cassava, cocoyam, groundnut, maize, pigeonpea, pasture grass, potato, rice, sorghum, soybean, wheat, and yam.

There is a close relationship between the type of crop grown and the land characteristic of the research station (Table 2).

Table 2 shows that although there are many possible combinations of the soil moisture and temperature, most of the crops are concentrated in the agroenvironments with isohyperthermic soil temperature and Udic or Ustic soil moisture regimes. Moreover, the large majority of research stations also occur in regions with isohyperthermic temperatures and Udic or Ustic moisture regimes. In Udic environments, soil fertility is critical; in Ustic moisture regimes, avoidance of drought becomes more critical. While the range of agroclimatic zones covered by IBSNAT is relatively narrow, the variations in edaphic factors

Table 1. Soil temperature classes.

	Difference between mean summer and mean winter temperatures	
Mean annual soil temperature	>5°C	<5°C
>22°C	Hyperthermic	Isohyperthermic
15-22°C	Thermic	Isothermic
8-15°C	Mesic	Isomesic
<8°C	Frigid	Isofrigid

Table 2. Relationship between crop and land characteristics at IBSNAT research stations.

Temperature regime	Moisture regime				
	Aquic	Udic	Ustic	Xeric	Aridic
Thermic				Wheat	
Hyperthermic					Irrigated rice
Isohyperthermic	Flooded rice	Cassava, Cocoyam maize, upland rice soybean, yam Beans	Cassava Sorghum Pigeonpea Groundnut		
Isothermic		Potato	Potato		
Isomesic		Potato Wheat	Potato Wheat		

add another large dimension to the range of land characteristics in the network of research sites.

Weather

Virtually every research station in the network has an operating weather station. Air temperature and rainfall data are most frequently recorded. Wind speed and direction and relative humidity are less often recorded. The most obvious deficiency is the lack of data on solar radiation.

Most of the weather stations are checked daily, and about one-third of the stations have historical weather data extending back 30 years or more.

Conclusion

A network of research stations needs to be selected to generate performance data for development and validations of a general agricultural management model for agrotechnology transfer. Each benchmark station in the operating network will be fully characterized for soil and climate. It will probably be necessary to replace outdated weather stations with fully automated, high-frequency data-collecting stations designed for efficient data analysis.

The network of research stations should conform to the minimum number of benchmark sites needed to achieve the objectives of every IBSNAT cooperator.

A desired output of this symposium is a specification of the characteristics of a network consisting of this minimum number of benchmark research sites.

Annexure 1. International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT): Sample questionnaire.

Complete separate form for each research station or site.

1. Countrv ______
? Name of station/site ______
3 Loration ______
   a. longitude ______
   h latitude ______
4 Elevation (meters) ______
5. Area (hectares) ______
6. Kinds of research being conducted (check appropriate items)
   a. ______plant breeding
   b. ______varietal testing
   c. ______soil fertility and mineral nutrition of plants
   d. ______irrigation
   e. ______pest control
   f. ______soil erosion and conservation
   g. ______cropping systems
   h. ______salinity and sodicity
   i. ______
7. Weather — is there a weather station on or very near this station?______Yes______No
   If yes, indicate the number of years weather has been monitored and the kinds of weather variables measured.
   a. number of years in operation______
   b. air temperature______Yes______No
   c. soil temperature______Yes______No
   d. rainfall______Yes______No
   e. solar radiation______Yes______No
   f. wind speed/direction______Yes______No
   g. pan evaporation______Yes______No
   h. relative humidity______Yes______No
   i. other variables______Yes______No
   ______Yes______No
   ______Yes______No
   j. data collection______automated______manual
   k. data collected______hourly or less______daily______longer interval
8. Climate
   a. mean annual temperature______°C
   b. mean annual maximum temperature______°C
   c. mean annual minimum temperature______°C
   d. mean annual rainfall______mm
   e. climate classification if available______
9. Soil
   a. Has a soil survey of the research station been conducted?______Yes______No
   b. If yes, was it a______detail______semi-detail______reconnaissance survey
   c. Is there a soil survey report of the area______Yes______No
   d. According to Soil Taxonomy, the soils of the station would classify as:

Classification	% of stations covered by this soil
1)	
2)	
3)	
4)	

Continued

Soil *Continued*

e. it soils have not been classified according to Soil Taxonomy, identify soil according to system used in your country;
   1)
   2)
   3)

f. Indicate major soil problems on station
   1) aridity ______________
   2) salinity ______________
   3) drainage ____________
   4) acidity ______________
   5) erosion _____________
   6) soil infertility _________
   7) ____________________

10. Crops—List crops in order of decreasing importance.
    a.
    b.
    c.
    d.
    e.

11. Telecommunications — Do you have access to one or more of the following:
    a. telephone_______________________Yes____________________No
    b. telex___________________________Yes____________________No
    c. cable__________________________Yes____________________No

12. Computer facilities—Do you have access to a computer?____Yes____No
    If yes, what type (name, model, storage capacity, etc.)?

13. Please provide any additional information about this research station that may be useful.

Concepts and Considerations of the Benchmark Sites Network

H. Eswaran*

Abstract

Benchmark soil, benchmark site, and the network of benchmark sites are concepts fundamental to the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) and these are defined. After evaluating the attributes that a benchmark site should have, guidelines for selecting the sites are provided. The rationale for selecting soils to comprise the network is considered and a list of soils with potential collaborating countries or organizations is proposed.

To utilize the data generated by IBSNAT, the mechanisms of developing a soil data base are presented. A combination of data files maintained by the countries with a similar set located at IBSNAT, periodically updated, will form one of the data bases for agrotechnology transfer

Practically every country in the world has some kind of agricultural station, and the nature of the work done ranges from observation studies to rigorous research on fertility, breeding, or cropping systems. An extension of the stations are the farmers' fields, where a wider range of site variables can be tested and farmers involved in the research activities. The common objective of all experiment stations is to conduct research so that the findings can be used to improve the agriculture in the region.

Although an agricultural research station is a permanent institution, it is surprising that in most countries (at least in the older stations) selection of the site was usually made on considerations other than scientific reasons. Availability of land, proximity to a town, and even political considerations were the motivating forces. Fortunately, in recent area development programs in some developing countries, a judicious selection of sites has been made.

The point of these initial observations is that, to develop a network of agricultural research stations in less developed countries (LDCs), at least two kinds of stations must be considered:

a. Stations established for specific agricultural development projects. These are frequently recent stations and there is a high probability that conditions are fairly representative of the area the stations are designed to serve.
b. The older "established" stations, which have historical significance and which may have to be reexamined to evaluate their representativeness.

The U.S. Agency for International Development's (AID) project—the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT)—of the University of Hawaii aims to develop the linkage between selected agricultural experimental stations for the horizontal transfer of agrotechnology. The vertical transfer—from experimental stations to farmers' fields—is a responsibility of the national institutions and so is not considered here.

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The purpose of this contribution is to provide some preliminary thoughts on the selection of benchmark sites, which are crucial to the development of a viable network. Although the ideal situation would be to develop new sites in each of the collaborating countries as was done to some extent in the previous Benchmark Soils Project of the universities of Hawaii and Puerto Rico, financial considerations would make this impractical. It is anticipated that the sites in the collaborating countries would be at existing experimental stations of both kinds; therefore, site characterization—to be elaborated later—would be an initial task of IBSNAT and the collaborators.

Benchmark Soil, Benchmark Site, and Network of Benchmark Sites

As these terms will be repeated in the text, a brief definition of each is given.

Benchmark Soil

A benchmark soil is a reference soil that is adequately characterized in terms of its properties and environmental conditions. It is also sufficiently significant in terms of its distribution so that performance data derived from experiments on it may be related to other soils with similar characteristics. The information about benchmark soils can be extended to many of those closely related in classification and geography.

Benchmark Site

A benchmark site is an area of land where the dominant soil is a benchmark soil and where there are few or no dissimilar soils. The homogeneity of the land, with respect to variation in critical properties from the typifying benchmark soil, is its most important attribute.

Network of Benchmark Sites

Benchmark sites within a country or region linked together by a commonalty of research objectives forms the network of benchmark sites. Sharing of research data and collaborative work on development of models for crop performance and soil use leading to a rational basis for agrotechnology transfer is the common goal of network collaborators.

Attributes of a Benchmark Site

To serve as a benchmark site, the area must have all or most of the following attributes:

1. The soil at the site must be well-characterized and also conform to the definition of a benchmark soil.

   The underlying principle of IBSNAT is that the success of agrotechnology transfer depends on the use of a common language—Soil Taxonomy. The soils at all the IBSNAT sites will be described and analyzed according to the norms established by the Soil Conservation Service of the U.S. Department of Agriculture (USDA), and classified according to Soil Taxonomy. In addition, fertility parameters will be monitored periodically.
2. The site must have few or no dissimilar soils, particularly limiting inclusions. This requires a detailed soil survey of the experimental fields and a careful selection of the sites.
3. The agronomic history of the site must be reasonably well-documented.
4. The soil at the site must be of significant extent in the region. In addition, to become part of IBSNAT, it also must be one of the test soils of the network (which will be described during this symposium).
5. Weather records must be well-established or, if a new site, facilities must be available to monitor weather parameters.
6. The site must be located so that experiments can be monitored daily, particularly with respect to insect and pest damage and the collection of phenological information.

Considerations in the Selection of IBSNAT Sites

The area occupied by the IBSNAT crops, on a global basis, is probably a good basis for the selection of benchmark sites. Few such estimates are available and, in addition, more than one crop may be tested at a given site. Further, as the concept of agrotechnology transfer is soil-based, kinds of soils are used for the selection of the sites.

Tables 1 and 2 give an idea of the distribution of soils in the tropics. The absolute numbers in the two tables are not reliable, although their relative magnitudes are useful. Of most concern are the weathered and leached soils (Table 2) that occupy about 50% of the tropics; of these, about 65% are in the semi-arid tropics where moisture stress is an added problem. These soils will receive priority attention in the network.

From the operational point of view, it appears desirable for IBSNAT to be composed of several subnetworks, defined on soils. Table 3 presents an outline of subnetworks and lists some potential collaborators. In each of the soil orders in Table 3, at least two suborders are selected to represent contrasting soil moisture regimes. Other soils,

Table 1. Approximate extent of major soil orders in the tropics (million ha).

Order	Africa	America	Asia	Total area	Percent
Oxisols	550	550	0	1100	22.5
Aridisols	840	50	10	900	18.4
Alfisols	550	150	100	800	16.2
Ultisols	100	200	250	550	11.2
Inceptisols	70	225	110	400	8.3
Entisols	300	100	0	400	8.2
Vertisols	40	0	60	100	2.0
Mollisols	0	50	0	50	1.0
Others	0	350	250	600	12.2
Total	2450	1670	780	4900	too

Source: Estimates by M. Drosdoff, Cornell University. Ithaca. NY. USA.

Table 2. Distribution of soils in the tropics (million ha).

Soils	Moisture regime			Total	Percent of tropics
	Udic	Ustic	Aridic		
Highly weathered, leached soils (Oxisols, Ultisols, Alfisols)	920	1540	51	2511	51
Dry sands and shallow soils (Psamments and lithic subgroups)	80	272	482	834	17
Light-colored, base-rich soils (Alfisols, Aridisols)	0	103	582	685	14
Alluvial soils (Aquepts, Fluvents)	146	192	28	366	8
Dark-colored, base-rich soils (Vertisols, Mollisols)	24	174	93	291	6
Moderately weathered (Andepts, Tropepts)	5	122	70	207	4
Total area	1175	2403	1306	4894	too
Perent of tropics	24	49	27	too	100

Source: Sanchez (1976).

Table 3. Some soils and potential collaborators for the network of IBSNAT.

Soils	Potential collaborators
Vertisol Network	
a. Usterts	India Venezuela, Sudan
b. Xererts	ACSAD[1] countries
Oxisol Network	
a. Orthox	Malaysia, Thailand, Cameroon, Burundi, Hawaii
b. Ustox	Venezuela, Brazil, Zaire. Philippines, Puerto Rico, Hawaii
Aridisol Network	ACSAD countries, Pakistan. Sudan
Alfisol Network	
a. Udalfs	Thailand, Cameroon, Pacific Countries
b. Ustalfs	Venezuela, India, Pakistan. Brazil, Panama
Ultisol Network	
a. Udults	Malaysia, Costa Rica, Burundi. Cameroon, Panama, Brazil, Pacific islands, Indonesia, Philippines
b. Ustults	Thailand, Cameroon, Brazil. Ecuador, Philippines
c, Humults	Burundi. Pacific islands, Indonesia, Philippines
Inceptisols	
a. Andepts	Indonesia, Philippines, Hawaii, Cameroon, Rwanda, Ecuador, Costa Rica, Pacific islands
b. Aquepts	Most countries

1. Arab Center for Study of Arid Zones and Dry Lands.

including sites with different soil temperature regimes, may be added if there are enough collaborators.

Selection of and a decision on the sites will be made on the recommendation of the collaborating agencies and institutions. To facilitate the selection, an initial appraisal of the site will be made using the information provided in a questionnaire (see Annexure 1, Uehara, these Proceedings) sent to all collaborators. This is followed by an on-site inspection of the potential sites. Once the site is selected and characterized, planned experiments can than be implemented.

National Networks and IBSNAT

It is neither feasible nor practical for IBSNAT to be involved in every experimental station in each country. Consequently, it will be desirable to have the IBSNAT approach on an international scale duplicated on a national scale. The National Bureau of Soil Survey and Land Use Planning of India already has launched an INDIBSNAT program in collaboration with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the Soil Management Support Services (SMSS) of the USDA. Other countries already have national networks such as the SCAN program of Pakistan. Small countries, such as the island nations of the Pacific, could form regional networks.

It will be mutually beneficial if the national or regional networks are linked to IBSNAT.

A Soil Data Base

To utilize the information generated by IBSNAT, it is essential that a central data base of soils information be established and periodically updated. This data base is crucial to both the horizontal and vertical transfer of agrotechnology and will be comprised of national files maintained by each participating country. In turn, the national files will be linked to the international network maintained by IBSNAT and SMSS.

A rational basis for selection of benchmark soils worldwide or within a country or a region is the geographic extent of such soils. Soil resource inventories within countries usually contain information giving the area distribution of these soils; however, these inventories usually give local names to the soils, which may or may not be classified according to an international system. This is one of the constraints faced by an international program such as IBSNAT and basically one of the weakest links in the process of agrotechnology transfer.

The objective of developing the data base is to partially rectify this situation. In addition, the data base will help to answer several questions such as:

a. How extensive is a given soil, in a given region or in the world?
b. In what countries is this soil to be found?
c. What kinds of crops are grown on this soil in each country?
d. What are the farmers' yields, experimental yields, and target yields on a given soil in the different countries?
e. What are the management practices and the special problems?
f. Whom do I contact for more information on these soils?
g. What alternative crops or farming systems can I consider?

In addition to the soil classification and management information, a second file—a pedon data bank—will contain soil and site information on selected families. This file has already been developed in conjunction with the EPIC (ALMANAC) model of the USDA; data on non-U.S. soils are provided by the SMSS, and the file now contains more than 250 pedons. Because the quality of the input data is very important, only pedons described and analyzed by the Soil Conservation Service, USDA staff, have so far been included in this file. Once the experimental sites of IBSNAT collaborators have been selected, the SMSS will arrange for the soils to be characterized and the information included in the pedon data bank.

The pedon data bank has several uses. The ALMANAC crop-soil-weather simulation model relies heavily on this bank for developing and testing the models. It is hoped that crop performance information can be generated for specific soil families. Such information will be invaluable for agricultural development. The pedon data bank also will serve a useful purpose in teachihg and training.

Developing and maintaining this data base depends largely on the active collaboration of participating countries. As mentioned previously, each participating country will maintain a national file. A user-friendly, query-response interface program for use in a minicomputer will be developed by IBSNAT-SMSS, and the software transferred to the countries. If national institutions do not have readily available hardware, IBSNAT-SMSS will be willing to provide the print-outs at periodic intervals or on request. Once the network has been established, one of the services provided by IBSNAT-SMSS would be to respond to queries on soil use, examples of which were listed previously.

Minimum Data Sets

Minimum Data Sets for Agrotechnology Transfer

Henry A. Nix*

Abstract

Prescription of appropriate technologies at farm level, at the transfer site, demands a systems understanding of the land, labor, capital, and management resources of the individual farmer. If it were possible to predict the performance of any crop production system at any location given a specified minimum set of crop-site-weather-management data, then it would be possible to prescribe appropriate technologies at the level of the farmer and his farm. It is argued that this is an ultimate and attainable objective of agricultural research, but only if there is a shift in emphasis away from reductionist and analytical research to holistic and systems-based research.

A systems-based research strategy centers on balanced development of two interactive components: (a) crop models (b) data base. Because model predictions are required at different levels of resolution and accuracy, a hierarchy of models is envisaged. The data base contains only those physical, biological, social, and economic data specified as necessary for development, validation, and implementation of the model or models. Recognizing differing objectives and differences in level of resolution and accuracy required, a three-level system of minimum data sets for agrotechnology transfer is presented as a basis for discussion.

Introduction

Whatever the goals of technology transfer, implementation of a new technology ultimately rests with the individual farmer. But each farmer (and his farm) is unique! How then do we prescribe a technology that is relevant to the land, labor, capital, and management resources of each individual? Traditional methods of agricultural research are unlikely to yield solutions to this problem, since results typically are specific to location, season, cultivar, and management; i.e., results apply only under the specific combination of conditions of the experiment. If it were possible to predict the performance of any crop production system at any location given a specified minimum set of soil-crop-weather-management data, then it would be possible to prescribe appropriate technologies. I have argued (Nix 1968, 1976, 1979, 1980, 1981) that this is an ultimate objective of agricultural research and have described progress towards this goal along an evolutionary path from simple observation, trial and error, transfer by analogy, correlation and regression, and analysis of variance to systems analysis and simulation techniques.

Proposals that standardized data sets be collected from field experiments are not new. The principle has been adopted in a number of nationwide and international agricultural research programs. What is new about the concept of *minimum* data sets is that it arises directly from adoption of a systems-based research strategy. The development of crop system models hinges on development of a matching data base. Each model specifies the minimum data set necessary

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for its successful development, validation, and implementation. The whole emphasis is on *minimum* rather than some notional *optimum* data set. Those data used directly in computation or that provide tests of model predictions have priority.

Background

Following development of the concept that systems-based research strategies would require identification of *minimum* data sets (Nix 1968), attempts at formulating a national framework for Australia were initiated. In 1973 the Commonwealth and State Plant Production Committee set up a Working Party composed of Commonwealth (CSIRO) and State Department of Agriculture representatives. H.A. Nix and his associates in the Land Evaluation Unit of the CSIRO Division of Land Research (now Water and Land Resources) produced a draft of a technical document and standard formats for computer coding of minimum data sets for agronomic experiments, as a basis for critical comment and discussion by the rest of the Working Party. A relatively high degree of consensus was reached, in correspondence, following a very extended period of circulation of the documents within State Departments of Agriculture. Problems remained in terms of measurement and/or scaling of pest and pathogen damage and crop nutrient status.

While acceptance of the concept at intellectual level was high, serious doubts were raised about its implementation within a Federal-State system where research responsibilities are divided. Frequently expressed concerns related to the ultimate development of centralized data banks and the role and the rights of the individual scientist. Some foresaw a future for themselves as nothing more than data-gatherers for a remote "ivory-tower" group of crop-modellers. Many were concerned that even a specified *minimum* data set would add an intolerable burden of additional measurement to their existing network of field trials. Although these concerns had been anticipated and possible safeguards and solutions suggested in the draft document prepared by Nix and associates, it became obvious that a nationwide conference would be needed to resolve them. But financial support for such a meeting was not forthcoming and, in the meantime, other events assumed dominance.

Stimulated by a CSIRO paper (Angus et al. 1974), an International Expert Consultation on the Use of Improved Technology in India, Thailand, and Malaysia between November 24 and December 13, 1974, urged the FAO to sponsor a further workshop consultation to be organized by the CSIRO. P. Oram, Chief, Research Development Center, FAO, obtained FAO funding and with support from the Australian Development Assistance Agency (ADAA), an FAO/ADAA Expert Consultation on Soil-Crop-Weather Relationships was organized by H.A. Nix and held in Canberra in May, 1977.

The objectives were:

1. to provide senior agricultural research administrators from developing countries in the Asian and Pacific region with a better understanding of crop-soil-weather relationships and resultant crop performance;
2. to use this improved understanding to explore more efficient methods of data acquisition for agronomic experiments, the emphasis here to be placed on upgrading results from existing experimental networks, through collection of a standardized and balanced set of crop, soil, weather, and management data; and
3. to explore possible mechanisms for international exchange of standardized sets of data from agronomic experiments.

Participants were primarily from the southeast Asian and Pacific region, but with expert consultants on crop modeling from North America and Europe.

Once again, a remarkable consensus was reached on *minimum* data sets, although it became obvious that such a consensus would never be reached on some notional set of *optimum* data. The need for variation in minimum data sets to cope with the specialized requirements of particular production systems such as paddy rice and tropical tree fruits was recognized, as was the need to involve fully all those subject specialists with research interests in crop production systems. But, the impact of this Expert Consultation was limited because of financial stringencies, which became acute at that time, and the lack of an appropriate organizational umbrella or framework to carry plans and proposals through to completion.

Now, a decade later, it seems to me that both attempts at promoting the concept of minimum data sets were premature. The missionary zeal of the converted systems scientists was not backed up by convincing demonstrations of the utility of such a research approach. At the time, few wholly operational crop models were available, and experience of their use in real-world application was very limited. Accordingly, the rationale for collection of model-specified minimum data sets was diminished. Concessions had to be made to the prevailing logic and methods of agronomic research and thus much of the argument and discussion centered around addition of standardized minimum data sets as a means of upgrading existing conventional agronomic experiments. While there is no doubt that this would confer benefits, it makes much more sense within the context of a wholly systems-based agricultural research strategy. Now that operational models of crop systems are available or are under active development, such strategies are feasible, and the IBSNAT proposals are both timely and relevant.

Systems-based Agricultural Research Strategies

The central concept of the systems approach is that the whole system must be understood in order to evaluate changes in any single component. But the *level* of understanding required will vary with the problem to be resolved. Any complex system can be viewed as a hierarchy of levels of organization, each of which has an appropriate scale of resolution in both space and time. At one extreme, the crop system is viewed as a vast complex of interlocking levels with response times in seconds and minutes. At the other extreme, the crop system is viewed as a green (not black) box that might extend over thousands of hectares and simple statistical models of response to major environmental controls and/or treatment effects will account for a significant proportion of the variance in system performance. The choice of appropriate level is determined more by data limitations than it is by problems of conceptualization and programming. Many years of practical experience suggest that it is neither necessary nor desirable to model a crop system or subsystem at a level of detail greater than is necessary for useful prediction.

Adoption of a systems approach emphasizes interdisciplinary teamwork, since understanding gained from physical, biological, social, and economic disciplines is necessary. It formalizes what is known about the crop production system, identifies the major components and processes and their interactions, and helps to identify bottlenecks to improved performance. A comprehensive model of a crop production system does not stop at the biophysical level, but would extend to incorporate harvesting, processing, marketing, and consumption components. Few, if any, such models exist. Yet!

So freely has the word "systems" been affixed to titles of research institutions and programs in recent years, that it is almost debased currency. My own view is that very few, if any, existing agricultural research strategies are truly systems-based. Active development of crop simulation models and access to sophisticated computer technology are not, in themselves, sufficient evidence of adoption of systems-based research strategies. How then might we recognize such a strategy?

Many interpretations are possible, but my own is shown as a simplified flowchart in Figure 1.

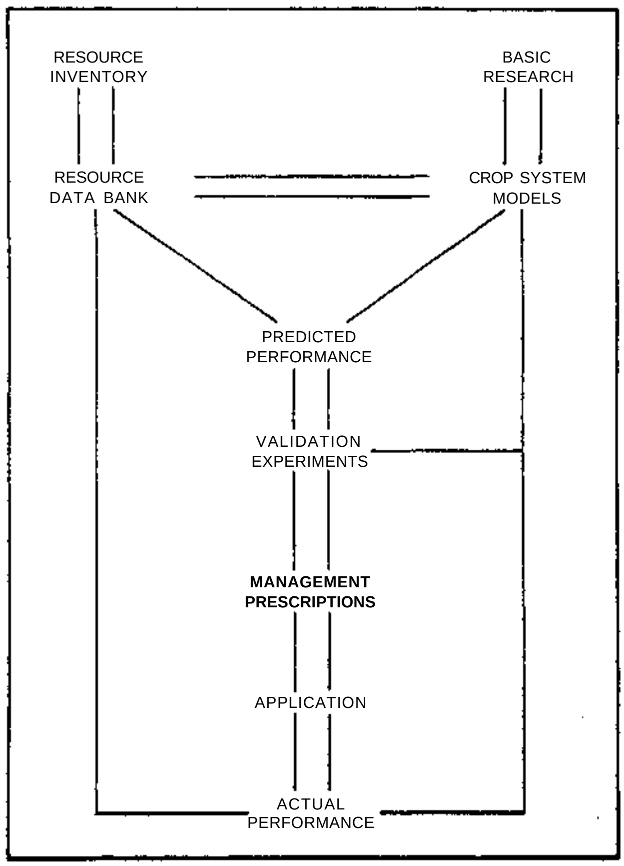

Figure 1. Diagram of a systems approach to developing and testing models.

Essentially, it has a core of two primary interactive components:

1. crop system models
2. resource data base.

Balanced development of these two components is essential. Without access to a prescribed matching data base, models cannot be implemented. Conversely, acquisition of resource data for which there is no specific requirement is wasteful of scarce resources.

The crop system models are coupled to the resource data base (e.g., terrain, soil, social, economic data) in order to make predictions of system performance (e.g., crop yield, total dry matter, soil loss, nutrient leaching) at specified locations. These predictions are tested in field experiments. Feedback from these tests may lead to improvements in the model and requirements for additional resource data. When satisfactory prediction is achieved, management prescriptions for specific parcels of land can be prescribed. Application of this information and actual performance of the crop system may be monitored to provide further necessary feedback for improvement of the whole system.

Model Development

The development of any model of a crop system demands constant and close interaction between:

a. conceptualization and programming;
b. directed experimentation;
c. data-base development (minimum data sets);
d. testing and validation;
e. integration into information systems (extension).

Explicit statement of objectives is necessary in order to determine the appropriate level of resolution generally required of the model. Thus, for instance, models may be used in applications such as:

- determination of which crops/cultivars are best grown where;
- development, testing, and application of new and modified management strategies and tactics;
- development of optimum networks for research and extension activities;
- development of improved understanding of the structure, process, and function of crop systems and subsystems; and
- production forecasting.

It is useful to develop a hierarchy of models that are capable of operation over a range of scales and levels of resolution and accuracy. What these models have in common is that they aim at predicting crop response to at least the major radiation, temperature, moisture, and nutrient regimes, but with a time step for calculation of internal processes that may range upwards from seconds to hours, days, and pentads (5-day periods) or standard weeks (7-day periods). Although monthly time steps are used with moderate success in continental-scale applications, my own view is that the standard week is the longest time step desirable in modeling agricultural systems.

Whatever the scale of application and the level of resolution required, the development of appropriate crop models is hampered by the lack of balanced soil-crop-weather-management data from widely contrasting environments. Field, laboratory, and controlled-environment experiments are the major sources of data for development, testing, and validation of response functions, process models, and whole-crop models. Few of these provide sufficient data to define the major radiation, temperature, water, and nutrient regimes that modulate crop response.

Resolution of this problem can be approached in two ways, one passive and the other active, but not mutually exclusive.

The passive approach is least likely to disturb existing traditional agricultural research strategies, and simply aims at upgrading experiments, through additional measurement and observation, to yield minimum data sets.

The active approach involves radical revision of current strategies and aims at generating specified minimum data sets in the shortest possible time and with the most economical use of land and labor resources. This involves design of novel experiments that engineer the widest possible range of genotype x environment x management interactions at one or a few carefully chosen locations. Nix (1980) describes one such experiment as an "omnibus" experiment.

In either approach we still face the problem of defining a balanced and minimum data set.

Recognizing differences in objectives and available facilities, it is best to consider a hierarchy of minimum data sets. Each level aims at a balanced monitoring of the whole crop system, but with successive upgrading of the frequency, precision, and accuracy of measurement. At each level, the emphasis is on the *minimum* data set that is required for explanation of system performance and subsequent prediction at that level. The three-level system presented here is an example of such a rationale and may provide a basis for discussion and argument.

Hierarchy of Minimum Data Sets

Level 0

Data collected are the absolute minimum required for simple analysis of genotype/environment interaction and comparative analysis of crop performance at widely spaced sites and/or seasons. The data set is just sufficient for calculation of biophysical indices, for initializing and verifying runs of the simplest crop models, and for development and testing of empirical yield prediction equations. A weekly time step is adequate.

Weather data. Global solar radiation, maximum and minimum temperature, precipitation, and potential evaporation data are required. Only precipitation must be measured on-site. All other weather data can be obtained from an adjacent meteorological station, providing that climatic gradients are subdued. Thus, it is preferable to locate experiments near existing weather stations that meet these requirements or that can be upgraded by installation of additional instruments for the duration of the experiment. Alternatively, estimates of long-term weekly mean values of radiation, temperature, and potential evaporation can be generated using sophisticated surface-fitting techniques and used directly or adjusted according to actual weekly precipitation values (Richardson 1981). But, no weather data, no experiment!

Soil data. Initial (preseeding or at seeding) and final (harvest or post-harvest) soil-water status in the profile must be determined. Where nutrient status is being manipulated, appropriate measurements should *be* taken. Once-only data might include bulk density profile, upper and lower extractable water storage values, and pH.

Crop data. Total biomass, yield of harvested product, phenology (dates of seeding, anthesis, harvest). Phenological data permit analyses of environmental effects at different phases of development. The ratio of harvested product to total biomass (harvest index) provides an index of stress in the system during development of the harvested product.

Management data. Records of all treatments, their timing, and level of inputs (e.g., fertilizer, herbicide, irrigation, insecticide, mechanical cultivation) are needed. Records of land-use history of the plot can be of diagnostic value.

Usually management is directed towards control of weeds, pests, and pathogens. If these are not controlled, then sampling (weed dry matter at anthesis and harvest) or time and rating of damage by pest and/or pathogen should be recorded.

Level 1

Data collected provide a basis for development and testing of process-based models of growth, development, and yield. Generally the level of monitoring and sampling required will restrict this to experiments at or closely adjacent to regional research centers. A dairy time step is indicated.

Weather data. Daily records of global solar radiation, maximum and minimum temperature, precipitation, and potential evaporation must be measured at or close to experimental site.

Soil data. The soil profile should be sampled for water content and target nutrients at seeding, floral initiation, anthesis, physiological maturity, and upper and lower extractable water content limits down the profile to the estimated limit of root activity. Again, pH and electrical conductivity profiles may have diagnostic value.

Crop data. Partitioned dry matter and canopy cover (or leaf area index) sampled at or close to key developmental stages—e.g., floral initiation, terminal spikelet, ear emergence, last flower, physiological maturity—are required. The number of samplings depends on the crop and the nature of its yield-accumulation process. Analysis of partitioned dry matter for mineral element uptake may be added if nutrient uptake is being modeled. Established plant density and tiller density and yield components should be determined.

Greater precision is required in definition of phenology so that regular monitoring and sampling is necessary. Floral initiation presents the greatest difficulties, since it requires regular sampling and subsequent dissection of stem apices under a binocular microscope. But the process can be streamlined by using long-term and/or current weather data and existing phasic development models to predict the expected date. Bracketing these data with more frequent sampling, storing the samples in an appropriate solution (e.g. FAA, then transfer to alchohol) and bulking for later determination in a laboratory is a practical solution to the problem. Until recently, reference charts that depict development of the floral primordium were available for few crops. But now a member of my program has produced (Moncur 1981) an atlas of floral initiation for more than 50 field crops, using scanning electron microscopy at moderate magnification to produce high-quality images.

Management data. Records of all treatments, their timing, and inputs are as for Level 0. Land-use history can be of diagnostic value. At this level, greater efforts may be directed towards monitoring of pest and pathogen populations and direct measurement of damage. Weed species and dry matter should be determined at each time of sampling for the crop data.

Level 2

Data collected provide a basis for more explicit representation of component processes such as photosynthesis, respiration, transpiration, morphogenesis, and nutrient uptake, their incorporation in crop models, and their validation and testing. The time step indicated is hourly, but may be in minutes for some processes. Experiments conducted at this level require major data-logging and data-processing facilities and high-level technical support. Although some may equate this level with the bandwagon period of micrometeorological research in the 1960s, none of these studies maintained the necessary balance of measurement of all major components of the system. Usually, some components were monitored in great detail, while other important components were totally ignored. These experiments did add to our understanding of key component processes such as photosynthesis or transpiration, but added little to our understanding of whole-system function

At this level the frequency of sampling of crop and soil components emphasizes the need for nondestructive sampling and use of specialized monitoring instruments, e.g., soil-water status monitored using neutron modulation techniques and fixed-access tubes. The resources required to mount a field experiment at this level are such that very careful planning and management are required. Past experience would suggest that such a sampling can become a major sink for scarce resources.

Since it is neither necessary nor practical to model a crop system or subsystem in more detail than required for explanation and useful prediction, it should be obvious that our major interests will be served by minimum data sets at Level 0 and 1. Provided that the whole system is monitored at Level 0, there is no reason why a particular subsystem should not be monitored at higher levels (1,2) if it is of particular interest. Once adopted, the concept of minimum data sets leads inevitably to fewer, carefully located, better monitored field experiments. But this, in turn, leads to a reexamination of prevailing agricultural research strategies (Nix 1968, 1980).

As mentioned earlier, a more active approach to the acquisition of minimum data sets for any specified crop production system involves some radical innovations. One possibility is that of a combinatorial, multifactorial, nonrandomized, nonreplicated design that has been dubbed an "omnibus" experiment (Nix 1980). The objective function is to generate a set of treatments that span the widest possible range of genotype x environment x management interactions in the shortest possible time with the most economical use of available resources. Every effort is made to identify the major sources of potential variation in crop performance and to test the whole gradient of values of the factor studied. Thus, for example, line-source sprinklers, together with rain-out shelters, may be used to engineer a gradient in water regime. For a given crop species, cultivars that span the widest possible range of developmental patterns will be used. Serial seeding at monthly intervals at one, two, or three very carefully selected locations will expose the experimental treatments to a wide range of climatic conditions. Population, geometry, and fertilizer application present no particular problems in engineering gradients.

For any crop production system considered, this strategy very quickly gives rise to hundreds of individual treatments. Obviously if these are to be randomized and replicated in a conventional design the strategy becomes unworkable. Provided that each treatment is monitored in terms of minimum data sets required to provide adequate explanation of variations in performance, randomization and replication are unnecessary. Each treatment is unique. However, replication and randomization of within-treatment sampling is advisable in order to provide measures of sampling error and within-treatment variability. Considerable reductions in land and labor requirements can be achieved by monitoring core treatments at Level 1 and a constellation of peripheral treatments at Level 0. The data generated provide a basis for exploration of functional responses to a wide range of treatments and treatment combinations and for development and testing of crop models that have greater generality. When coupled to the appropriate resource data base, such models can be used to predict yields, to explore potential alternative management strategies, and to explore the consequences of differing growth and development strategies between cultivars. This then brings us to the question of development of an appropriate resource data base.

Data-base Development

Each model developed will specify the minimum data set necessary for its successful implementation. Application of the model to the general problem of prescribing an appropriate technology at a site demands that a minimum data set be available for the site. Essentially, this means just sufficient weather, soil, crop, and management data as initializing and/or input data to run the model. Whether the model is to be used for

a. real-time crop monitoring for yield forecasting, or
b. analysis of historical weather data series in evaluation of management strategies or tactics, or
c. analysis of long-term weekly mean data as a basis for estimating the likely performance of a new crop or production system,

the problem is one of deriving the necessary minimum data set for a specified site or area.

Existing agricultural research strategies rely heavily upon the analogue concept or the transfer of information by analogy. Since it is physically impossible to replicate every experiment on every farm in every season, a "representative" site is chosen and results extrapolated to other sites and/or seasons that are classified as having "similar" properties. The central hypothesis is that all occurrences of a defined class should respond in a "similar" way to management. Climate and/or soil and/or vegetation classifications provide the basis for selection of a "representative" site. Because successful extrapolation of results is seen to hinge on the degree of similarity and proximity to the experimental site, there is never-ending pressure to extend the network of sites.

Given that present research strategies are firmly based upon the analogue concept, a network of experimental sites is a necessity. But field experimentation is expensive, and any rationalization and upgrading of such networks could have substantial benefits. Modern techniques of pattern analysis or numerical taxonomy offer prospects of more objective classifications of land, climate, soil and/or vegetation as a basis for regionalization. The most useful classification is one that is specific for the target crop or crop production system. Thus we might expect a very different agroecological classification for rainfed paddy rice and tropical tree fruits. Ideally, the data used in the classification should be derived from a model coupled to the climatic and soil parameters at sample sites/locations. General-purpose multi-attribute classifications have very limited utility.

New technologies currently under development offer prospects of freedom from the shackles of the analogue approach and static, multi-attribute classifications. First, with computer storage of geocoded data and high-speed map-plotting equipment, new classifications can be generated at modest cost, whenever required. As crop models improve and new algorithms are developed for interpolation of data between points, the level of resolution of the classification can be improved.

Thus, for example, most countries have been mapped at scales of 1:250 000 or even 1:100 000, and frequently the more important agricultural regions at 1:50 000 or even less. With modern automatic digitizing equipment, contour maps can be stored as fields of grid points. Sophisticated surface-fitting algorithms can be used to reconstruct the terrain surface and store this information, very economically, as a set of equations. This data file of terrain information can be used to estimate slope, aspect, elevation, and length of slope above and below any specified point or sample parcel. Combined with similar algorithms that permit estimation of long-term mean climatic data at any point (given latitude, longitude, elevation, and aspect), the stage is set for derivation of much more relevant agro-ecological and hydrological parameters at levels of resolution that are useful in technology transfer. These parameters can be used in classification or used directly as input data to models. Where soil maps are available at matching scales, these too can be digitized and stored.

The resource data base then would consist of geocoded data sets, either stored as sets of equations that describe continuous phenomena (terrain, climate) or as grid-point or grid-cell data for discrete phenomena (soil, vegetative cover, socioeconomic, administrative, etc). The models are coupled to this data base to generate predictions of performance of any specified land use at a point, a land parcel, or for whole regions.

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Summaries of Discussions

Summaries of Discussions

Sessions 6 through 10 of this symposium consisted of a series of group discussions on the crops, data sets, experimental design, and structure and working of the International Benchmark Sites Network for Agrotechnology Transfer. Summaries of these discussions follow.

Minimum Set of Crops

Chairman: P. vander Zaag
Rapporteur: S.B. Deshpande

In the introduction to the session, Goro Uehara summarized the strategy for the next 2 days: (1) identify the collaborators, (2) identify minimum data sets, (3) design experiments, and (4) identify benchmark sites both for model development and for testing and utilization of the model.

The first step taken to select crops was to have each country list its five top priority crops, based on research importance. It was emphasized that this was to show the relative importance of the crops and help decide which crops needed to be studied. It was noted that, despite variation in size, all countries would have equal weight, because it is important that research done at different sites be of international relevance (see Table 1).

Table 1. Crops suggested for use in IBSNAT experimerits, in order of priority.[1]

Food crops		Nonfood crops	
Crop	Total points	Crop	Total Points
Maize	48	Cotton	4
Cassava	31	Rubber	4
Rice	28		
Sorghum	24		
Wheat	21		
Beans	16		
Sweet potato	10		
Soybean	9		
Pigeonpea	7		
Coconut	7		
Cocoyam	6		
Plantain/banaba	5		
Sugarcane	5		
Barley	4		
Millet	4		
Lentils	3		
Oil palm	3		
Yams	1		
Groundnut	1		
Chickpea	1		

1. Points were given by each country's representative at the symposium; priority was determined by totaling points for each crop.

Based on Table 1, the ten crops chosen, in descending order of importance were: (1) maize, (2) cassava, (3) rice, (4) sorghum, (5) wheat, (6) beans, (7) sweet potato, (8) soybean, (9) pigeonpea, and (10) coconut. Considerable discussion was raised on the proper approach to selecting crops. Some participants felt that all the crops could be included in the model development and testing; others, that we should take representative crops from each set.

A statement by James Cock summarizes this:

> Crops of different types have very different requirements both in physical and socioeconomic terms. For example, root crops are generally difficult to handle after harvest; cereal grains tend to have critical growth phases when stress may drastically reduce yields; and grain legumes tend to be tricky crops to manage. It would appear wise in the IBSNAT project to include representatives of each of these three major groups, the cereal grains, the grain legumes, and the root crops. Thus, the major problems encountered in technology testing and transfer would be covered; however, if any one of these crop groups is lacking, major gaps may be left. It would also seem wise to have two crops in each major group, choosing crops which cover different ranges of adaptation to the agroecological variability to be covered by the overall study.

The group was generally in agreement with Dr. Cock's statement but also felt that the site selection would affect the crops that would be grown. It was stressed that we should choose crops that would yield a wide range of information and from which widely applicable principles could be derived. The crop should also be examined, not in isolation, but as part of an entire system. The emphasis in our research should be not only on crop or soil or climate but on technology transfer.

Minimum Data Sets

Chairman: S.M. Virmani
Rapporteurs: C. Mathieu
S.B. Deshpande

Discussion was raised on the level of the development of the models for the list of crops given. For some crops, models are already tested; for others, they are in the developmental stage. However, the key issue was the model framework and its limitations, which should be put into perspective.

Framework of Model Development

At this point H. Nix and J. Jones, in that sequence, gave presentations on the framework of model development. Nix listed four means of technology transfer:

trial and error;
transfer by analogy;
regression and correlation;
systems analysis and simulation.

He stressed four levels of detail in systems and simulations, from simple to complex models. For the simple model, the minimum data set included temperature, solar radiation, and water balance with 5- to 7-day time steps. More detailed models will require daily or even hourly readings. He indicated that the development of a model required a detailed data set; the testing of a model required weather, soil, water, dry matter, leaf area, and yield data as minimum. The operational model at the farm level was not relevant to the symposium and so was not discussed in detail.

For the development of the model, Nix stressed the active approach, and described his "omnibus" experiment with 55 species, 5 cultivars each, radiation variables, temperature variables, water gradients, and nutrient levels as experimental variables. He tended to exclude pests and pathogens. This would require about a 2-ha area, a series of plantings, and as many crops as can be grown at the location.

Jones talked about a two-phase approach to model development: Phase 1—model/data for matching soil, variety, and climate potential; Phase 2—model/data for evaluating production and management for "candidate" (best) crops and varieties. Data requirements are much greater for Phase 2.

The possible minimum data set for Phase 1 (simple) model would be :

1. Varieties—resistance to disease, nematodes, insects; length of the growing season (requires phenology model); and drought tolerance (needs water-stress model).
2. Climate—temperature, precipitation, latitude, longitude, and solar radiation.
3. Soil—pH, depth of root zone, propensity for pests.

He stressed that this was not a complete list but could lead to minimum data sets.

Discussion

Considerable interest was generated in the omnibus experiment that Nix has completed in Australia, in which he used 55 crop species x 5 cultivars x 18 other treatments with 3 locations over 3 years with 4 people. This was an example of the active approach to model development.

A question was raised about separating temperature and radiation and photoperiodism. This is a problem but can be manipulated by having sites at different latitudes for studying photoperiod; at different altitudes for temperature; or by increasing photoperiod by artificial light. This gave the group an example within the realm of possibility.

Nix did not disagree with Jones' minimum data sets, but through an example stressed some important parameters for measuring crop development. Early and late crop growth are two critical time periods. We need to know planting dates, seeding rates, date of emergence, floral initiation, anthesis date, physiological maturity, and water balance at the beginning and end of the experiment. He agreed that LAI, dry-matter components of yield, solar radiation, temperature, precipitation, and evaporation are also necessary data.

Discussion reverted to the analogue approach, which should not be dropped but can be effectively improved, especially in relation to a soil data base for improving soil classification. However, the contention was that to move to a higher level of predictability, the systems analysis and simulation approach was necessary.

Discussion centered on the point that models are not going to transfer technology but can help to modify and improve chances of successful transfer of technology. Some aspects of the technology can be transferred directly, others need to be changed, based on model predictions and local experience. The model approach has limitations, as it stresses genotype adaptability but is weak on soil-specific responses to fertilizer application, etc. Therefore, we must use some elements of the analogue package. There are many components in producing technology which relate to crop adaptation. The EPIC and ALMANAC models take into account various management, fertilizer, and tillage aspects.

In summary, it was decided that we must discuss and decide on the options available. What is the minimum data set? Assure that it is relevant, understandable, and usable by developing countries' scientists; i.e., it is available, it is shared by all, and that the models generated are effectively used for the ultimate aim, at the operational phase, of improving farm productivity. It was felt that training was the key to making the whole IBSNAT project successful.

Small group discussions were thus held on developing minimum data sets for crops, soils, and weather, as well as on model development and on making IBSNAT operational from an administrative perspective.

Site Selection

Chairman: R.W. Arnold
Rapporteur: S.B. Deshpande

Factors to be considered in site selection were listed by the group as follows.

Site Information

1. Surface configuration.
2. Soil variability (morphology and taxa) 1:1000± maps.
3. Location—in relation to surrounding area, elevation, longitude, and latitude.
4. Upper 30~cm layer management (nutrient) variability.
5. Past history of use and management.
6. Characteristics of dominant soil (pedon) by standard sampling technique.
7. Phreatic zone.
8. Susceptibility to flooding.

Soil Information

Some characteristics are soil and/or crop-specific.

1. Nutrient status
   Soil pH (H_20, KCI, $CaCI_2$), EC, CEC, and exchangeable cations, Ext. Al (KCI), carbonates, P-fixation isotherm, extractable P (Oisen-P, Bray-P, etc.), total nitrogen and carbon, available K, sulfur-fixation isotherm, nitrite-N, micronutrients (determined by DTPA method), organic matter, and mineralogy.
2. Water availability
   Moisture retention at 1/3 bar, 15 bar, and 1/10 bar (sandy soils) for all the horizons, infiltration, field capacity (in the field), and moisture changes with time and depth.
3. Aeration
   Surface drainage, bulk density, color, porosity, internal drainage, permeability.
4. Tilth
   Infiltration rate, aggregate stability, bulk density, COLE, particle size, distribution.
5. Toxicity
   Soluble salts, inch drip, boron, At, Mn, sulfur.

Soil Analysis and Classification

Requirements were listed as follows.

1. A reference laboratory and the host country laboratory should analyze the samples, following standard methods of analysis.
2. Field description (landscape and soil) standards are needed.
3. Soil Taxonomy classification is to be given (family and higher categories), plus placement in other taxonomies where appropriate.
4. Soil quality variability is to be assessed between sites.
5. Proposed sites are to be judged on the basis of low, medium, or high nutrient availability, water availability, aeration, tilth, and toxicity.

Group Discussion

The group discussion was brief. Sombroek of the International Soil Museum in Wageningen, the Netherlands, asked that monoliths of each site selected be sent to the Museum. Arnold recommended that one laboratory analyze samples from all sites.

Modeling

Chairman; D. Wallach
Rapporteur: C.A. Jones

The data required for crop modeling depend on the purpose of the model and the way in which the data will be used. Models can be developed (1) for classifying areas as to their suitability for various crops, (2) for comparing various long-term management strategies, (3) as a real-time decision aid for the individual farmer, or (4) as an aid to understanding the processes important in crop growth and development. Data can be used for model development, model checking, or model application, and this group considered: models for long-term management decision, data for model development, and data for model testing.

The minimum data for testing a model for long-term management decisions are: meteorological conditions, soil properties, initial soil conditions, and management practices, together with a very few crop managements (see Table 2). Although in principle crop yield alone would be sufficient to test a model, yield components and dates of critical phenological events have also been included because they greatly increase our understanding of how that yield was reached, while adding only moderately to the effort of the data collection.

The suggested full data set for model development is presented in Table 3. In addition to the

Table 2. Minimum data set for mode! testing.

Meteorological
- Daily maximum and minimum temperatures
- Precipitation
- Solar radiation
- Wind speed and direction
- Humidity
- Rainfall intensity
- Class A pan evaporation, where available data are inadequate for calculating potential evaporation[1]

Soil
- SMSS-SCS characterization
- Water, NO_3, NH_4^+, and extractable P
- Measurements to be taken once, around planting time, by layer: top layer no greater than 15 cm, subsequent layers 30 cm, down to 2 m or bedrock

Crop
- Yield components
- Timing of phenological events
- Dry matter and N and P contents of plant parts
- Timing of measurements
  - At harvest
  - Around flowering[1]

Management
- All management interventions should be recorded in detail; e.g. date, depth and implementation of tillage; date, rate, depth, and pattern of sowing; date rate and method of irrigation; date, rate, depth, method, and product used for fertilization, pesticides, and herbicides.

Pest damage
- Pest damage should be estimated, at least qualitatively.

1 Suggested addition to minimum data set.

Table 3. Full data set for modal development.

Meteorological	
	same as minimum data set (see Table 2)
Soil	
	SMSS-SCS characterization[1]
	pH, bulk density, organic C, organic N; measurements to be taken by soil layer[2]
	Water, NO_3 -, NH_4+, and extractable P
	Measurements to be taken by soil layer[2]
	At start of crop
	At harvest
	At critical development stages
Crop	
	Dry matter and N and P of crop parts
	Numbers of crop parts
	(plant subdivided as appropriate for crop)
	Leaf area
	Measurements to be taken
	At start of crop
	At harvest
	At critical development stages
	Timing of phenological events
	Yield components
	Rooting depth (at anthesis or as appropriate)
	Root length and density by layer[2] (at anthesis or as appropriate)
Management	
	Same as minimum data set (see Table 2)
Pest damage	
	Pest damage by plant part, as appropriate
Crop residue	
	Weight of crop surface residue
	Measurement to be taken at harvest monthly thereafter
Runoff and erosion[3]	
	(Runoff and erosion measurements in small runoff plots)

1. Measurement at the start of every crop, rather than just once per field, is necessary where tillage or fertility are treatment variables.
2. Top layer no greater than 15 cm. subsequent layers 30 cm. or as appropriate to soil profile, down to 2 m or bedrock.
3. Suggested addition.

minimum data set for model testing, this full set contains soil measurements throughout the growing season, and data on pest damage and crop residues. These should aid in following the growth and development of the crop, and also in evaluating the long-term effects of the crop on soil properties. (To evaluate long-term erosion effects, runoff, and erosion, measurements in small plots are recommended).

It was suggested that even for model development, not all treatments need be sampled to provide a full data set. Field sampling could be done in only a certain number of core treatments, with more limited sampling in the remaining treatments. The capabilities of the experiment station would finally determine the overall sampling effort.

It was also noted that knowledge acquired by the experimenters is vitally important, and would be extremely valuable to the modelers. This experience then could also be considered part of the minimum data set for a crop.

Crops

Chairman: P. vander Zaag
Rapporteur: J.A. Silva

The consensus of the group discussion on crops and crop selection for IBSNAT is presented here.

1. In the pilot phase only selected food crops will be considered initially, but other crops may be grown depending on the sites, resources, and progress of the pilot-phase crops.
2. Selection of the crop is based on their ability to demonstrate a broad range of principles.
3. The proposed crops are grouped as follows:

Cereals	Pulses	Root Crops
Wheat C/W/D*	Bean *(Phaseolus)* C/W	Cassava H/D
Sorghum H/D	Soybean H/W	Potato C/W
Rice H/VW	Groundnut H/D	Aroids H/W

*C = Cool, D = Dry, H = Hot, W = Wet, WV = Very wet.

4. Not all crops are to be grown at all model development sites; however, each crop must be grown on two or three sites.
5. Some crops may have to be dropped because of difficulties in transfer of clean germplasm of appropriate varieties. This will depend on the location of the selected model development site.
6. A minimum of three varieties of each crop which represent a range of adaptability will be grown at all sites that select that crop.
7. Management Levels.
   It was suggested that the crops be grown at three management levels: (1) minimum functional; (2) recommended for transfer; (3) maximum biological potential.
8. It is recommended that the minimum crop data set for the model development sites be identified by the modelers and specialists for the crops selected.
9. The minimum crop data set for the model testing and utilization sites would contain 12 items:
   Date of planting
   Germination test (laboratory)
   Planting populatiorv-initial and final
   Date of emergence
   Key visual phenological parameters (crop-specific)
   Disease rating (crop-specific)
   Pest rating (crop-specific)
   Lodging rating (crop-specific)
   Harvest date
   Estimated range of harvest dates
   Total harvestable biomass
   Economic yield
10. The minimum management data set would contain:
   Previous crop history
   Land preparation and method used
   Fertilizer type, amount, date, and method of application
   Weed control
   Irrigation rate, amount, date, and method
   Biocides
   Animal control
   Miscellaneous noteworthy events

Discussion

1. The absence of maize from the list of crops was questioned, since it was the crop of major interest. The logic of selection was to select crops with narrower adaptability while maize had wide adaptability. After more discussion, maize was added to the list of crops, to make a total of ten crops.
2. There were queries about the aroids to be selected; however, this was not decided because the choice would depend on the site.
3. The absence of pigeonpea and millet was questioned. It was explained that this initial list was for the pilot phase of the project; the basic principle was that other crops could be added depending on the sites and resources.

Operational Framework for IBSNAT

Chairman: C.R. Escano
Rapporteur: D.M. Leslie

After some discussion the group agreed on the organizational structure for IBSNAT and defined the functions of its principal components.

External Advisory Committee

This group was seen to have an interest in IBSNAT but no direct responsibilities, and could be regarded more as a "watchdog" to ensure that the stated goals and objectives of IBSNAT were adhered to. The group could make recommendations and give advice to USAID on the course of the project.

Members of the committee would be selected by USAID in consultation with IBSNAT and the collaborators. It was felt that the committee should represent various institutions, and include regional and national representatives from both developing and developed countries.

IBSNAT Administration

The University of Hawaii has the contract with USAID for IBSNAT and thus has the responsibility for its implementation. Under the Principal Investigator, the staff of this University with the collaborators comprise the operational body for IBSNAT and would fulfill the IBSNAT coordinating role.

Collaborators

Collaborators would furnish inputs to IBSNAT and be identified on the basis of mutual benefit participation. They would come from international centers, regional centers, national centers, other agencies, such as FAO and SMSS, and other projects, and from other networks. The expectations and queries raised by collaborators involved with IBSNAT were addressed, and the group concluded that the main concern would be to transfer agrotechnology effectively. Other queries commonly raised by collaborators would be:

What is in it for my country/organization?
What does IBSNAT want from collaborators?
How do models benefit us?
What level of sophistication is required to fulfill IBSNAT requirements?
How can national capabilities (i.e. laboratory facilities) be strengthened so that collaborators can fully participate in IBSNAT?
What guidance can be given to assist potential collaborators in "selling" the IBSNAT package to governments?
Can IBSNAT assist in advising on new crops for countries and regions?

Communication Requirements

The establishment of an IBSNAT communication unit was considered to be vital to the project. Its reponsibilities would be to develop:

- newsletters and other publications;
- computer suport—data, software/hardware;
- timetable (i.e., protocol procedures);
- information flow plans;
- procedures for quick communication with collaborators; and
- visual aid support as required.

Conclusion

The group agreed that IBSNAT has the responsibility to develop a mechanism that collaborating nations can adopt, so as to benefit from agrotechnology transfer and avoid duplication in national research, with obvious savings in manpower, capital, and time.

Discussion

Lyonga: Many countries, before participating in IBSNAT, will require assistance in strengthening their national capabilites; for example, in soil survey, laboratory facilities, etc. Will IBSNAT assist in this area?

McGinnis: What is the level of national data gathering required to meet IBSNAT's expectations and will IBSNAT provide assistance with this data gathering?

Gill: We must separate what IBSNAT can give from that which must come from other sources. IBSNAT will provide training, models, etc., but funds to strengthen national capabilities (i.e. instruments, capital items, etc.) and physical assistance in the data-gathering process must come from other sources.

Comerma: Who is going to do the model testing?

C.A. Jones: The Temple group will be producing models and would wish to work with IBSNAT but does not wish to be the exclusive group for modeling, All our models will be made available to IBSNAT.

Ewing: We need an assurance that steps will be taken by all modeling groups to participate in and undertake this work.

Sombroek: IBSNAT could consider approaching other groups, with the view to acting as the liaison between all modeling groups.

Garagory: If we think people in some countries are going to freely generate data then it must be made clear how they get the data (i.e., from models) back. EMBRAPA, I'm sure, would like to be involved in the modeling, but recognition for authorship must be clearly established from the outset. Also, who owns the data? The computer programs must be simply written and understood to ensure immediate utilization.

Uehara: 1 wish to emphasize that the one big advantage of being in the network is that if you put in one set of data and nine others do also, you get back your data set, nine others, plus the model. To me, this will be the strength of involvement with IBSNAT.

Ewing: We need to establish a modeling group before the data-gathering phase starts.

Wallach: It is important to understand that the data gathered and requested for the model would be normal agronomic data that will be generated anyway—modeling is not.

Uehara: We see that collaboration is all about the modelers working with the data generators and all other users of the data.

Formulating the Experimental Design

Chairman: E.E. Ewing
Rapporteurs: J.R. Williams
Murari Singh

The discussion began with an example by Foster Cady, illustrating his concept of the end product. Basically, he outlined an approach where experimental results are compared with model-simulated results to obtain model effectiveness. He suggested that a 15% average error might be acceptable. This led to discussion of model testing and applications. Nix pointed out that maximizing yield may not be the optimal solution—economics must be considered. J.W. Jones suggested a two-step approach: (1) model testing and (2) determining near-optimal management strategy. Cock pointed out that the model must be tested at locations other than where it was developed.

Simulation techniques to estimate production potential were discussed briefly. These simple methods based on climatic data and soil can be used for broad-level screening. El Swaify emphasized the importance of cooperation between modelers and experimenters in designing and refining experiments. An example of successful application of regression equations was given. This was interesting, but has the disadvantage of being site-specific and may not apply to other areas. Uehara restated that all sources of information must be used in modeling—no special emphasis on soils, crops, etc.

The discussion turned to the model development phase. It was suggested that experimental design be flexible to the extent that each location should participate at a level appropriate to that location. The items considered were:

1. Number of crops per site.
2. Number of cultivars per crop—should this always be more than one?
3. Measurements—should all measurements be taken in all treatments?
4. Factorial or separate experiments.
5. Number of levels.
6. Replication.
7. Line source.

Allan Jones pointed out that the experiments need not be standardized because simulation is quite flexible in its use of experimental data. It was reemphasized that modelers and experimenters must cooperate in designing experiments. Uehara suggested that small groups of modelers and experimenters should meet and design experiments. Nix outlined a systems approach to testing and developing models.

It was emphasized that experiments at each site should be designed to match the three important stages of modeling—namely development, testing, and utilization—for maize, wheat, soybean, and sorghum. Furthermore, crops such as rice, cassava, potato, groundnut, aroids, and bean were discussed for experiment at the development stage.

Several scientists spoke about the types of minimum data sets they are collecting in various agroecological environments over their sites and

Table 4. Stage and type of experiment to be conducted under IBSNAT, as listed by prospective collaborators.

Country or institution	Scientist concerned	Crop
Malaysia	Kho Boon Lian	Rice (lowland), cassava, maize, soybean, and peanuts for development/testing/utilization.
Cameroon	S. N. Lyonga	Cassava for testing/utilization. Aroids, potatoes for development. Maize, rice, sorghum, and wheat for testing/utilization. Soybean for testing. Beans and groundnut for development
ACSAD countries	A. Matar	First year=wheat for development/testing/utilization at Syria (and possibly Jordan, Morocco, and Algeria). Second year=Sorghum and maize for development/testing/utilization in Sudan.
Panama	J. Jones	Upland rice, cassava, and maize for testing.
Guam	R. Muniappan	Cassava for development/testing/utilization
Burundi	C. Mathieu	Beans, potatoes, maize, and wheat for development
Thailand	S. Panichapong	Rice, cassava, soybean, maize, and sorghum for testing/utilization
Costa Rica	Julio Henao	Maize and cassava for development/testing
Fiji	D. M. Leslie	Groundnut, potato, aroid, maize, cassava, soybean, and rice for testing
Pakistan	A. Khan	Groundnut, for testing. Maize, wheat, rice (unirigated), sorghum and groundnut (rainfed) for development/testing
International Potato Center	P. vander Zaag	Potato for development
International Fertilizer Development Corporation	D. Godwin	Wheat, maize, and barley for development

urged that such scattered information be consolidated to make it more widely applicable.

Some discussion was needed on development of the models we standardize and on a compact form for data collection at various sites. Uehara favored the use of standard computer programs available for various models. HP. Nix's model implementation was emphasized. Cock mentioned that some effort should be made on the transfer of germplasm materials among the national and international centers. Upadhya responded that there are two distinct groups of centers, one of which handles germplasm material while the other does not.

Virmani emphasized the need for cultivation of some common crop(s) at each site. Nix responded against Virmani's choices and said that only the gradient of the response is important; as such, different crop combinations can be tried at various sites. Cady further pointed out two types of gradients of response: one within cultivar and the other across sites, so that one needs at least one cultivar that will be grown at all sites.

Representatives of various countries informed the group of their particular interests in conducting experiments at various stages (Table 4).

The participants then split into three groups according to crop interest—cereals, root crops, and legumes—to discuss the minimum data sets. Each group considered soil structure, weather conditions, and management practices, and the following questions:

Should all cultivars be tried at all sites?

Should the same experimental design be adopted at all sites?

What should be the degree of standarization of measurement?

What would be the sampling protocol?

How should we handle input data; processing; output; publication?

Minimum Data Sets for Agrotechnology Transfer: Summary and Recommendations

Minimum Data Sets for Agrotechnology Transfer: A Summary

It may be convenient and appropriate to review the deliberations and discussions of the symposium in the context of the objectives of the meeting as stated in the program brochure.

Research Station Network

The first objective was to "identify the number and nature of research stations in the network." Regarding the second part of this statement, Eswaran presented the desirable attributes of a benchmark site and those of a network of benchmark sites which should cover the complete spectrum of soil and climate conditions in the lower latitudes. Ideally, some IBSNAT sites should be located in what Nix has termed "tension zones," as a maximum of information can be extracted at these places. It was pointed out that there should be two kinds of benchmark sites: one for field-testing already existing models—i.e., model-testing sites—and one for generating the data needed for model development—model-development sites. In practice, however, the distinction between these two kinds of sites will not be as clear-cut, since testing sites will also provide feedback for further model development or refinement.

Sixteen countries represented at the symposium expressed interest in joining IBSNAT. The geographic distribution and the nature of the potential sites are shown in Table 1.

The establishment of one or more IBSNAT sites in these countries is, in most cases, still subject to approval by the respective authorities. If this network materializes, it would come very close to what Goro Uehara in his introductory remarks envisioned as the initial IBSNAT network. A careful analysis of the soil and climatic conditions at the potential sites may show the desirability of including other sites at agroecologically critical locations that are not represented in the network.

Table 1. Geographic distribution and type of potential sites for IBSNAT.

Region	Country	Type of site	Crops studied
Asia	India (ICRISAT)	Development	Groundnut
		Testing	To be decided
	Malaysia	Testing	Rice, maize, cassava
	Pakistan	Development	Groundnut
		Testing	Maize, wheat
	Thailand	Testing	All crops except wheat
Africa	Burundi	Testing	Maize
	Cameroon	Testing	Cassava, maize, sorghum
Near East	Syria (ACSAD)	Testing	Wheat, sorghum
Central America	Costa Rica (CATIE)	Testing	Maize, cassava
	Panama	Testing	Rice, cassava, maize
South America	Brazil	Testing	Wheat, possibly others
	Colombia (CIAT)	Development	Cassava
		Testing	Beans
	Venezuela	Development	Beans, potatoes
		Testing	To be decided
Oceania	Hawaii, USA	Development	To be decided
	Fiji	Testing	All crops except wheat
	Guam	Testing	Cassava

It was also noted that more sites should be established in Africa.

Crops to be Researched

The second objective was to "agree on the number of crops to be researched." This objective was rather fully accomplished. The potential collaborators recommended that ten crops be adopted, representing species of cereals, pulses, and root crops:

Maize	Beans	Cassava
Wheat	Soybean	Potato
Sorghum	Groundnut	Aroids
Rice		

Model development will be required for groundnut, beans, potato, and aroids; for the other crops operational models already exist. It was proposed that three varieties of each crop be studied at two to three levels of management inputs characterized as "minimal functional," "recommended for transfer," and "maximum biologic potential." The ten selected crops should be researched in the initial stages of IBSNAT and other crops may be added later.

Design of Experiments

The third objective was to "agree on the design of the experiments." The only agreement reached in this regard was that no standard experiment design was needed, but that many data sets should be generated over a wide range of agroecological conditions. A committee composed of representatives from the collaborating institutions will study the matter of experiment design in detail. There was a consensus that the "omnibus" approach discussed by Nix should be spread out in time and space for obvious operational reasons.

Minimum Data Set

The fourth objective was to "identify the minimum data set to be collected from each experiment." The symposium participants formulated two sets of minimum data, one for testing operational models, one for generating the data for model development,

Minimum Data Set for Model Testing

Climate

The minimum climatic data needed for model testing would be:
- Temperature
- Solar radiation
- Precipitation and rainfall intensity
- Relative humidity
- Soil temperature
- Soil moisture
- Wind speed and direction
- Evaporation

Soil

Soil data should include:
- Standard characterization
- Nitrogen and phosphorus characterization

Crop

Minimum crop data would be:
- Yield by yield component
- Crop phenology during growing season

Management

Management data should include a record of all management practices.

Pest Damage

Incidence of and damage by pests should be assessed.

Minimum Data Set for Model Development

This set will include all the above measurements and observations. In addition, there will be more emphasis on soil fertility parameters and on crop phenology. Foliar analysis, leaf area index, crop surface residue, etc., will also be included.

Specific minimum data sets will naturally vary from crop to crop and from soil to soil.

Data-base Management and Analysis

The fifth objective was to "formulate plans for data-base management and analysis."

Three speakers addressed data-base management with respect to climate, soil, and crop data, and covered the subject in general terms. Wallach's presentation on crop data-base management was particularly perceptive and pertinent.

Assignment of Responsibilities under IBSNAT

The sixth and last objective was to "assign responsibilities for data collection, data-base management, and data analysis."

The time allocated in the program for these topics was insufficient to discuss these issues in depth. It was decided, however, that a committee on experiment design and a committee on crop modeling should be established as soon as possible. Both committees should have their first meeting in the near future.

Besides addressing the objectives mentioned above, the symposium accomplished a great deal more. To many participants it provided an introduction to crop modeling. Nix's outstanding presentation conveyed an excellent philosophical and scientific framework and a proper perspective, and several modelers from Brazil, India, and the USA reported on the current state of modeling in various areas.

Many informal discussions often extending into the small hours of the night, proved invaluable for establishing new contacts and strengthening existing linkages. These personal contacts, intangible as they may seem, will nevertheless be of consequence in the smooth implementation and operation of IBSNAT.

An outstanding feature of the symposium was the spirit of cooperation that prevailed throughout the meeting. The interest in working together under the umbrella of IBSNAT that was expressed by the representatives of the national and international agricultural research centers was indeed impressive. Special mention must be made of the willingness of the USDA-ARS modeling group at Temple, Texas, to join forces with modelers elsewhere; the cooperative attitude of the International Fertilizer Development Center, the Food and Agriculture Organization (FAO) of the United Nations, and the Federal Institute for Geosciences and Natural Resources of West Germany; and the generous offer by Henry Nix of the CSIRO, Australia, to make his and his institution's considerable expertise available to IBSNAT.

In conclusion, I believe that the symposium has, to the extent realistically possible, fully achieved its objectives and thus marks a promising start for IBSNAT. The overall success of the first major activity of IBSNAT should be a source of real satisfaction to all the organizers of the symposium. More importantly, however, I feel that the success of this symposium should be very encouraging to all who are involved in IBSNAT.

Recommendations

The symposium recommended that:

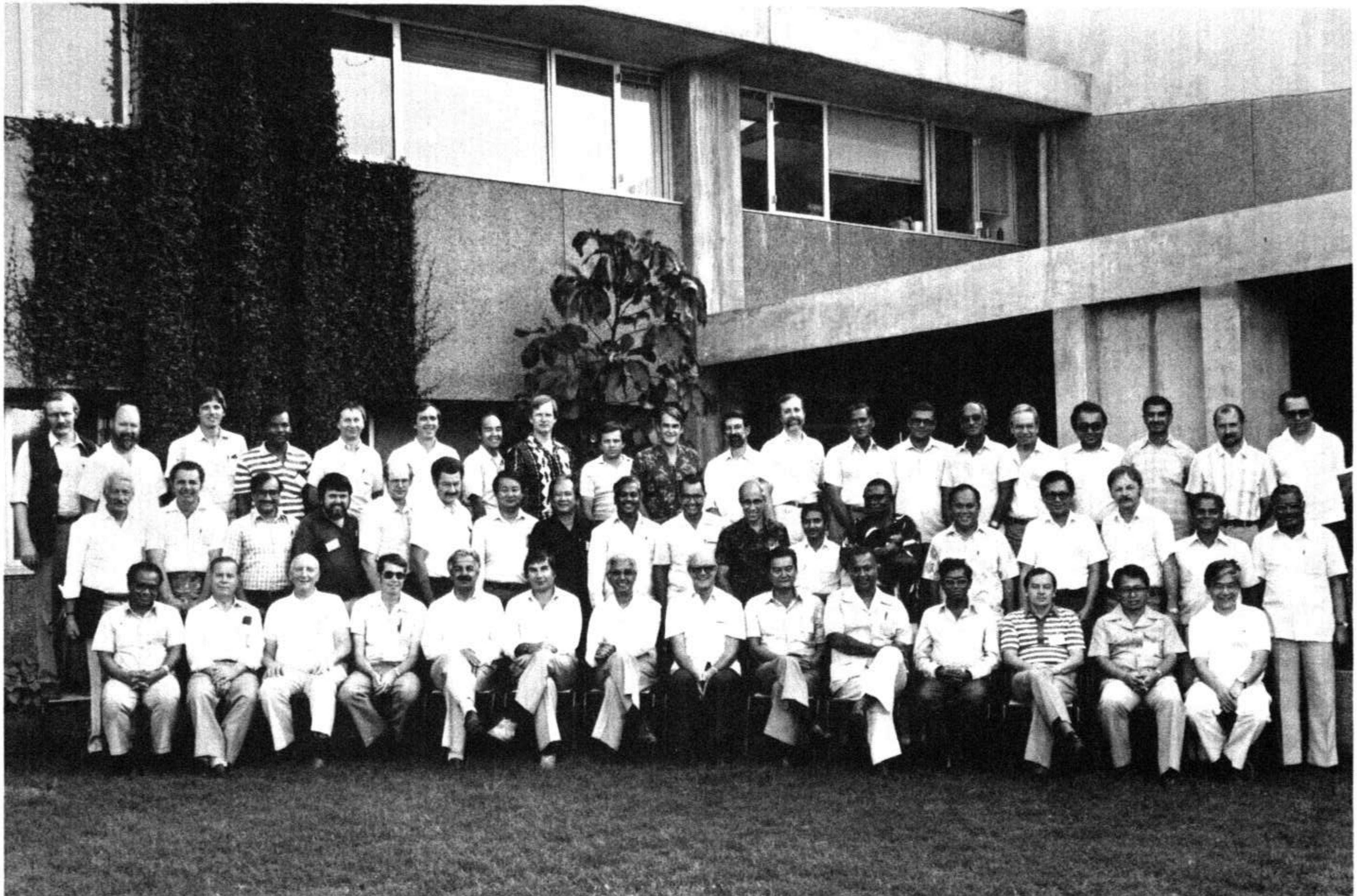
1. The second meeting of IBSNAT collaborators be held either in the Philippines or in Hawaii during the summer of 1984. The reason for proposing these venues is that IBSNAT field-work will be in progress at both locations at the time of the meeting. Proposed by C.R. Escano; seconded by J.H. Cock. Motion carried unanimously.
2. IBSNAT actively explore the possibility of internationalizing the funding of the project as a means to (a) ensure effective collaboration among centers of expertise, (b) increase the number of model development and testing sites, and (c) obtain adequate equipment and management support for the sites where this is needed. Proposed by W.G. Sombroek; seconded by J.A. Comerma. Motion carried unanimously.
3. The International Service for National Agricultural Research (ISNAR) of the CGIAR be approached regarding assistance in the identification of national institutions of the tropics and subtropics which may be willing to operate research sites under IBSNAT. Proposed by W.G. Sombroek; seconded by P. vander Zaag. Motion carried unanimously.
4. The various institutions engaged in the modeling of soil-climate-crop-management interrelationships be contacted and, if feasible, be involved in IBSNAT in order to promote a concerted effort relative to the development of simulation models and the field-testing of their applicability to agrotechnology transfer. Proposed by W.G. Sombroek; seconded by J.H. Cock. Motion carried unanimously.
5. IBSNAT pay close attention to the exchange of all data generated through the project by the collaborators. In particular, the computer program for the storage of various data sets and for the simulation models should be

effectively shared, implying the compatibility of the programs with the data banks of the participating institutions. Also, any reports or publications making use of significant data collected at IBSNAT sites by national institutions should be co-authored by the respective national scientists. Proposed by W.G. Sombroek; seconded by P. vander Zaag. Motion carried unanimously.

6. IBSNAT have a Program Advisory Committee to assure that the project is implemented and conducted in accordance with the objectives of IBSNAT. This Advisory Committee should include representatives from national and international institutions. It is further recommended that Regional Advisory Subcommittees be established. Proposed by A. Kassam; seconded by W.G. Sombroek. Motion carried unanimously.

Appendix 1

Participants



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