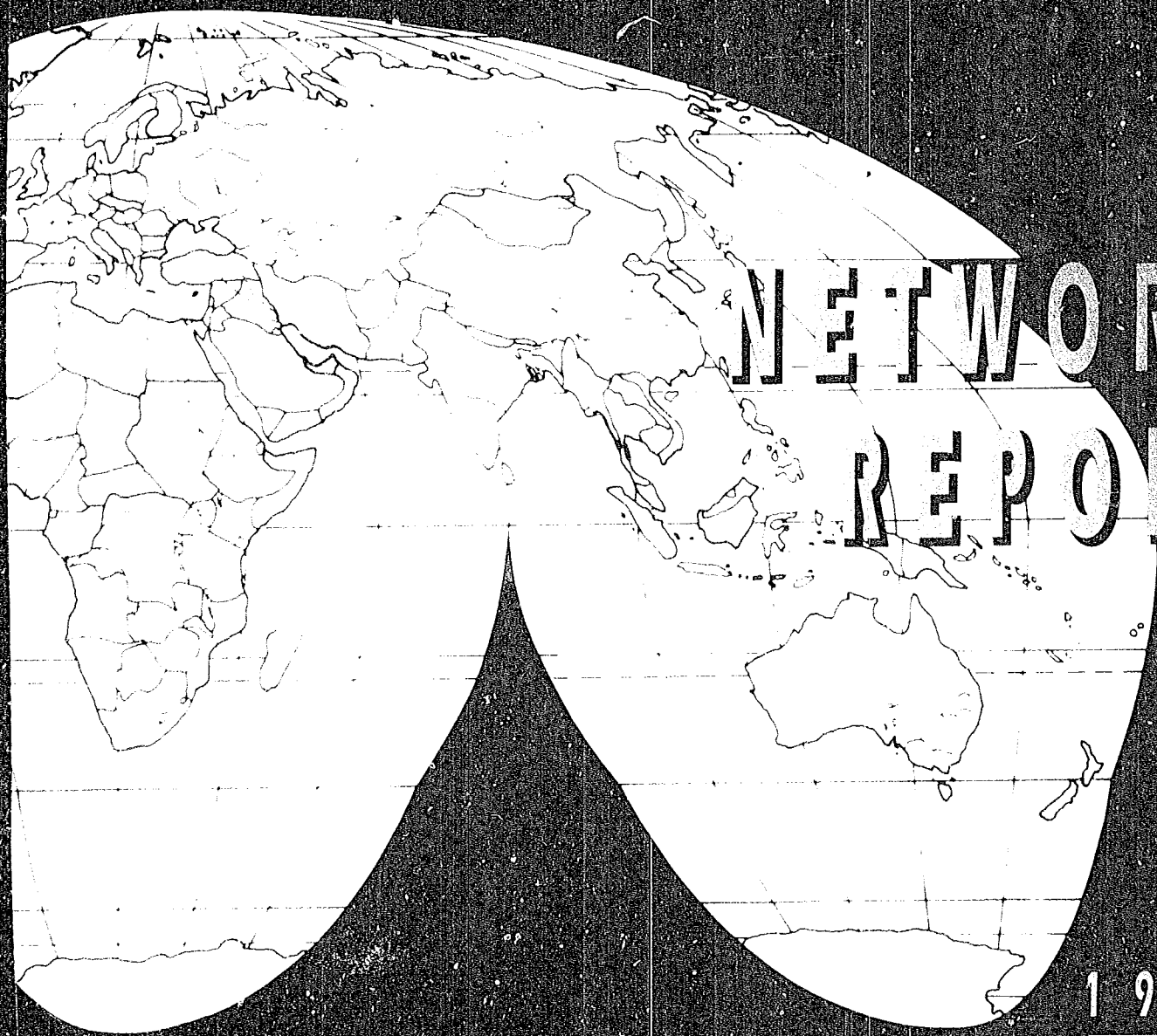
International Benchmark Sites Network for Agrotechnology Transfer



NETWORK REPORT

1987
1990

IBSNAT
Progress Report

1 September 1987—30 June 1990

International Benchmark Sites Network for Agrotechnology Transfer

IBSNAT, The International Benchmark Sites Network for Agrotechnology Transfer is a group consisting of the contractor (University of Hawaii) and several collaborators. Together they have created a prototype network of national, regional, and international agricultural research centers for the transfer of agrotechnology among and within countries in the tropics and subtropics.

IBSNAT is a program of the U.S. Agency for International Development under Cooperative Agreement No. DAN-4054-A-00-7081-00 with the University of Hawaii.

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IBSNAT PR-03-9/90 (1000)

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Project Summary Sheet

Project Title:

International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT)

Agreement Number:

AID/DAN-4054-A-00-7081-00
Project No. 936-4054

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1 September 1987 to 31 August 1992

Reporting Period:

1 September 1987 to 30 June 1990

Executive Summary

The International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) Project was established in 1982 to support continuing efforts of developing country governments to keep pace with the rising expectations of expanding populations. IBSNAT strives to accomplish this by helping decision makers take advantage of the powerful diagnostic and problem solving capabilities of information science and computer technology. The first phase of IBSNAT from 1982 to 1987 was implemented under a contract between the U.S. Agency for International Development (U.S. AID) and the University of Hawaii at Manoa. The second phase of IBSNAT began in 1987 under a cooperative agreement between the same parties. The cooperative agreement included provisions whereby additional resources would be forthcoming to IBSNAT through:

i) a cost-sharing commitment by the University of Hawaii, and
ii) a Basic Ordering Agreement (BOA) which permits other U.S. AID-funded programs to "buy-in" or transfer funds to IBSNAT to "acquire" technical services for research and/or training.

The central concept of systems-based research is that the whole system must be understood in order to evaluate changes in any single component. This approach enables the project to bring together existing knowledge of the farming system, identify major components and processes and their interactions, and seek to identify constraints hindering improved performance. The IBSNAT Project was designed to provide the structure and mechanism to link soil, water, weather, crop, and management research efforts into a coherent, problem-solving instrument, now called the Decision Support System for Agrotechnology Transfer or DSSAT.

At the conclusion of the first phase, the major accomplishment of the project was the development of a decision-making framework and the first prototype version of a decision support system software that linked the IBSNAT Data Base Management System (DBMS) to crop growth models. Development of DSSAT was achieved through the following activities.

- Identified 12 major food crops (maize, rice, sorghum, millet, barley, wheat, soybean, peanut, *phaseolus* bean, cassava, taro, and potato) for model development and simulation in farmers' fields, and the minimum soil, crop, weather, and management data to predict their growth, performance, and yield
- Selected the CERES model for barley, maize, rice, sorghum, millet, barley, and wheat; SOYGRO for soybean, peanut and *phaseolus* bean; and SUBSTOR for cassava, taro and potato.
- Produced, tested, and updated a manual for the experimental design and data collection procedures to be used by IBSNAT collaborators.
- Established a prototype network of 45 benchmark experimental sites in developed countries and 16 developing countries to collect the minimum data set to validate the crop models.
- Created the IBSNAT Data Base Management System to store and analyze the minimum data set collected by the network.
- Converted mainframe versions of crop models for use with microcomputers.
- Mobilized an international group of systems analysts, modelers, economists, breeders, and plant protection specialists to work on IBSNAT Project outputs.
- Designed a user-oriented decision support system that enables users to answer "what if" questions relating to strategic planning by policy makers and tactical planning by farmers and extension agents.
- Developed instructional materials to conduct training workshops on systems analysis and

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crop modeling for agrotechnology transfer for use in developing countries.

- Publicized the IBSNAT Project principles, concepts, and achievements through technical reports, brochures, conference proceedings, newsletters, and invited lectures.

During the first two years of Phase II, emphasis was placed on testing the linkages between the data base, crop models and strategy evaluation programs in DSSAT and in producing the User's Guide for DSSAT version 2.1. Outputs of the IBSNAT project have been identified under six categories. Three are related directly to components of DSSAT:

1) data base management system;
2) decision aids; and
3) user application programs.

The remaining three address activities related to:

4) the prototype network of IBSNAT collaborators;
5) application of DSSAT and IBSNAT concepts; and
6) acceptance of DSSAT through training.

The following are highlights of accomplishments for the period 1987 to 1989.

- Distributed a test version of DSSAT V.2.1, including version 2.1 of CERES-wheat and maize, SOYGRO V.5.42, and PNUTGRO V.1.02.
- Completed testing of the beta version of DSSAT V.2.0, including V.1.99 of CERES-wheat and maize, SOYGRO V.5.41, and PNUTGRO V.1.01.
- Completed development of a strategy evaluation program to perform risk assessment of simulated outputs from any of the four crop growth models in DSSAT.
- Completed installation of crop models for wheat, maize, soybean, and peanut; and of modified weather generator programs in DSSAT.
- Established soil data base consisting of all Soil Conservation Service/Soil Management Support Service (SCS/SMSS) international benchmark soils for DSSAT users and created program to estimate soil input file for crop models in DSSAT.
- Completed shell program to link data base management system, crop models, applications programs, and utility programs under DSSAT umbrella.
- Initiated work plans towards development of DSSAT version 3.0 to accommodate anticipated changes in file structures for DSSAT applications.
- Adoption of DSSAT and IBSNAT crop models for national (U.S.) and international projects estimating the impact of possible climate change on crop production by the Environmental Protection Agency (EPA) and the PAN-EARTH project of Cornell University, respectively.
- Application of DSSAT by ICRISAT and scientists from Indian institutions in a nationwide peanut (groundnut) model validation trial.
- Adoption of the IBSNAT minimum data set standard as a guide to data collection for validation of soybean models, including SOYGRO, by the American Soybean Association.
- Adaptation of the IBSNAT minimum data set concept by international group of dry bean breeders and their initiation of a network of locations to determine genetic coefficients of selected cultivars for use in validating BEAN-GRO.
- Established prototype IBSNAT-type program referred to as APINAT in Florida and OBSNAT in the South Pacific.
- Conducted training workshops on DSSAT at the Bangladesh Agricultural Research Council (BARC) in Bangladesh and at International Fertilizer Development Center (IFDC) in Muscle Shoals, Alabama; in the People's Republic of China, Senegal, and Venezuela with the PAN-EARTH project.
- Increased total number of MDS received for all crops to 134.
- Developed working versions of crop models for rice, sorghum, millet, dry bean, barley, potato, and cassava.
- Completed two field experiments to determine genetic coefficients on the island of Maui, Hawaii, for maize and soybean.
- Developed working version of a genetic coefficient estimator to estimate genetic coefficients for maize, wheat, and soybean.
- Developed collaborative research activities to link DSSAT outputs with a geographical information system in Puerto Rico.

- Published the following:
  DSSAT version 2.1 User's Guide
  Technical Report 5, version 1.1
  Technical Report 2
  Agrotechnology Transfer No. 6, 7, 8, 9, 10, and 11.
- Completed preparation for on-site panel review of IBSNAT by U.S. AID.

These accomplishments represent milestones and progress of events towards producing outputs to achieve project objectives. The following summarizes progress towards those objectives listed in the next section.

Summary of Milestones

- Documentation and release of DSSAT version 2.1 have been the major milestone events in Phase II. Both events were essential towards achieving one of the three stated objectives of IBSNAT: produce a prototype decision support system composed of decision aids and data bases for users operating at the policy and farm levels. Progress to improve the utility and application of future versions of DSSAT is now possible.
- Development and release of the prototype version of DSSAT also had an impact on the two other objectives:
  1) validation of decision aids; and
  2) demonstration of its utility through case studies.

The following statements summarize activities towards the achievement of these goals.

- A genetic coefficient calculator or estimator, to assist the user in obtaining a first approximation of coefficients for their cultivar from information derived from the MDS, is operational and ready for testing.
- Beta versions of CERES-rice, CERES-sorghum, and BEANGRO were installed in DSSAT for validation exercises in training workshops involving IBSNAT.
- Workshops held at ICRISAT, IFDC, and BARC provided avenues to demonstrate DSSAT to potential users, and explore collaborative research on model validation for rice and sorghum. Application of DSSAT by national agencies is under consideration in both Bangladesh and Thailand.
- The South Pacific Commission with technical support from DSIR, New Zealand, and resources from CIRAD and ORSTOM prepared a final document to establish OBSNAT to its member nations in mid-1989. Approval has been granted for a meeting of member nations' agricultural directors in March 1990.
- A PSTC program with ICTA in Guatemala in 1988 provided an opportunity for application of DSSAT and BEANGRO. A Rockefeller Foundation subgrant was given (starting January 1990), so that P.K. Thornton and J.B. Dent, IBSNAT scientists from the Edinburgh School of Agriculture, and U. Singh of IFDC, could begin activities with the University of Malawi in Lilongwe. This case study involves DSSAT and CERES-maize.
- A study involving IBSNAT and scientists using DSSAT, was initiated through an agreement between the U.S. Environmental Protection Agency and U.S. AID. The study seeks to research the effect of climate change on global food production and trade. In preparation for an international workshop jointly organized by the EPA and U.S. AID in January, 1990, a special version of DSSAT was developed to accommodate changes in temperature and carbon dioxide levels in the crop models.

The IBSNAT Project Goals & Objectives

Project Rationale

Agriculture, like most businesses, is a decision making enterprise. Farmers and policy makers are constantly faced with the task of matching and allocating time and resources to efforts that are likely to produce desired outcomes. Deviations from expected outcomes are often caused by random environmental variables, such as weather, over which the decision maker has little or no control. Thus chance, and therefore risk, enters the decision making process, and farmers and policy makers are unwillingly compelled to gamble with nature.

Farmers have traditionally learned to cope with nature by matching crop requirements to land characteristics through the slow and tedious process of trial-and-error. If farmers seem conservative, it is because they know from experience that there are risks associated with change. Where farming is especially risky, crops and practices are chosen not for producing high yields in the average year, but to produce adequate food or income in the worst years. Thus to assess risk, an innovation, whether it be a new crop, cultivar, or practice, needs to be evaluated over many years to expose hidden dangers which one or two years of on-farm trials cannot reveal.

A technology package typically consists of a product and a practice. In agriculture, the product might be the seed of a high performance cultivar, and the practice, a new method for protecting crops against pests. Although technology adoption is widely believed as necessary to improve farm performance, there is also widespread agreement that risk aversion is a major deterrent to technology adoption. This suggests that any effort to improve farm performance must take into account the role of risk, and attitudes towards risk, on technology adoption.

In farming, risk is minimized by matching the requirements of crops, products and practices to the physical characteristics of land, and the resource and behavioral characteristics of the farmer. There are three ways by which this matching process can be achieved. The first is by trial-and-error, the second by taking successful technologies to other locations with similar agro-environments (the analogue approach), and third, by understanding natural processes and using this understanding to diagnose and prescribe alternative ways to rectify mismatches through systems analysis and simulation.

One advantage of systems simulation is its capacity to generate whole probability distributions for uncertain quantities such as yield or

With an adequate water supply, terracing of stable hillsides such as this one in Banaue, Philippines, permits farmers to create conditions which can sustain rice production.

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profit. This capability provides decision makers with the means to compare not just averages, but the risk laden, lower tails of probability distributions. Although agricultural research is well equipped to generate and offer treatment means as estimates of expected outcomes, it is not geared to provide decision makers with estimates of risk. Recognizing this, it seemed timely to invest in research that could do both.

In 1982, the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) Project was established with the goal of accelerating the adoption rates of agricultural technologies by resource-poor farmers in the developing countries of the tropics. The project chose systems analysis and simulation as the principal means to achieve its goal.

Project Goal

The goal of the IBSNAT Project is to improve farm performance and increase family income of resource-poor farmers by enabling them to choose and integrate new crops, products, and practices, with existing farming systems without sacrificing stability and sustainability of production.

Project Objectives

To achieve its goal, the IBSNAT Project will establish an internationally constituted collaborative research network composed of an interdisciplinary team of systems-oriented scientists to:

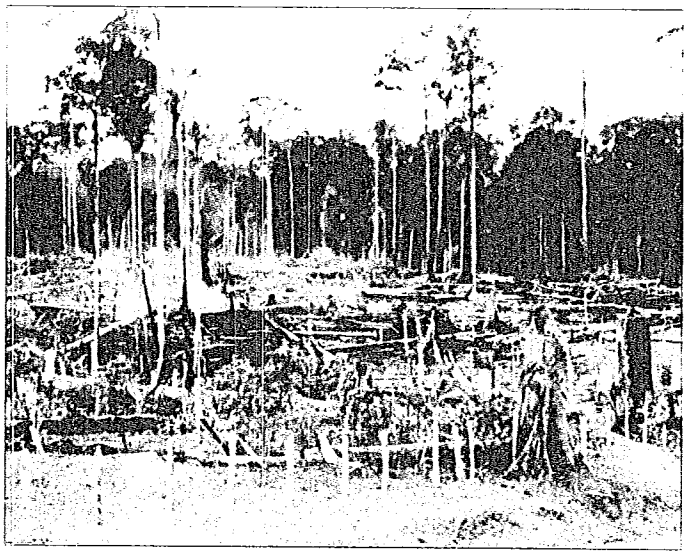
1. produce a prototype decision support system consisting of data bases and decision aids useful to decision makers operating at the policy and farm levels;
2. validate components of the decision support system to enable users throughout the tropics to simulate and evaluate alternative agronomic, economic, and environmental strategies; and
3. demonstrate the utility of the decision support system through case studies.

Project Approach

Information science and computer technology offer new ways to deal with old, intractable agricultural problems. One problem which all farmers face is how to match the biological requirements of crops to the physical characteristics of land. This problem of dealing with genotype by environment by management interactions is a long and tedious process primarily because land characteristics vary randomly over space and time.

The IBSNAT approach is to match crop requirements to land characteristics through systems analysis and simulation. This approach requires the use of crop simulation models and data bases. IBSNAT is standardizing existing crop models to operate on a common data base consisting of a minimum set of crop, soil, and weather data. This minimum data set (MDS) was chosen to ensure that users in developing countries are able to develop national data bases with minimum effort. The crop simulation models and data bases are components of a Decision Support System for Agrotechnology Transfer (DSSAT). DSSAT provides users with easy access to data bases and crop models to simulate outcomes of alternative strategies for improving farm performance. DSSAT is designed to operate on portable and personal computers.

The aim is to encourage investment in research based on systems analysis and simulation by demonstrating the capability of a decision support system to simulate agricultural processes and outcomes in a cost effective and timely way.



This photo of indiscriminate clearing illustrates the point that proper natural resource management must be practiced if agricultural production is to be sustained for generations to come.

The Decision Support System for Agrotechnology Transfer (DSSAT V.2.1)

DSSAT Components and Structure

A major milestone was reached in September 1989 when the IBSNAT Project began distributing the software and User's Guide for the Decision Support System for Agrotechnology Transfer (DSSAT V.2.1). DSSAT is essentially a computer software shell designed to accommodate standardized crop models. Figure 1 shows a schematic of the components of DSSAT V.2.1 and their relationships. The Data Base Management System (DBMS) provides user friendly entry and editing of several types of data. Retrieval programs are designed to extract the data from the centralized data base and create files for running the crop models. Output from the models can then be printed or graphically displayed and compared with observed results. A validated crop model may be used to evaluate alternative strategies for improving farm performance using computer programs especially designed for this purpose. These programs facilitate running crop models for different soil types, planting dates, planting densities, varieties, irrigation amounts, dates, strategies, fertilizing timing, depth, and type, over several seasons to determine the most promising and least risky combinations of site management.

The DSSAT Shell

The programs to perform the different functions outlined above are written in various computer languages such as FORTRAN, dBASEIII, Quick BASIC and PASCAL. The shell program, written in "C", enables users to gain access to any of the DSSAT programs irrespective of language or program execution. The integration of the different components required definition and standardization of data structures as described in Technical Report 5 (1988, 1990).

The DSSAT software also includes an install program that automatically creates all of the directories on the disk as specified by the user. Installation options include flexibility for putting components on different disks. A data file which specifies the path and name of each program and data component is also maintained. Under the Utilities Menu, users can change the location of any DSSAT component, and after any program is executed in DSSAT, control is returned to the DSSAT shell which stays in memory.

Data Base Management System (DBMS)

For validation, crop models are used to simulate crop responses under specific experimental conditions for which observed data are available. Validation requires a minimum data set (MDS) of:

1) weather data for the duration of the experiment;
2) soil properties;
3) management options used; and
4) experimental data.

All data are stored in the DBMS, along with data retrieval and utilities programs which facilitate the use of the data bases.

Crop Models

Four crop models are currently available in DSSAT: maize, peanut, soybean, and wheat. DSSAT-compatible models for sorghum, millet, dry bean, rice, potato, and other crops are also being developed. All IBSNAT crop models are process oriented, designed to have global applications, and be independent of location, season, crop cultivar, and management. The models simulate the effects of weather, soil water, genotype, and nitrogen dynamics on crop growth and yield.

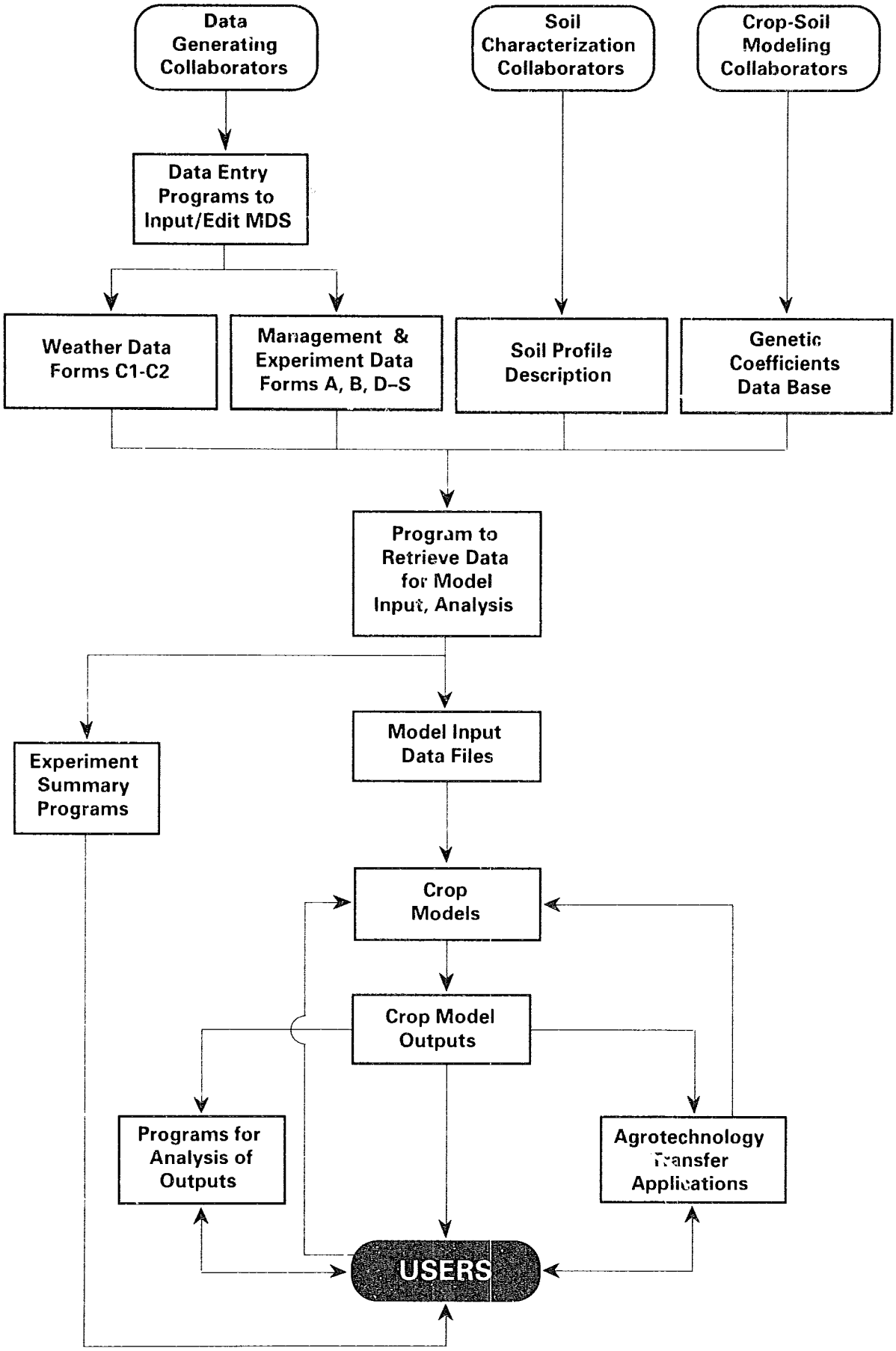


Figure 1
Schematic drawing of DSSAT V.2.1 components and their relationships.

DSSAT Strategy Evaluation

Since weather is a major source of variance in farm performance, a given management option may be simulated over many years of weather experience that subrepresents the wide range of conditions. If for example the crop is seeded on a particular day of the year, DSSAT will simulate the growth and development of the crop for up to 50 consecutive years. The option might be to delay or advance the planting date, choose a shorter or longer duration cultivar, alter the row spacing or plant population, increase or decrease the nitrogen rate, or compare rainfed with irrigated farming on a sandy or clayey soil. DSSAT allows up to 15 combinations of options to be simulated in a single experiment. A typical scenario might compare two cultivars, seeded on two separate dates, and supplied with three nitrogen rates resulting in 12 treatment combinations. The same experiment can be repeated on different soils, using different sources of nitrogen fertilizer, including green manures of varying carbon-nitrogen rations. Management factors which can be included in strategy evaluation are listed in Figure 2. Today's computer hardware enables DSSAT to generate, in a matter of a few hours, amounts of data that have traditionally required a lifetime of work by an agronomist. To be useful, DSSAT must also achieve two other objectives. It must analyze the simulated results and present them in a manner that enables the user to discriminate and choose from many options, and it must overcome the distrust decision makers have of computer generated information.

One way to gain user confidence is to demonstrate DSSAT's capability to reproduce familiar and remembered historical events to local audiences. Exceptionally bad and good years are often remembered. Good agreement between simulated and remembered events, and good outcome is necessary to build user confidence and to serve as site-validation of the model. Following such a demonstration, users can be encouraged to suggest alternative ways to improve performance.

Individuals may disagree on what constitutes improved performance, but DSSAT offers the

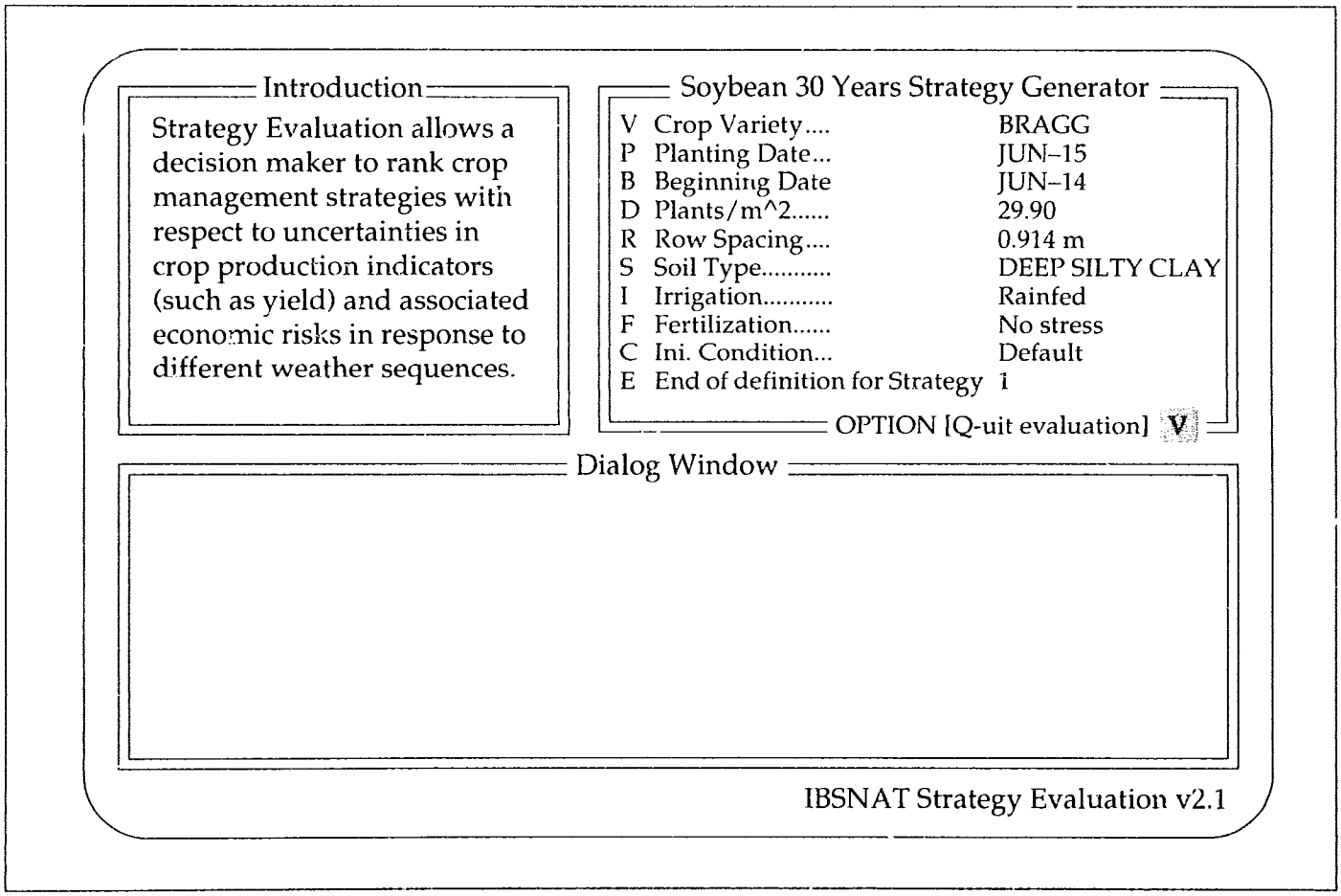


Figure 2
DSSAT displays management options which users adjust to formulate new strategies to improve farm performance.

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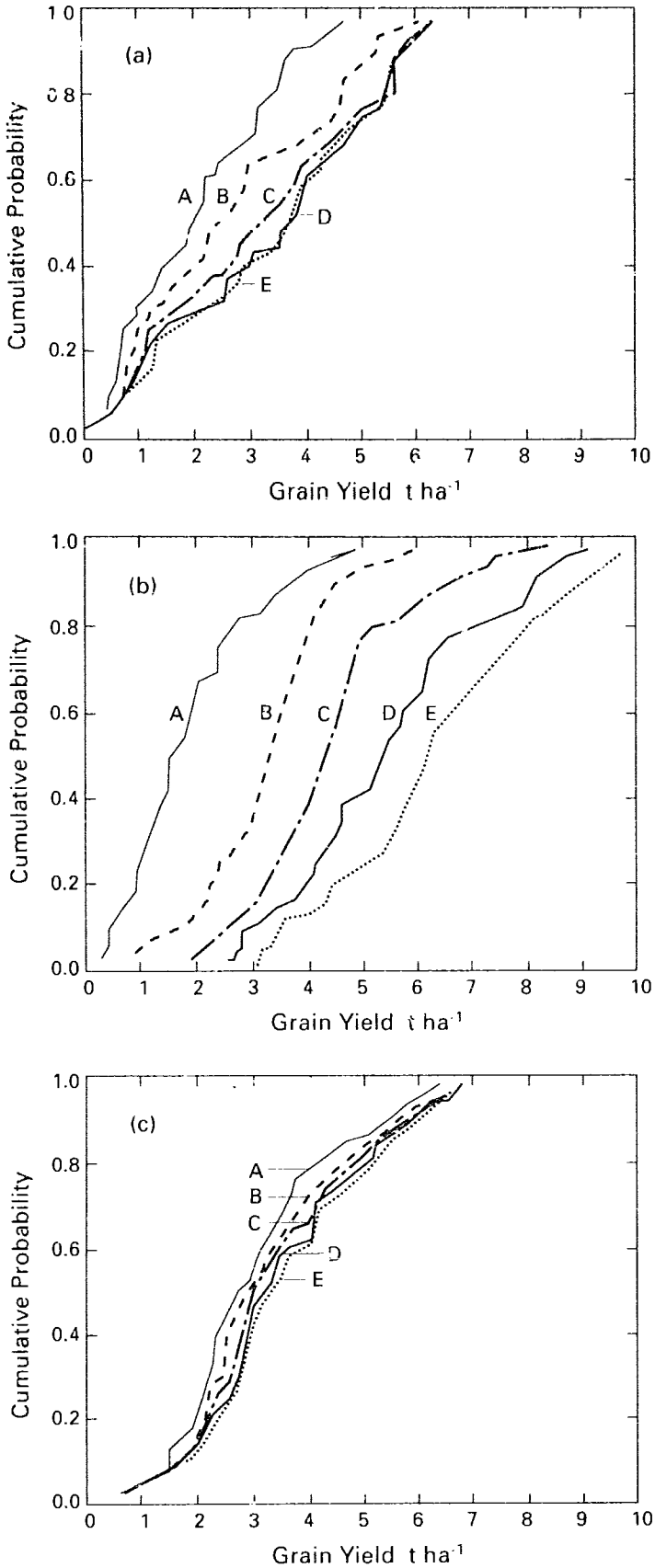


Figure 3
Cumulative probability functions (CPF's) of simulated wheat grain yield for five nitrogren fertilizer rates (0, 30, 60, 90, 120 kg/ha for A, B, C, D, and E, respectively) at (a) Warooka, (b) Rothamsted, and (c) Topeka (Godwin and Vlek 1985).

decision maker with a choice. The choice often depends on the chooser's objectives and attitude towards risk. One farmer may choose to add nitrogen fertilizer in a way that maximizes profit; another may be seeking ways to minimize nitrate contamination of groundwater. In either case, results of long term simulations must be displayed in a way that is easily understood. DSSAT aids individuals to exercise choice, by displaying simulated results according to rules based on mean-variance and stochastic dominance analysis. A simple application of mean-variance analysis involves a plot of means against variances. Assuming that high means and low variances are the desired traits of a variable quantity, a decision maker can choose strategies having these traits.

In stochastic dominance analysis, probability distributions are displayed as cumulative probability functions (CPF), in which simulated results for a particular management option are ranked and plotted in ascending order. Each result is assigned a probability equal to the reciprocal of the total number of simulations. For easy comparison,

DSSAT can display six CPF's on a single graph. In first order stochastic dominance, the CPF of the dominant strategy lies entirely to the right of the dominated strategies. In choosing the stochastically dominant strategy, it is assumed that a decision maker prefers more to less of the uncertain quantity. If the variable were nitrate concentration entering groundwater, the opposite would be true. For example, the decision maker would want less to more of the variable quantity. In cases where the CPF's are clearly separated, choosing the preferred or dominant strategy is easy. This is not the case when two CPF's intersect one or more times. In such cases, higher stochastic dominance analysis is required to interpret the results. In the current version of DSSAT, stochastic dominance analysis is restricted to the first order (Fig. 3).

Weather Data & DSSAT

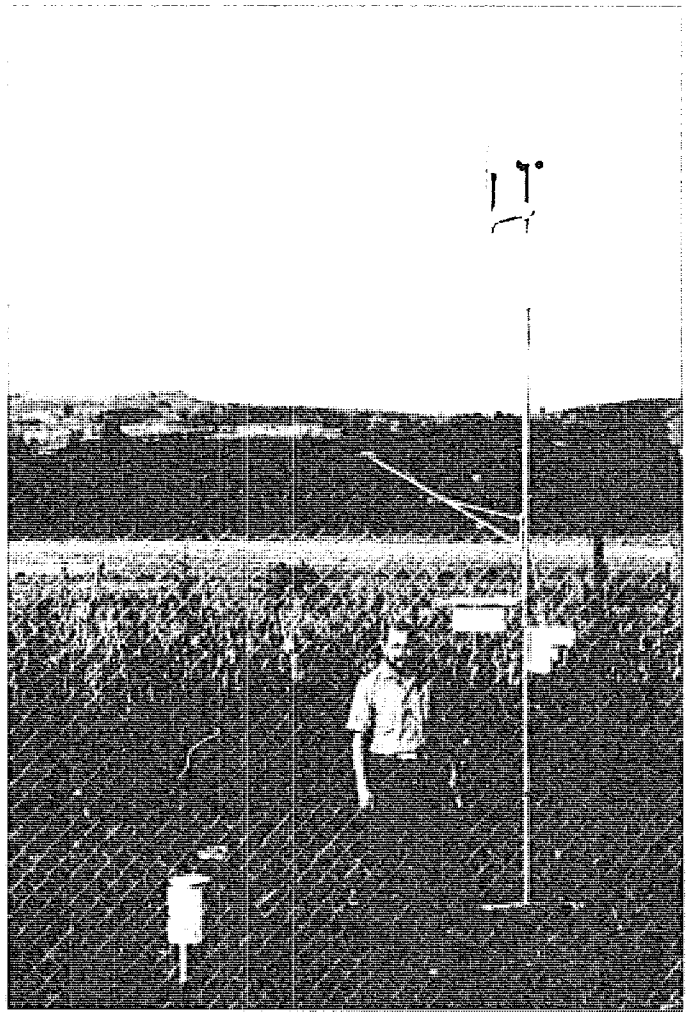
Although the MDS is designed to contain the minimum number of variables, it still contains data that are not normally or readily available. Solar radiation and daily weather data are examples. Three options are offered to the DSSAT user to circumvent weather data problems. If daily data are available, the models may be driven by the data. If, on the other hand, the daily record is not of sufficient historical length, a weather estimator developed by Richardson and Wright (1984) called WGEN is used to generate coefficients from the available data, which in turn is used to generate statistically similar daily data for longer periods.

Another weather estimator developed by Keller (1982, 1987) called WMAKER uses monthly means and standard deviations of potential evapotranspiration, average temperature, precipitation, and wet days to compute coefficients for generating long-term daily weather data. Another, even less data demanding weather estimator (Geng et al. 1986; Geng and Auburn 1987) is being considered as a third option. The aim is to offer the user alternative ways to generate weather MDS for regions where data are sparse.

The Future of DSSAT

When the IBSNAT Project ends in 1992, only 12 crop models will have been standardized to DSSAT specifications. To make a difference in the developing countries, more crops will need to be added to the list. In addition, many more modules to deal with insects, pathogens, and weeds; and soil constraints, such as salinity, sodicity, soil acidity, aluminum toxicity, and micro- and macro-element deficiencies, will need to be developed for use with the crop models. The long-term aim is to enable users to access a library of decision aids to diagnose and deal with site-specific problems. While such a library cannot be developed by a single project or even by entire institutions, it can be developed by international cooperation. International cooperation and interdisciplinary research can occur provided a framework for accommodating efforts from diverse disciplines and nationalities exists.

DSSAT's future rests on its capacity to serve as an instrument for integrating the efforts of many.



Continuous recording of the minimum weather data set is required for model validation.

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Decision Aids

THE CROP MODELS

CERES Models

The CERES (Crop-Environment Resource Synthesis) family of crop models is used in DSSAT to predict the performance of several grain crops. The two most tested models include maize and wheat (Figs. 4 & 5). Fully developed but less tested models include rice, sorghum, barley and pearl millet. These models, designed to use the IBSNAT minimum data set (MDS), are daily incrementing and require daily weather data consisting of maximum and minimum temperature, solar radiation, and rainfall. They calculate crop phasic and morphological development using temperature, daylength, genetic characteristics, and vernalization where appropriate. Leaf expansion, growth, and plant population provide information for determining the amount of light intercepted, which is assumed to be proportional to biomass production. The biomass is partitioned into various growing organs in the plant using a priority system. A water and nitrogen balance submodel provides feedback that influences the development of growth processes.

Over the course of Phase II, IBSNAT collaborators in several countries have helped with model development, testing, and improvement. Their contributions are outlined in the following pages.

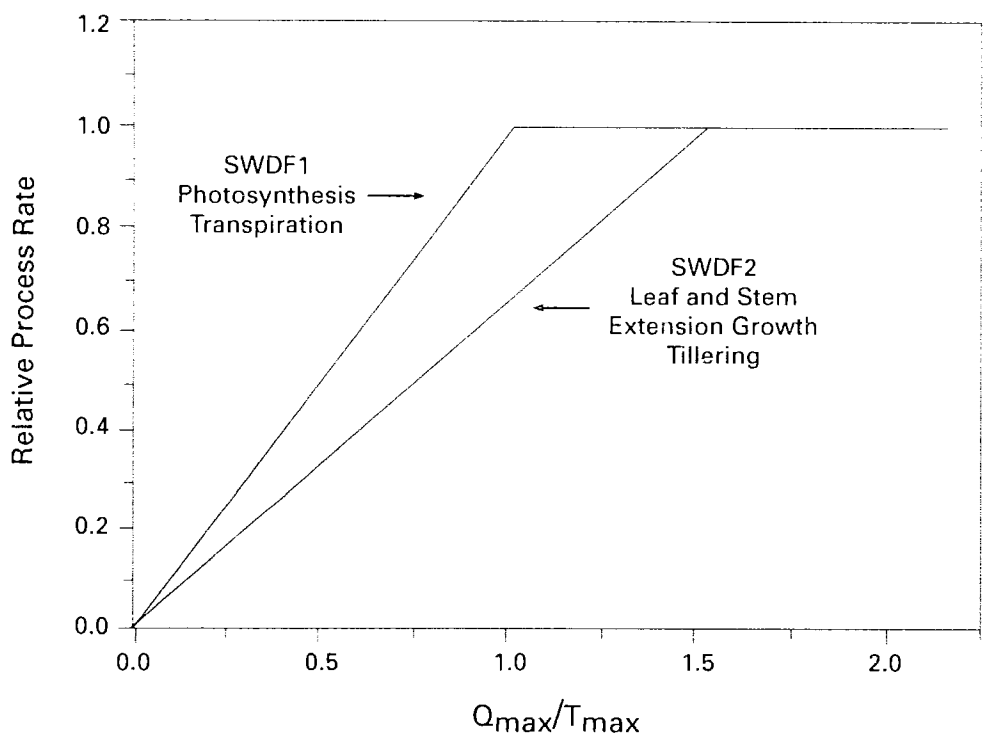

Figure 4.
The impact of plant water stress in the CERES-maize model, is calculated from the ratio of the maximum possible water uptake from the root system (Qmax) and minimum transpiration rate (Tmax). The processess of extension growth (SWDF2) are more sensitive to stress than photosynthesis transpiration (SWDF1).

CERES-RICE MODEL

The CERES-rice model, which should be ready for installation in DSSAT next year, simulates the development, growth, and yield of rice under upland as well as lowland conditions. The model also simulates the effects of cultivar, planting density, weather, soil-water balance, and nitrogen dynamics on crop growth.

The CERES-rice model has been tested using MDS collected from experiments in Thailand, the Philip-

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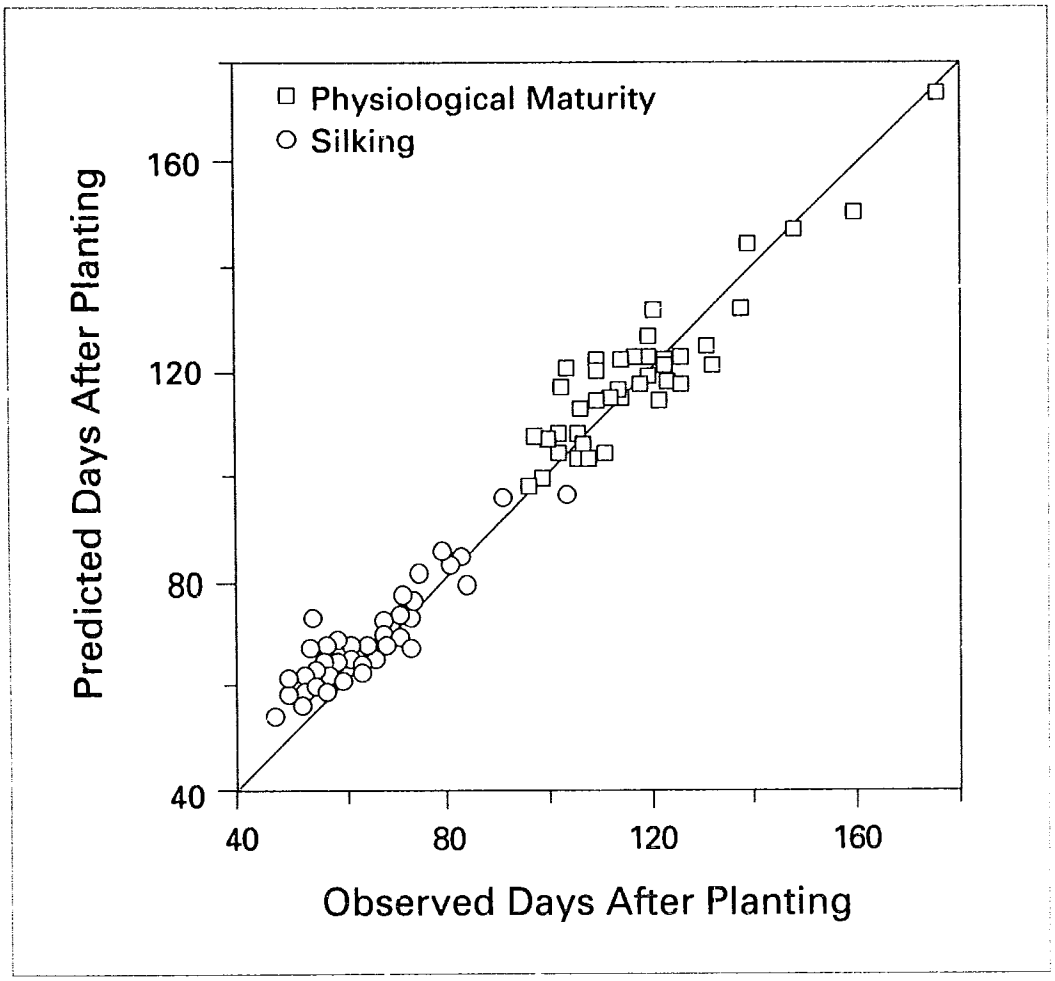


Figure 5
Testing CERES-maize in the tropics for predicting phenology.

pines, and the United States (Hawaii). These experiments were conducted under upland direct-seeded rice and flooded transplanted rice conditions.

The observed and simulated number of days to anthesis and physiological maturity based on the model are presented in Figure 6. The model adequately simulated the growth stage durations as influenced by cultivar, planting date (day-length, temperature), location (temperature, latitude-daylength) and delay due to trans-planting.

Cumulative probability density functions for simulated grain yield response to fertilizer strategies using CERES-rice, are shown in Figure 7.

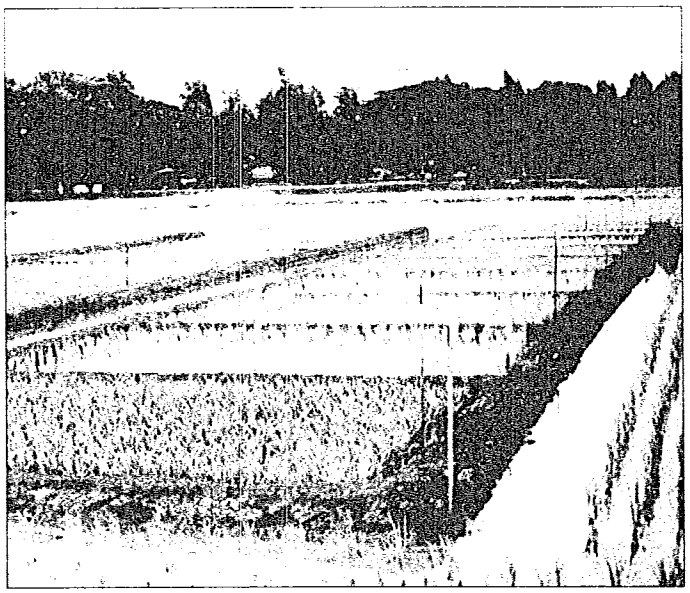
CERES-SORGHUM

The sorghum model was modified to enable it to differentiate short-semi dwarf from tall, traditional varieties. The nitrogen stress and tissue concentration modules were also modified. Since then the model has been validated with sorghum data from Australia, and IFDC/ICRISAT experiments.

Retrieval programs for CERES-sorghum have been developed between IFDC and the University of Hawaii, and the model is scheduled for installation into DSSAT by mid-1990, at which time IFDC will issue a User's Guide.

CERES-MILLET

Additional calibration and testing are necessary before CERES-millet can be released for validation. Difficulty in obtaining adequate data sets for calibration has impeded progress. In 1989, G. Ramakrishna Rao of CRIDA, Andra Pradesh, India visited Michigan State during his study leave, to test CERES-millet. CERES-millet will likely be available for installation in DSSAT by early 1991. Calibration and validation exercises will be conducted by both IFDC and Michigan State, using data sets from ICRISAT.



The CERES-rice model is capable of simulating crop growth and development of rice cultivars grown under both lowland & upland conditions. Pictured here are paddy fields in Phimai, Thailand.

CERES-BARLEY
This model was developed through the collaborative efforts of Michigan State and ICARDA (through separate U.S. AID funding) and IBSNAT. At present, validation of the CERES-barley is continuing at Michigan State University. Programming structure of input files and outputs are similar to the CERES versions of models installed in DSSAT.

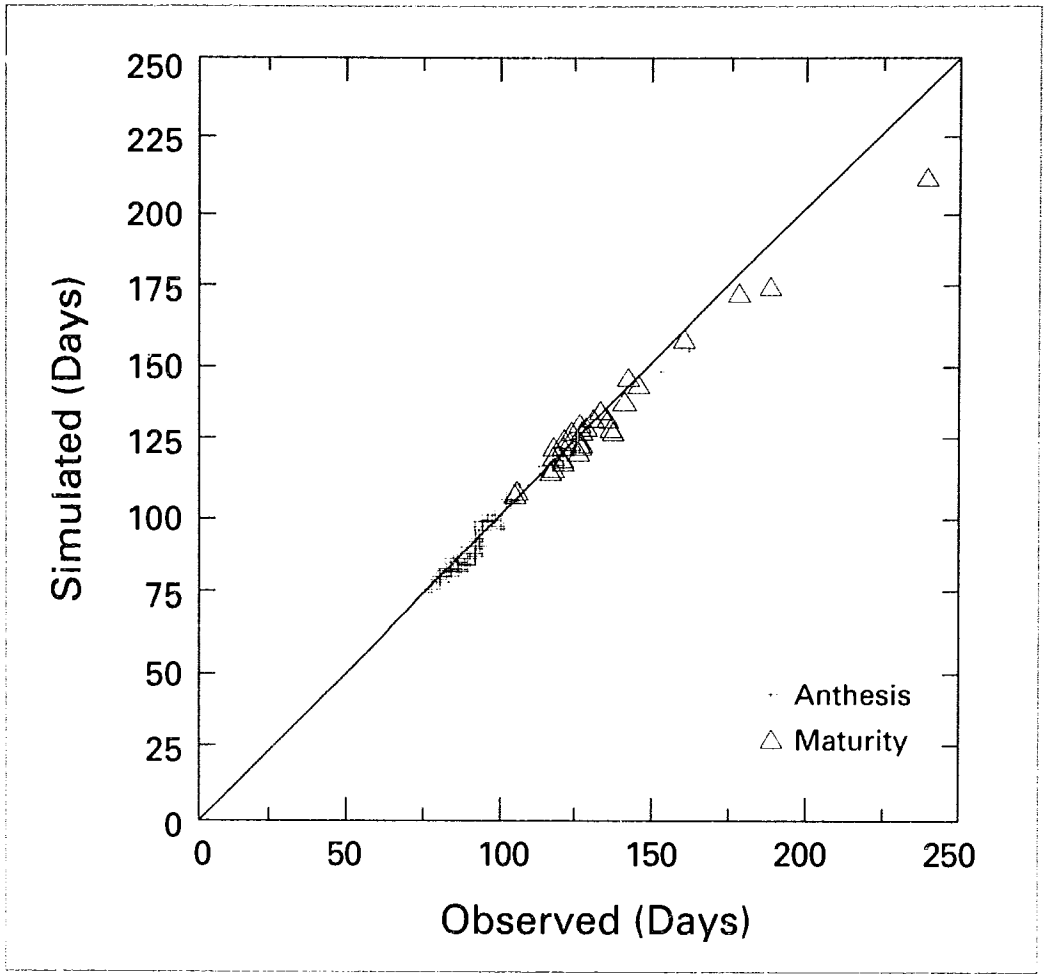
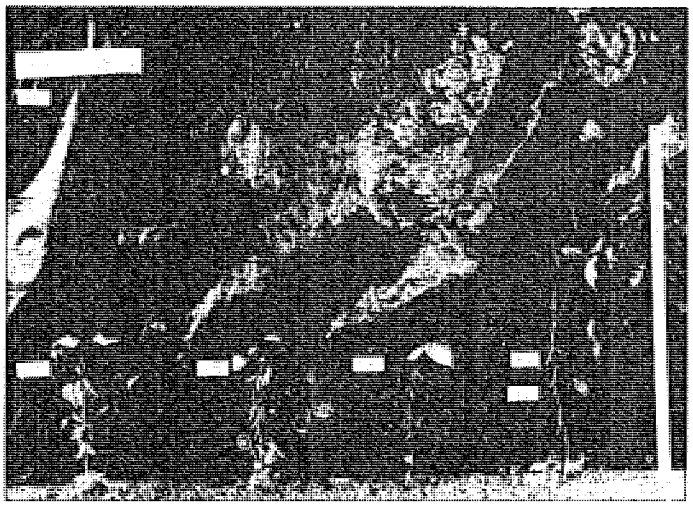


Figure 6
Comparison of observed and simulated days to anthesis and maturity, CERES-rice model.

Grain Legumes: Soybean, Peanut, and Dry Bean
The GRO models are process-oriented computer models which simulate vegetative and reproductive growth and yield for three grain legume crops: soybean (SOYGRO), peanut (PNUTGRO), and dry bean (BEANGRO), all of which are included in DSSAT. These models simulate the timing of phenological events, dry matter production and yield, under different soil, weather, and management conditions. Crop-specific data files provide coefficients to represent characteristics of each crop, and cultivar specific data files provide coefficients for simulating the responses of different cultivars to the environment. These cultivar-specific coefficients quantify the photoperiod and temperature responsiveness of the cultivar as well as vegetative and reproductive growth characteristics. Growth in each model is based on carbon, water, and nitrogen balances in the plant. A one dimensional soil-water model simulates water availability to the plants. The models require daily weather data, soil-water retention and root development characteristics, and management information.



Phenological events are routinely monitored on a daily basis at IBSNAT's Haleakala Research Station.

Some of the applications of the GRO models are:

- Irrigation Management
- Pest Management
- Variety Screening
- Climate Change Impact Studies
- Yield Forecasting

During the past two years, modifications to SOYGRO V.5.42 and PNUTGRO V.1.02 were

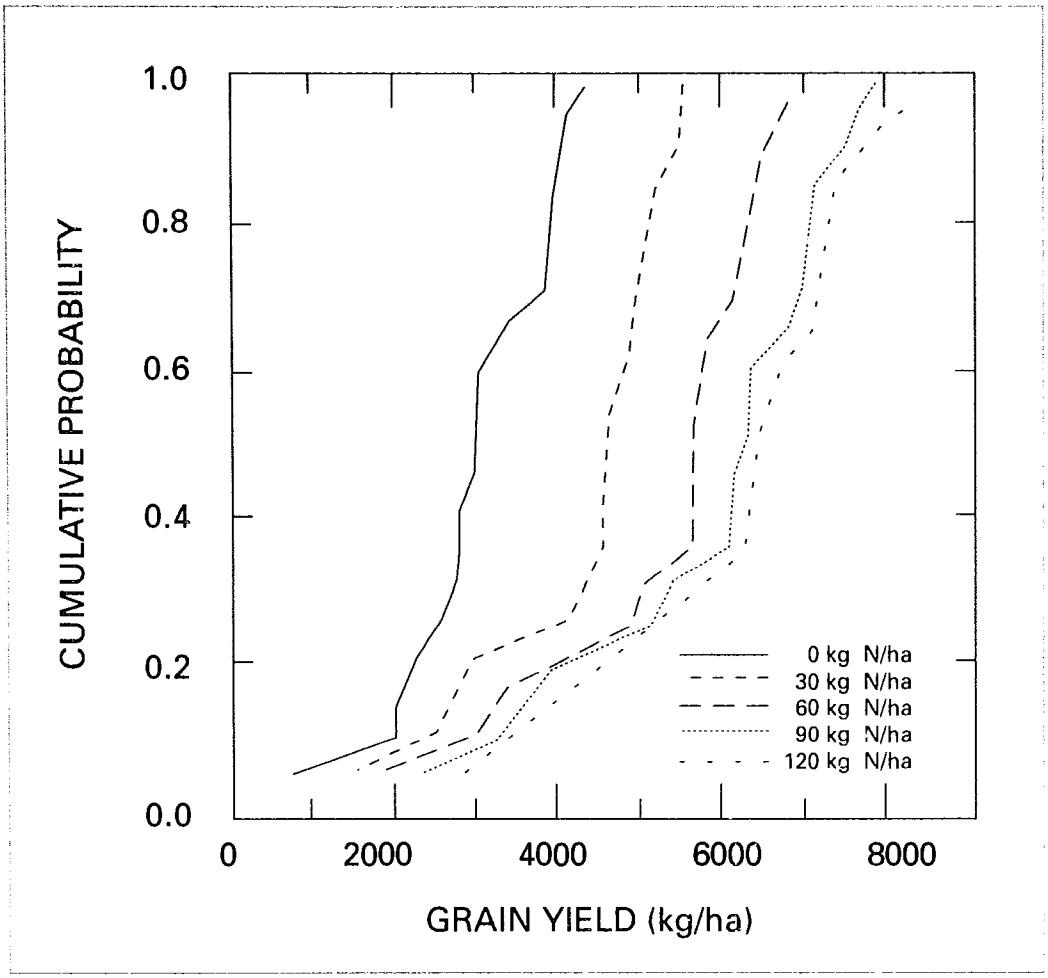


Figure 7
Cumulative probability density function for simulated grain yield response to five fertilizer strategies at Chiang Mai, Thailand.

made to incorporate hedgerow photosynthesis routine. The purpose of this change is to improve simulation of row spacing and plant population, but these changes have not been incorporated in the versions of the GRO models currently installed in DSSAT V.2.1. Additional testing of the changes within the DSSAT framework is necessary before this occurs.

SUBSTOR: Root Crops

The SUBSTOR potato and root crop model is being developed as part of an irrigated cropping system modeling project for eastern Washington. It is to be integrated with available models for other components of cropping systems such as tillage methods, soil-water infiltration and runoff, organic carbon-nitrogen dynamics, mineral nitrogen transformations, water and fertilize scheduling, pesticide decomposition and movement, pest development, and canopy microclimate. At its present stage of development, the model accommodates for the following plant growth and soil processes: net photosynthesis, leaf area expansion, root distribution, light interception, stages of tuber development, effects of nitrogen and water stress on development, tops/root/tuber, dry matter partitioning, water movement (infiltration, runoff, drainage), evapotranspiration, nitrogen transformations and movement, plant uptake of nitrogen, soil temperature, and release of mineral nitrogen though the breakdown of crop residue and organic matter. A large part of the model is composed of the standard user interface and soil process subroutines identical to those in the other IBSNAT models. SUBSTOR uses the standard IBSNAT input and output files.

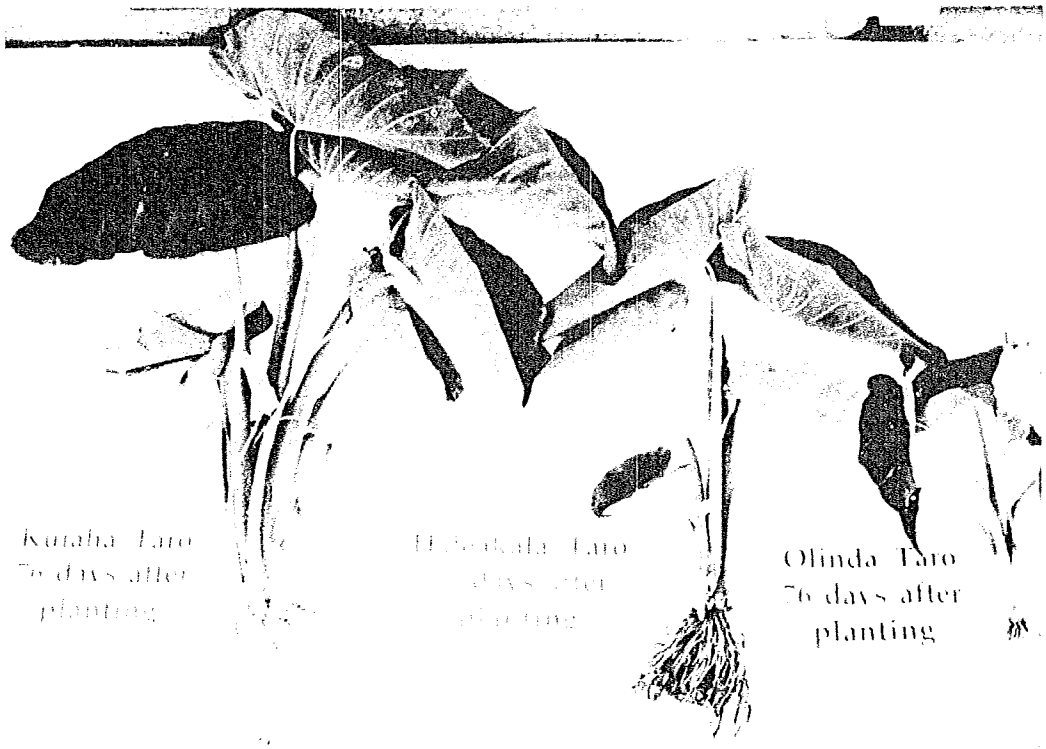
CASSAVA

The original cassava model was developed by Shu Fukai and associates at the University of Queensland, and modified with the assistance of IBSNAT scientists at Michigan State University, to

Taro (Colocasia esculenta), is a commonly grown aroid in the Pacific, the Caribbean, and southeast Asia.

include modules for water balance and nitrogen dynamics. Interest in continuing development of the model has been received from the International Institute of Tropical Agriculture (IITA).

Progress in the calibration of the cassava model has been constrained by the lack of adequate data sets. Data sets for model calibration were collected at three locations in Hawaii. Additionally, scientists with the Department of Agriculture in Thailand are monitoring the performance of several cassava cultivars at their Field Crops Research Center in the southeastern part of the country (Rayong) for the Centro Internacional de Agricultural Tropical (CIAT) regional trials.



IBSNAT crop models must be versatile and accurate in order to predict the performance of a cultivar planted on the same day at three locations of differing elevations and mean air temperatures. Here, taro grown at three different elevations at Kuiaha, Haleakala, and Olinda Stations on the island of Maui.

AROID

Development of an aroid model has focused on a cultivar commonly grown in the Pacific, Caribbean, and southeast Asia, known as taro (*Colocasia esculenta*). Subroutines for crop development (phasic stages) have been coded, and available data sets are being reviewed and compiled for use in developing the modular growth components.

Data sets for model calibration and validation are being generated by researchers with the USDA/ARS in Puerto Rico, the University of the South Pacific, Fiji, and the University of Hawaii. Calibration and testing of the model have been carried out in collaboration with U. Singh at IFDC. The USDA/ARS effort in Puerto Rico is a major one and should substantially accelerate model development.

Nutrient Subroutines in IBSNAT Crop Models

Nitrogen Dynamics: CERES Models

The nitrogen submodel of the CERES crop models, developed by D.C. Godwin and U. Singh at the International Fertilizer Development Center (IFDC), is designed to interact with the CERES water balance and plant growth routines. The submodel, which is currently functional within the CERES wheat, maize, barley, sorghum, and millet models as well as SUBSTOR, simulates the processes of organic matter turnover with the associated mineralization and/or immobilization of N nitrification, denitrification, and hydrolysis of urea. Fluxes of nitrate and urea associated with water movement are also simulated. Nitrogen uptake is simulated as a process that is sensitive to soil nitrogen concentrations, root length density, soil-water availability, and plant nitrogen demand. In addition to these processes, the nitrogen submodel of the CERES-rice model simulates transformations in the floodwater and paddy soil which affect the supply of nitrogen to the plant. The model simulates the effects of nitrogen deficiency on photosynthesis, leaf area development, tillering, senescence, and remobilization of nitrogen during grain filling.

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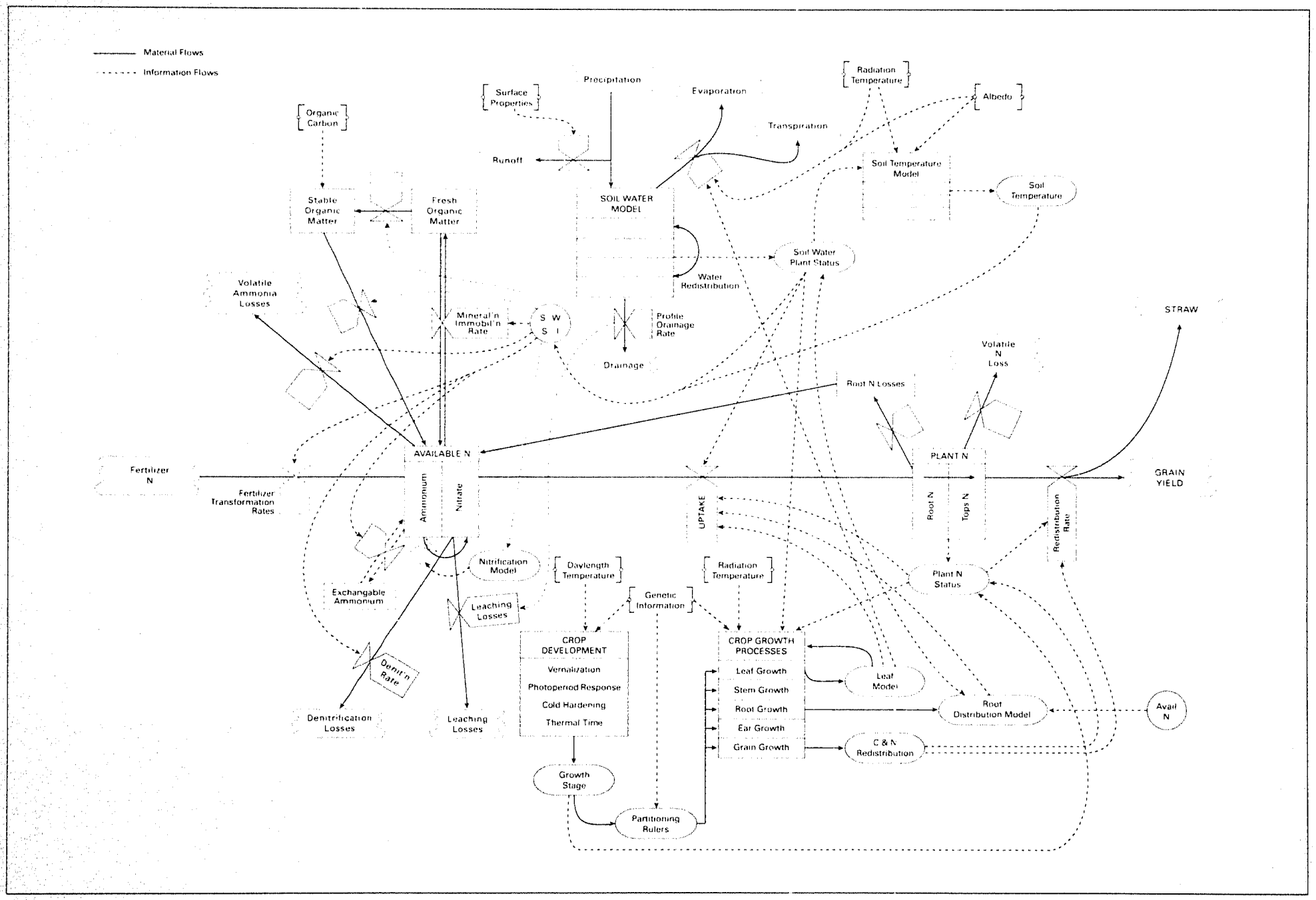


Figure 8
Systems diagram of upland nitrogen model.

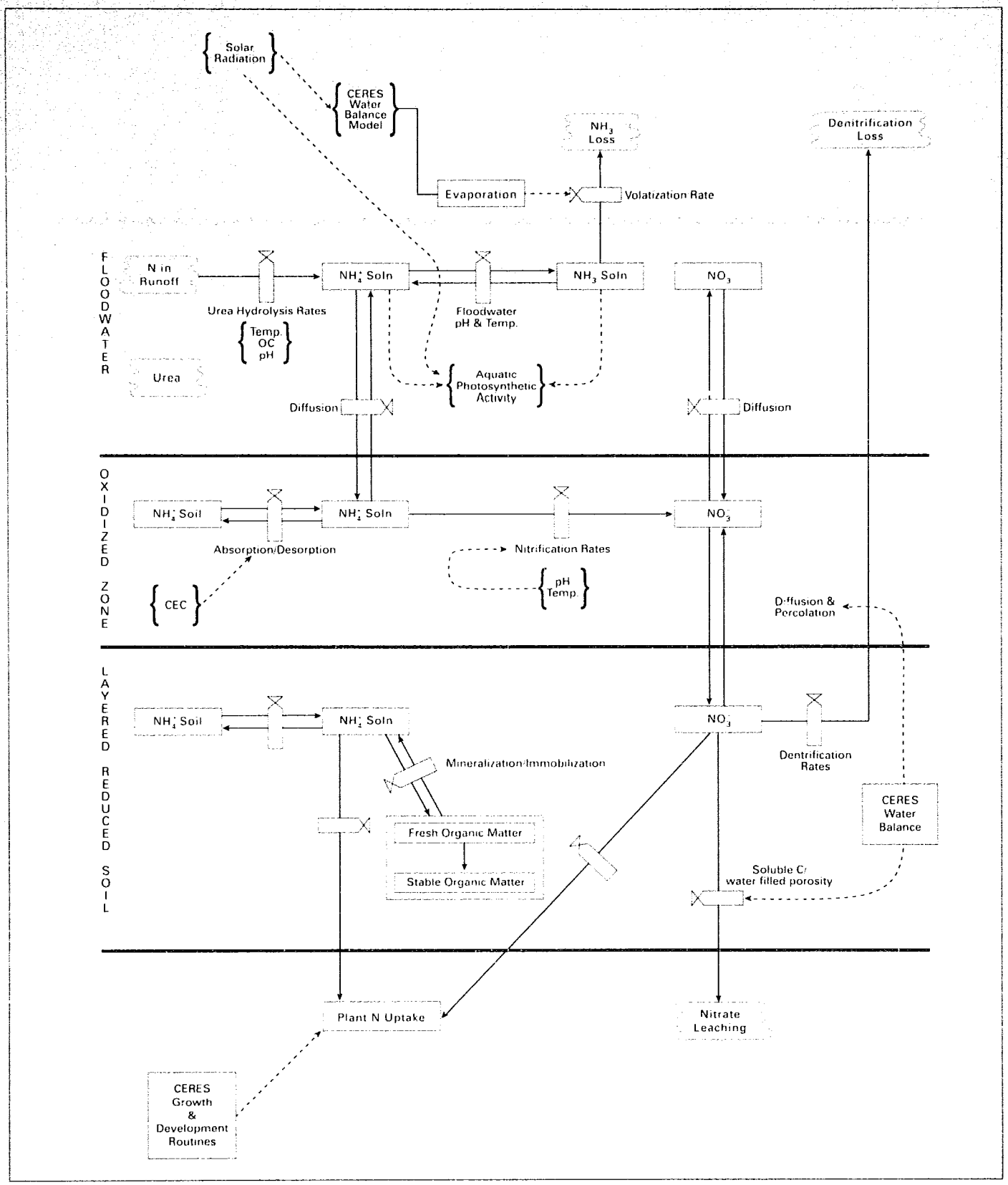


Figure 9
Systems diagram of lowland nitrogen model.

In the CERES-rice model, two processes are described: a) upland, and b) lowland. The upland model simulates the processes of mineralization, immobilization, urea hydrolysis, movement of urea and nitrate with drainage and evaporation, nitrification, and denitrification, uptake of nitrogen by the plant, and the expression of the effects of plant nitrogen deficiency on leaf expansion, senescence, tillering, and photosynthesis. Remobilization of nitrogen within the plant during grain filling is also simulated. (See Figure 8.)

The lowland rice model is designed to operate

under permanent flooding, fully upland, or intermittent flooding conditions. It simulates the processes described above with allowances for flooded conditions and also simulates the following processes associated with the presence of floodwater: runoff over the bund, diffusive fluxes of NH_4^+, NO_3^-, and urea between soil and floodwater, floodwater biological activity, floodwater pH, and ammonia volatilization (Fig. 9).

TESTING

The simulation of crop response to nitrogen has been extensively tested. Summary testing of CERES-wheat against 233 observed data indicates that it performs reliably. Some testing of nitrogen balance has also been performed, and more detailed testing of the nitrogen transformations is continuing. Testing of the rice model is in the early stages, and the preliminary results are encouraging.

Nitrogen Dynamics: GRO Models

In previous versions of the crop simulation models developed for soybean, peanut, and dry bean (SOYGRO, PNUTGRO, and BEANGRO), it was assumed that nitrogen was nonlimiting. Since nitrogen is often a limiting nutrient even in grain legumes, new subroutines have been developed by J.W. Jones, K.J. Boote from the University of Florida, and G. Hoogenboom from the University of Georgia, to simulate nitrogen uptake, fixation, and remobilization. A priority scheme dependent on the nitrogen fixation capabilities of each species, determines the balance between nitrogen uptake and remobilization. A fraction of the available photosynthates on a given day, based on the nitrogen demand and developmental stage, is allocated to the roots and the nodules to allow for a nitrogen fixation, nodule growth, and nodule initiation. The subroutine also accounts for the depressing effect of high fertilizer nitrogen on biological nitrogen fixation.

Phosphorus Dynamics

A phosphorus submodel of the IBSNAT models is under development at IFDC under the leadership of U. Singh and D.C. Godwin. This submodel will be closely coupled to the water balance, nitrogen balance, and plant growth routines. The submodel will simulate absorption and desorption of soil phosphorus, organic phosphorus turnover, and the dissolution of rock and fertilizer phosphate. The model also simulates phosphorus uptake and the effects of phosphorus deficiency on photosynthesis, leaf expansion, tillering, senescence, assimilate partitioning, and plant development. Phosphorus uptake is simulated as a process that is sensitive to soil phosphorus concentrations, root length density, soil-water availability, nitrogen availability, and plant phosphorus demand. The phosphorus submodel is sensitive to broadcast versus banded application of fertilizer. For inputs, the model requires commonly available soil parameters to generate estimates of organic phosphorus, labile phosphorus and solution phosphorus pools, and phosphorus buffering capacity.

The phosphorus uptake process is simulated as a function of root length density, soil-water status, shoot and root biomass, nitrogen and phosphorus

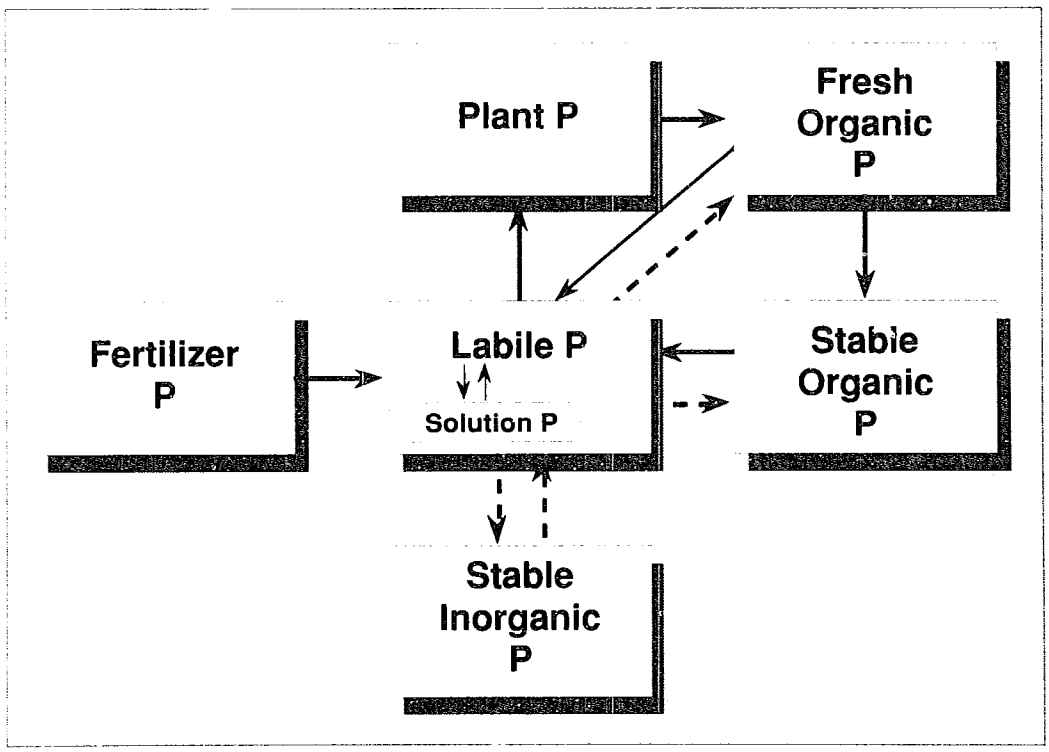


Figure 10
Phosphorus pools and their relationships in the CERES models.

concentrations, and soil mineral nitrogen and soil solution phosphorus concentrations. The daily phosphorus demand is the sum of demands due to new growth and deficiency in the tissue. The new growth demand is the amount of phosphorus required for growth of new tissue. The deficiency demand on the other hand is the amount of phosphorus required to raise the actual phosphorus concentration to a critical phosphorus concentration (Fig. 10).

The daily phosphorus demand is reduced if the actual N:P ratio for that day is greater than the upperbound N:P value, for example, the effect of nitrogen deficiency on phosphorus uptake. Likewise the nitrogen demand in the nitrogen submodel is reduced if the N:P ratio falls below the lowerbound value. The N:P ratio must lie within the bounds shown in Figure 11.

The phosphorus supply for each layer is calculated using soil solution phosphorus concentration, maximum uptake per unit root length, root length density, and soil moisture index. The actual phosphorus demand is further reduced if it exceeds the amount of phosphorus supply for that day.

Testing of the model with field data from around the world is a high priority. Phosphorus model validation experiments are currently in progress in Kenya, the Philippines, India, Hawaii, Malawi, Syria, and Indonesia.

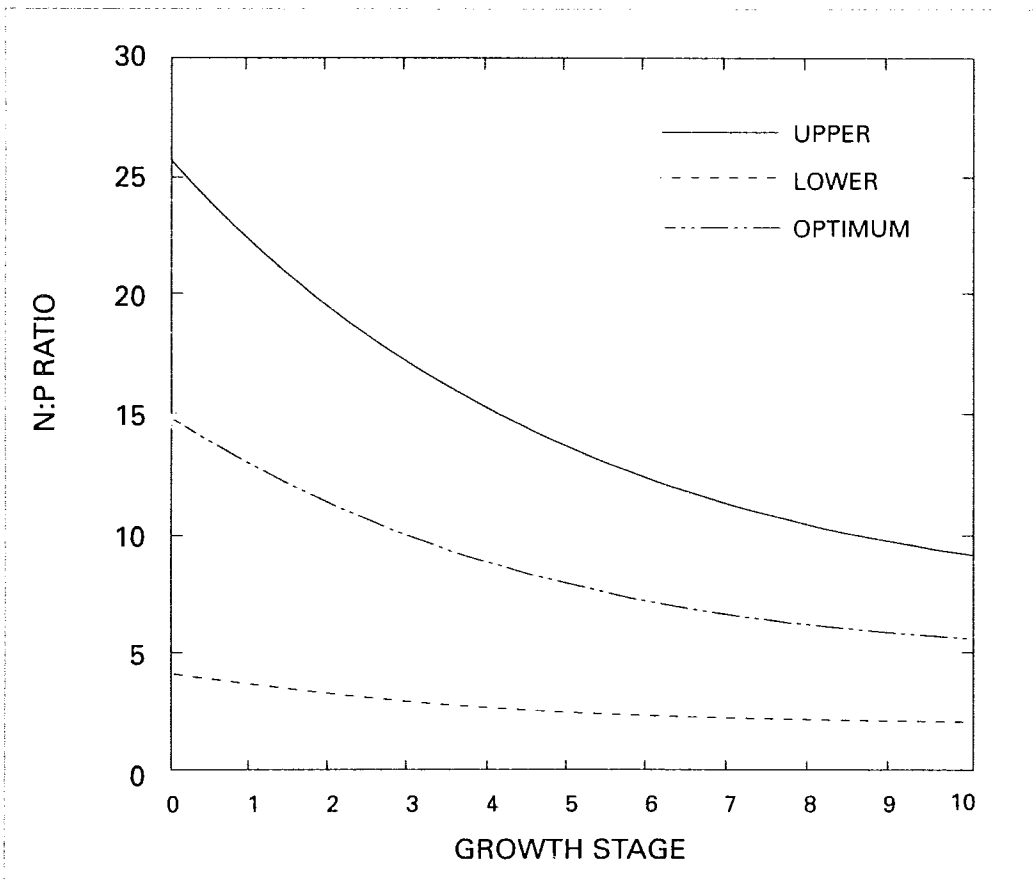


Figure 11
N:P ratio in maize as related to growth stage.

Pest-Crop Coupling

At this time, the Decision Support System for Agrotechnology Transfer (DSSAT V.2.1) system consists of:

1) crop models;
2) soil and weather data;
3) collaborators' experimental data; and
4) application programs to enter and retrieve data, link the models with site and experimental data files, and analyze the observed and simulated data for specific objectives.

Work is now proceeding to develop and link pest components to DSSAT.

Pest Linkages

Most crop and pest models require the same weather data. The critical need is to define linkage points between the two models. A linkage point is a known, quantifiable effect that a pest has on a crop. Pests can be classified according to their potential effects on a crop (i.e., the type of linkage points).

The coupling of a pest model to a crop model starts with identifying which of the linkage points best describes the particular pest-crop combination. With some pests, it may be possible to explain most of the effect in terms of just one coupling point, as with defoliation by the Colorado potato beetle, in which case the effect of the pest population over time may be

modeled by incorporating a defoliation curve.

Successful linkages of pest models to the IBSNAT crop models require that the pest models be functional types requiring daily time steps. Pest models should be developed along similar levels of detail as the crop models so that the two will be nearly identical in the time required for the simulation. Many mechanistic models require too much information and computer time for IBSNAT purposes. Rational empiricisms have to be developed that simplify a mechanistic system to make the models functional.

The aim is to incorporate a few prototype pest models into a new version of DSSAT. These prototypes will serve as examples of the detail level needed for other pest models.

Genetic Coefficients for the IBSNAT Crop Models

Crop cultivars differ one from another in a whole array of morphological and other characteristics. Some of these characteristics have been documented by cultivar testing authorities, and summarized in lists for distribution to both the scientific and farming communities. Other cultivar characteristics have been documented and summarized by computer modelers, who have used the list so produced as inputs to dynamic simulation models. In this context, the characteristics for one cultivar have been termed the "Genetic Coefficients" for that cultivar. They can be defined as:

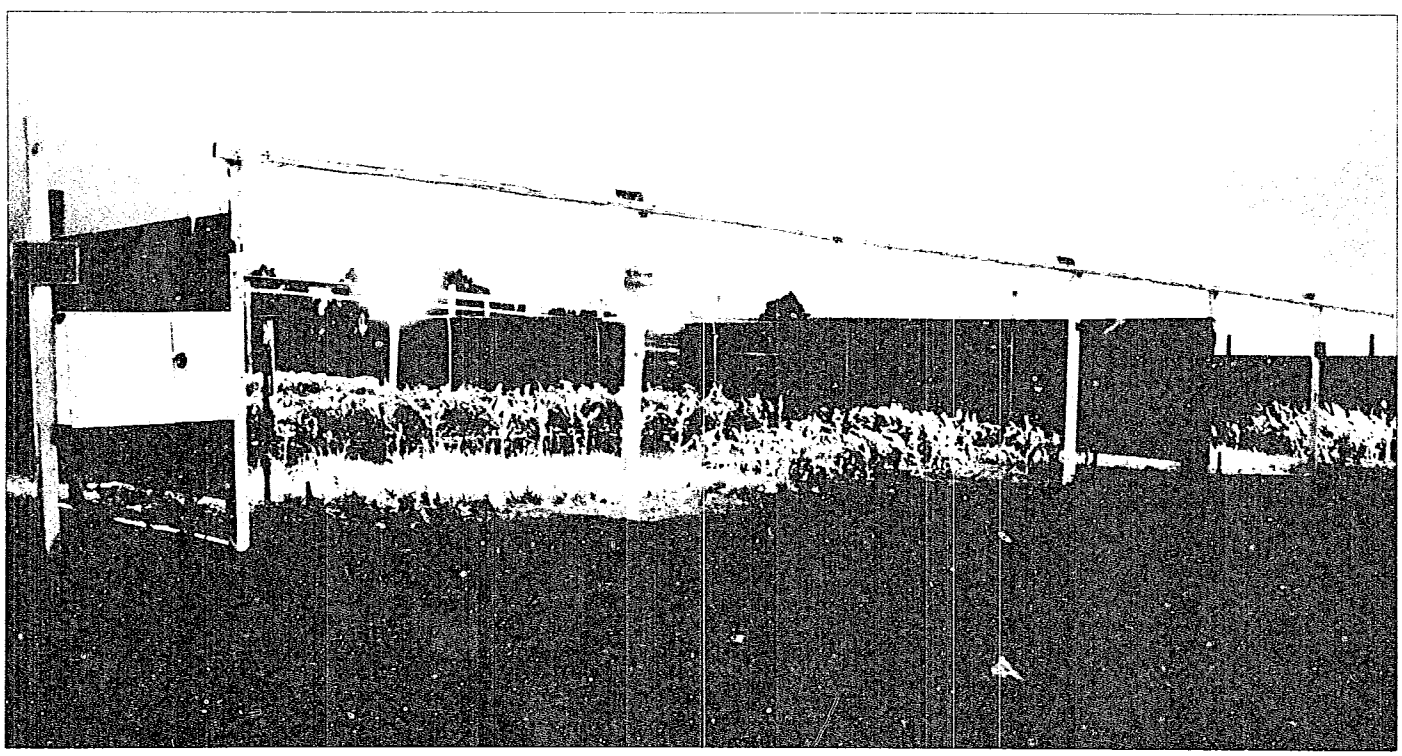
> Coefficients that summarize the way in which a specific crop cultivar divides up its life cycle, responds to different aspects of its environment (e.g., day length, temperature, moisture stress, disease organism), or appears/changes morphologically.

The number of potential genetic coefficients is very large. However, the general aspects of adaptation to any given environment are determined by a few responses, and it is these that have been taken into account in the current IBSNAT models.

For maize there are five coefficients. Three relate to development and the progression through the life cycle, while two relate to growth aspects. The development coefficients summarize either,

a) the minimum duration of some of the phases that a maize plant passes through during its life cycle or,
b) the modifications to these durations brought about by photoperiod.

Not all phases of development, which are



Black saran cloth separates treatment modules with artificially created photoperiods of 14, 17, and 20 hours. Other treatments use only natural day lengths, which range from 10 hours to a maximum of 12 hours.

delimited by specific developmental stages, have genetic coefficients, some being assumed constant across all genotypes. The phases that are considered relate to:

a) the juvenile phase,
b) the tassel initiation phase, and
c) the linear grain filling phase.

The duration of the tassel initiation phase is presumed to be affected by photoperiod to a degree that is genotype dependent, with the response for each genotype being assumed linear with respect to photoperiod at values greater than 12.5 hours. The maize development coefficients are complemented by two growth coefficients that relate to seed set and seed growth.

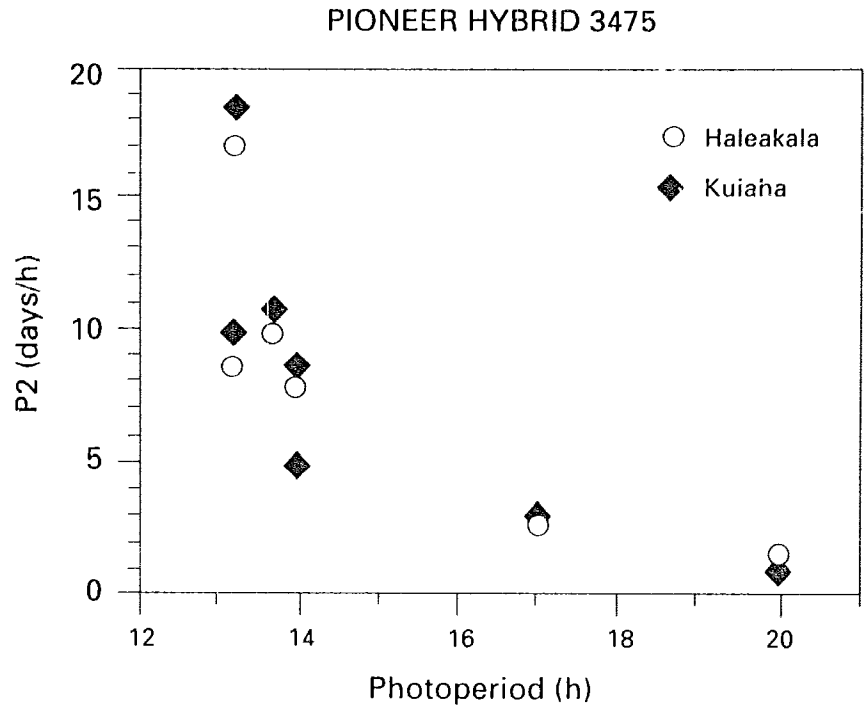


Figure 12
Photoperiod sensitivity coefficient (P2) determined for maize at various photoperiods.

The development coefficients for soybean are like those for maize. They can be broken into two categories: the minimum phase durations, and the phase length modifiers. Like maize, soybean durations are not expressed in terms of chronological time, but unlike maize, "biological days" rather than "degree days" are used. The phase duration coefficients in the soybean model are complemented by two phase length modifiers; one deals with the response to photoperiod, while the other deals with the threshold photoperiod for response to be observed. Also, as for maize, the development coefficients are complemented by a number of growth coefficients, with both vegetative and reproductive growth being considered.

Wheat is simpler than soybean, with the array of coefficients being somewhat similar to those for maize. Unlike maize and soybean, however, the coefficients are not presented as such, but are reduced to scale values running from zero for those genotypes showing minimum expression of the trait in question, to some upper value for those genotypes showing maximum expression.

Genetic coefficients can be determined in a controlled-environment setting indoors or outdoors. Work to establish parameters to determine genetic coefficients outdoors has been undertaken at two sites on Maui: Haleakala, and Kuiaha, and with two species: maize and soybean. The results (Fig. 12) for maize indicate that it may not be appropriate to determine the photoperiod sensitivity coefficient (P2) where the natural daylength is short. Work to determine the sensitivity with which coefficients can be determined in the field with different species is continuing.

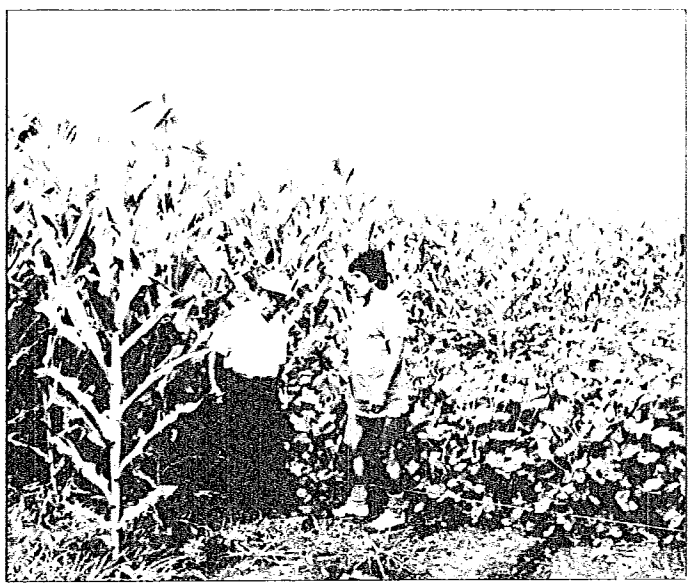
The use of special facilities may not be appropriate for some crops, and situations, however, and a third approach in which coefficients are estimated from field data sets in which dates of phenological events and yield components such as grain number and weight have been measured, may be the one that will become most widely applied. Work to develop software for this application has been undertaken, and a coefficient generator that can operate in a "stand alone" situation has been developed. Installation of the generator into DSSAT has been initiated.

The genetic coefficients used in the IBSNAT crop models are thus constants that characterize certain aspects of a cultivar's performance. Coefficients determined in one region should be similar to those determined in other, possibly contrasting, regions. Until this is proven, however, the models should not be used in regions different to those in

which the coefficients were determined. Further, the array of genetic coefficients currently used does not encompass all aspects that may be of significance in determining the performance of a specified cultivar in a given region. Factors that relate to physical stresses, diseases and perhaps also insects, will have to be taken into account before model outputs can be used directly for decision making at the farm level in some areas. Work to incorporate in the available models coefficients for some diseases and pests has also been initiated.

Intercropping

Robert Caldwell of the Department of Agronomy and Soil Science at the University of Hawaii, is developing an intercropping model called CropSys. CropSys is a simulation model capable of analyzing a variety of maize/soybean cropping systems, including mixed, row, and strip intercrops. The model is based on SOYGRO V.5.41 and CERES-maize V.2.0. New routines were added to these IBSNAT models to combine them and allow them to simulate competition for light and soil moisture. CropSys can be used to evaluate intercrops by simulating Land Equivalent Ratios and replacement series. DSSAT users can perform stochastic strategy analysis of not only the intercrops but sequences of crops. Output files conform to IBSNAT formats and can be graphed with DSSAT.



An intercrop of maize and soybean is used to validate outputs from CROPSYS, an intercropping model which utilizes CERES-maize and SOYGRO.

Whole-Farm Systems

The translation of agronomic research findings into technology packages which can be widely adopted by farmers constitutes major problems in the development of agriculture in many countries. There are many factors that contribute to the difficulty in the identification and the delay in the adoption of technology, but most are related to an incomplete appreciation of the biological, economic, social, and cultural constraints that impinge on small-farm production systems in many parts of the world. One way of attempting to deal with these factors is through the use of whole-farm modeling. This logical extension of IBSNAT Project activities is being developed by J.B. Dent and P.K. Thornton at the Edinburgh School of Agriculture.

The principal advantage of farm system modeling as a methodology is that a specific technology can be assessed ex ante in a whole-farm context. For example, interactions between the various farm activities during the course of the whole year are included in the assessment process. A full appreciation of the resource demands of the farm is necessary, and limitations of these as well as managerial and social implications will influence the impact of new agrotechnology on farmers and their families.

Field experimentation, either in outlying research stations or in farmers' fields, is the normal basis for determining suitable crop technologies within most research frameworks. The results of these experiments are heavily dependent on the season's climate sequence, the specific soil type, and numerous management factors such as, pest control, plant population at establishment, and the timing of cultivation. The critical issue is whether the results from such crop experiments have much relation to the way technology packages based on them will operate in the fields of resource-poor farmers in a different place, year, and soil type, where farming operations are constrained by socio-economic factors neither experienced, nor perceived at the research station. Some of the activities being carried out under the IBSNAT umbrella are concerned with the development of techniques that could potentially address this problem. (See Figure 13.)

Crop Models

A suitable model can simulate crop growth, development and final yield in any fully specified

environment. When confidence is established that a crop model can produce similar results to those obtained from field trials, a completely new model philosophy can be established. Field trials can be set up specifically to validate the models in a particular location, and these can then act as the medium for the generation of extension data, using for example, simulated weather data. Repeats of an experiment over many simulated climate years could then be carried out on the computer, to produce an outcome distribution for yield (or other output of interest) related to a particular technology package.

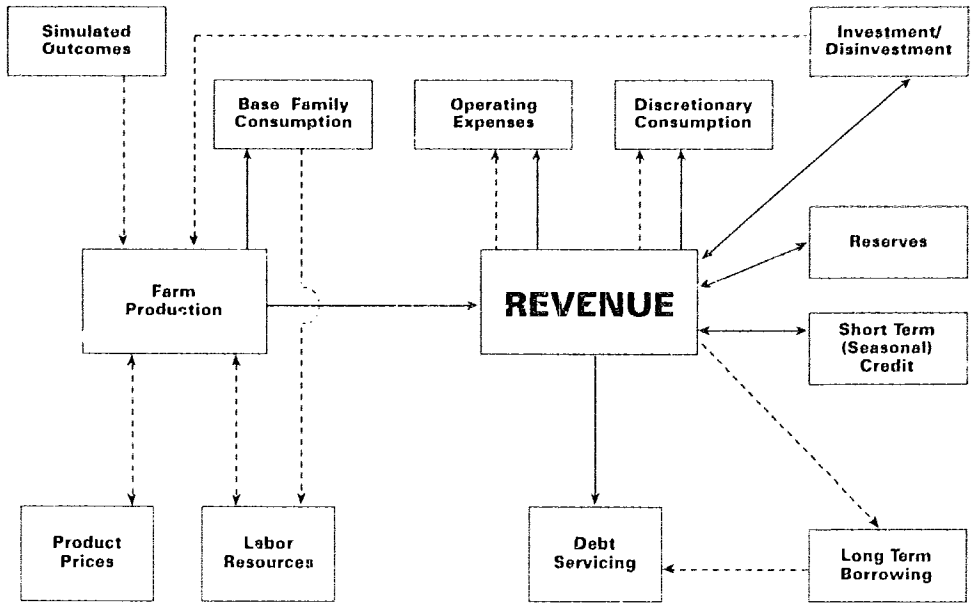


Figure 13
Conceptual whole-farm systems model.

Whole-Farm Level

Smallholders rarely operate only one farm enterprise. Changes in the management and/or performance of a single enterprise will have implications on other farm enterprises. Perhaps new technology has increased labor demands for maize production which, when seen in a whole-farm setting, puts a labor squeeze on the management of beans. To take such factors into account, the modeling concept must be taken a stage further. There is also an obvious need to have appropriate models for crop and livestock farm enterprises. This may increase the biological complexity involved, because of the interactions. Some reorganization of individual models will also be necessary to permit individual farm fields to be simulated in parallel so that allocation problems between crops for scarce resources can be studied and rotational alternatives explored.

This next stage involves integrating a number of crop simulation models that can then represent rotational and multiple cropping practices, with elements representing the most important socio-economic factors that constrain or impinge upon agricultural production and decision making. With such a structure it becomes possible to examine alternative technologies within the farmer's total household framework. If the farm model is set up for a representative farm household in a district, technology can be designed with a much clearer notion of the likely adoption and the overall impact it may achieve on production.

A number of approaches to socio-economic modeling have been pursued, based on a variety of optimizing and non-optomizing techniques, but it is essential that the whole farm framework take into account consumption behavior, attitudes to risk, borrowing and investment, and seasonal labor availability. A further layer to this framework consists of factors of two broadtypes: socio-economic constraints, and the most important of the host of nontechnical factors that impinge on farmers' decision making. For example, labor use might depend on such things as the division of labor between the sexes, and household attitudes and objectives, as well as the availability of labor for hire in the district, and the household's ability to hire it. One of the ways in which some of the more-difficult-to-quantify factors can be handled is through the use of rule-based algorithms, or the if-then constructs of procedural computer language and expert system programmers. Work is in progress to attempt to link the way individuals make decisions to their socio-economic circumstances.

Once this is accomplished, these structures

could be developed for socio-economic factors, and sets of rules can then be built either for incorporation in an Expert System framework, or subroutines written in standard computer language. Linked together with a bioeconomic farm model, such Expert Systems would be a first attempt to model farm decision making.

A farm model such as this could be used in two major ways:

1. To estimate the timing of the likely social, cultural and economic impact of a specific technology on farm households. By implication, such estimates will provide crop technologists with better guidance on research priorities.
2. To determine the agricultural and regional policies such as price support, credit provision and extension networking, required to establish a specific technology in a district.

Such constructs may then provide the linkage between biological models and the larger framework in which they are resident. The construction of farm models is underway, linked to case studies in Guatemala, Scotland, and Malawi.

Regional Level

One logical step further in the scope of crop modeling is to make a contribution at the regional level. One way in which decision support can be provided to policy makers involves the development of a spatial land-use data base for a region,

Agricultural sustainability and crop modeling

The challenge facing agriculture, particularly in the developing countries, is how to cope with the increasing demands of a population growing in size and aspirations, and how to meet these demands in an equitable way without compromising the long term stability and sustainability of the production system.

A sustainable system is defined as one that can generate high average yields or profits and still maintain low variance; that is, a system which combines high productivity with high stability. Technology may be defined as the application of science to produce desired outcomes, and technology transfer as the process of duplicating the outcomes elsewhere. Researchers have long known that increasing yield through improved technology is relatively easy. However, while productivity can be increased with existing technologies, technology adoption by farmers is constrained by how a new crop or cultivar, product or practice affects the agricultural system.

To say that a particular production strategy promotes sustainability is to say that we can assess with some degree of confidence outcomes in the future. However, few agricultural research projects are designed to predict future outcomes, and risk taking always accompanies change. The risks associated with the sustainability and stability of agriculture are related to the uncertainty of weather, the occurrence of pests, and the fluctuation of costs and prices. The decision making capacity of resource planners, extension agents, and farmers would be greatly enhanced if they had some means of quantifying risks associated with particular strategies. For example, in order to develop optimal fertilizer application strategies in any location, it would be desirable to have different fertilizer rate experiments conducted over many years. Unfortunately such long term experimental data are seldom available. For locations where long-term weather data exist or, alternatively, by using weather estimators, crop models can be used to simulate crop performance over several seasons to quantify variability and calculate risk over time.

The strategy evaluation program in DSSAT, coupled with data bases, crop simulation models, and weather estimators, examines the variability in output associated with selected strategies and identifies those strategies that maximize returns and minimize risk. DSSAT's strategy evaluation program has procedures for selecting strategies under conditions of uncertainty, while providing due recognition to farmers' attitudes toward risk.

based upon a Geographic Information System (GIS). A GIS can also contain data relating to soils, climate, existing farming systems, and the immediate socio-economic environment of villages and households, with linkages to whole-farm simulation models. Significant new research innovations have already been taken within the U.S. and in Europe with the objective of putting in place preliminary information systems.

A GIS could be set up so that crop models could be run for any location, by extracting the relevant soil and climatic characteristics. The system could then be used to identify a region for study, and for each locality, extract soil and climate information to extract local socio-economic information and then carry out a simulation involving a particular subsidized credit scheme together with a fertilizer application schedule, over many years of simulated weather. After this, one can aggregate the results, and assess biological and farm income stability, and household and village attitudes and objectives, to give an estimate of regional impact.

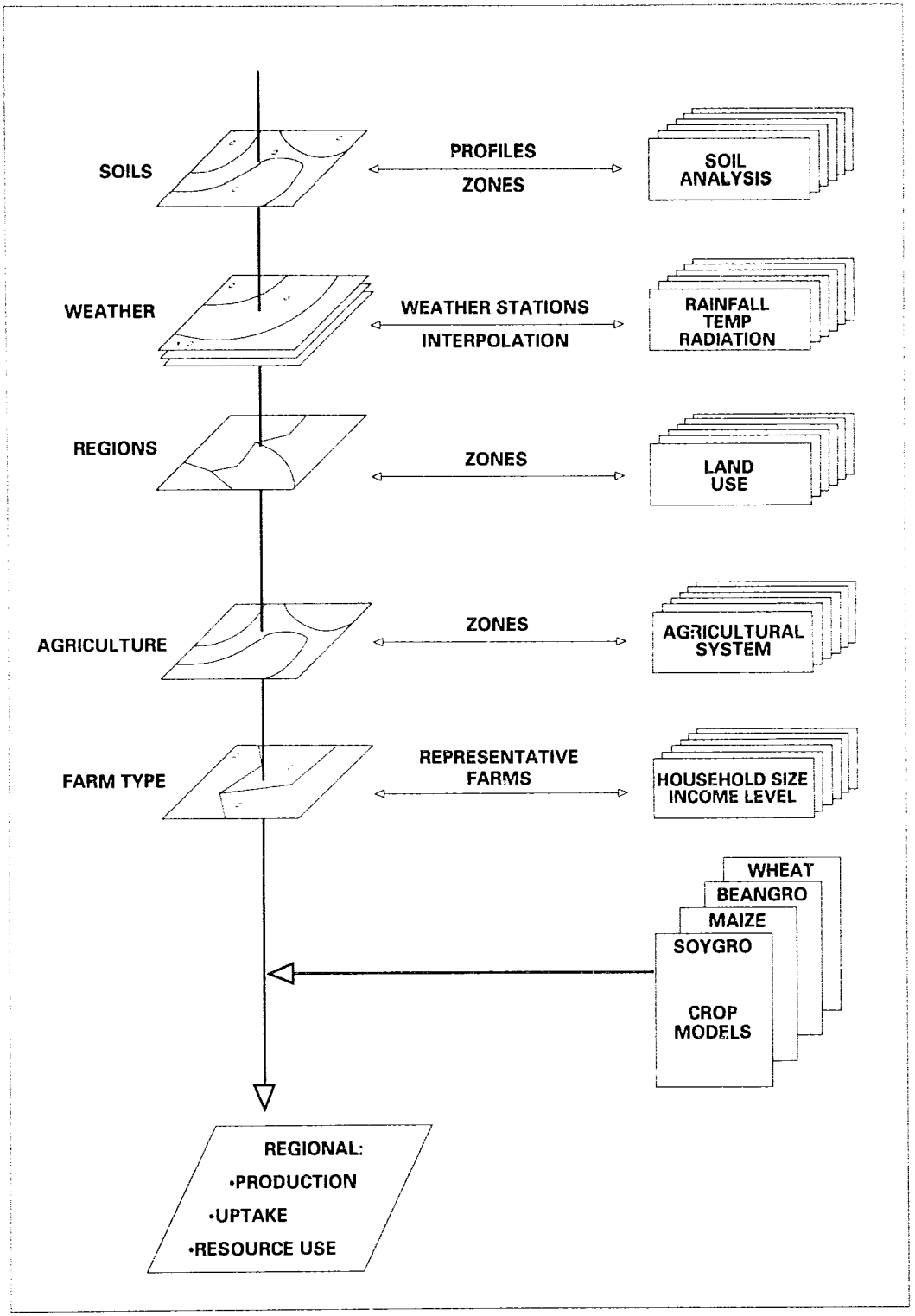


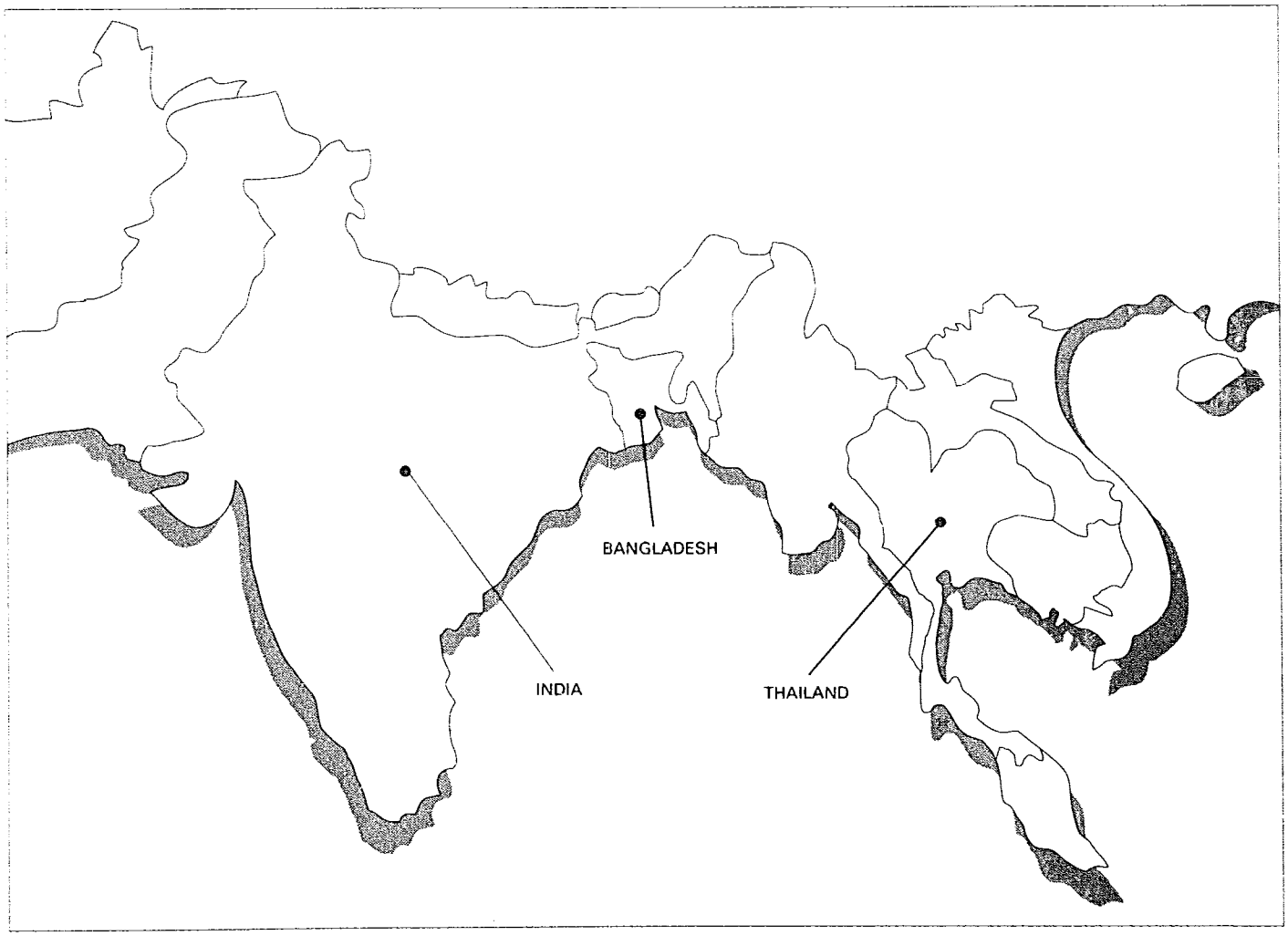
Figure 14
A Geographic Information System can contain data relating to existing farming systems and the immediate socio-economic environment of villages and households.

Applications & Acceptance of DSSAT

The successful practical application of DSSAT in LDC situations presupposes its ability to produce reasonably accurate output under the conditions prevailing in most developing countries. The project has made considerable efforts to supplement its budget in order to assess the performance of DSSAT in LDC settings, and demonstrate its utility.

Bangladesh

A workshop on DSSAT and crop simulation models was conducted in Dhaka, Bangladesh at the request of the Bangladesh Agricultural Research Council (BARC) with the support of the U.S. AID mission in Dhaka. The two-week program was held at BARC headquarters 13-27 January, 1989, and was attended by 22 participants representing nine government agencies and educational institutions. The prerelease version of DSSAT was used to demonstrate the efficacy of using existing and available weather and soil data bases in Bangladesh to run simulation models for maize and rice. Strategies were developed during the workshop to determine by simulation, the possibility of sustaining or increasing yields by changing planting dates and/or cultivars. Work that would normally require the lifetime of a researcher was achieved in an hour, proving that such a demonstration of DSSAT's application programs conveys the present capability of this decision aid.



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A joint proposal was drafted prior to the conclusion of the workshop for a collaborative research program between BARC and IBSNAT to link DSSAT with farming systems research at BARI and the agroecological zones program of BARC for Bangladesh. Funding sources were not identified.

Total cost of the program including travel of IBSNAT staff to Dhaka, amounted to $35,000 which was provided through BARC and U.S. AID/Dhaka.

India

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has been an IBSNAT supporter since they hosted IBSNAT's inaugural meeting in 1983. Validation of PNUTGRO was accelerated through a cooperative effort with ICRISAT scientists and their collaborators at several sites in India. This effort was initiated after a workshop on systems analysis and crop modeling was jointly organized with ICRISAT and held in Secunderabad in 1987. K.J. Boote of the University of Florida returned to India in 1988 and traveled with S.M. Virmani to each site to review and assess the collection of the MDS to validate PNUTGRO. All local transportation and travel expenses were met by ICRISAT.

To assist in completing this task, ICRISAT provided full support for one of their senior scientists, P. Singh, for a six-month study leave at the University of Florida, to compile and organize the data sets to validate the model. Singh completed this task in December 1989.

Also during December, J.W. Jones of the University of Florida was invited to participate in a workshop organized by the Asian Grain Legume Network (AGLN) at their expense. Jones lectured on the need for standardizing data collection and storage for application with crop models and systems research.

CERES-sorghum was the focus of a workshop organized at ICRISAT in September 1989. D.C. Godwin and U. Singh of IFDC, J.T. Ritchie of Michigan State University, and G. Alagarswamy of ICRISAT, conducted much of the program. It is anticipated that one outcome of the workshop will be the sharing of data sets to validate CERES-sorghum.

Thailand

At the invitation of collaborators from the Department of Land Development and the Department of Agriculture, a presentation of DSSAT was made to the research and administrative staff of both organizations in Bangkhen in February 1989. A similar presentation was made earlier at the U.S. AID mission in Bangkok at the request of David Delgado, Director of Agricultural and Natural Resource Development. Both presentations included a demonstration of potential outputs from DSSAT.

Proposals were jointly prepared with both the Department of Land Development (DLD) and the Department of Agriculture (DOA) for submission to U.S. AID via DTEC to support collaborative activities among both the DLD and DOA with universities in Khon Kaen and in Chiang Mai. Backstopping on model validation and DSSAT application would be provided by IBSNAT.

Department of Agriculture researchers have provided data sets from Surin and Suphan Buri for validation of the CERES-rice model and are actively involved in genetic and phenological data collection of cassava in CIAT regional trials. These data sets may be applicable in developing the cassava model. Application of crop models with outputs of Geographic Information Systems for Songkla and Chiang Mai through compatible natural resource data bases is being examined by the Soil Information Systems group in the Department of Land Development. The soil conservation group of the DLD has also collected and submitted to IBSNAT for model validation, MDS collected from 1987 to 1988, for maize, peanut, and sorghum, from Rayong, Khon Kaen, and Lampang.

Malawi

IBSNAT collaborators at the Edinburgh School of Agriculture developed a proposal for a project on the validation of the maize model in Malawi, and submitted it to the Rockefeller Foundation. The project was approved and funded with $110,000 for a two-year period starting in January 1990. P.K. Thornton of the Edinburgh School of Agriculture is principal investigator, and A.R. Saka, University of Malawi, and U. Singh, IFDC are co-principal investigators.

The objectives of this project involve building up regional climate and soils data bases and using the maize model to predict yield and crop development, but the emphasis is more on the use of the model to direct research within the Malawian Maize Program. This is especially important, as some 90% of maize in Malawi is grown by smallholders using local varieties that yield an average

of 1 t/ha. The prospects of raising production through cheap inputs, such as improved seed and the use of Malawi's rock phosphate deposits as a source of phosphorus, are production changes that are well-suited to treatment using CERES-maize. In addition, the model will be used to help derive regional fertilizer recommendations for maize growers.

Botswana

In March of 1990, a seminar on the use of DSSAT was given by IBSNAT personnel, and attended by staff members from the Department of Agricultural research, and other agricultural institutions in Botswana. IBSNAT collaborator A. Mayeux has three seasons (1988-1990) of complete data to validate the IBSNAT peanut model. The performance of the model with the 1989 data was very satisfactory. U. Singh (IBSNAT/IFDC) will be working closely with Mayeux and Persaud to fully validate the peanut model with existing data.

The sorghum model will be tested with existing data from tillage experiments and trials. In future experiments some additional data on leaf area index and total biomass will be collected. With existing neutron probe data, the soil water balance component of the crop models will also be validated.

The scope and impact of DSSAT in Botswana could be extensive, as it would utilize available computerized climatic and soil data bases and validated crop models, and use them for decision making, land use planning, and simulating crop variables for Geographic Information Systems. The IBSNAT crop models have marked advantage over many other models as their data management options can be simulated and models are being constantly validated in tropical sites as well as by collaborating institutions.

Uganda

In response to a request from the Agricultural Development Officer (ADO) at U.S. AID/Uganda, IBSNAT, IFDC, and SMSS project personnel visited Kampala in March and September 1987, and subsequently prepared a project proposal entitled "Technology for Resource Evaluation and Agricultural Development: A Systems Approach to Efficient Land Use Planning and Farm Management in Uganda." The ADO intends to finance the project with funds from the Manpower for Agricultural Development (MFAD) Project which is conducted in Uganda by Ohio State University with U.S. AID support. That strategy failed to materialize. However, IBSNAT activities were incorporated in the work plans of the MFAD Project and $28,500 of MFAD funds were budgeted, mainly for consultancy and training. The IBSNAT involvement was to commence in May 1989, and to continue over a four-year period, but the MFAD project has yet to initiate this collaborative effort. The status of IBSNAT in Uganda is thus uncertain.

Guatemala

Under its Program in Science and Technology Cooperation (PSTC), U.S. AID funded a project titled "Biological and Socio-economic Modeling of Bean-based Farming Systems in Guatemala." The project was developed by various IBSNAT collaborators under the leadership of the University of Florida in cooperation with the Instituto de Ciencia y Tecnologia Agricola (ICTA). P. Masaya of ICTA was the original principal investigator but he, as well as his successor, subsequently resigned owing to changes in government, and the position is now vacant. J.B. Dent and P.K. Thornton of the Edinburgh School of Agriculture, G. Hoogenboom of the University of Georgia, and J.W. Jones of the University of Florida represent IBSNAT, and are collaborating with ICTA. The three-year project became effective in April 1989 and has a total budget of $150,000.

Project objectives are:

1) to validate the bean, maize and sorghum models;
2) to construct whole-farm simulation models for smallholder bean-based systems; and
3) to utilize these tools to evaluate changes to production systems.

Project progress has been impeded by administrative and personnel problems. For example, funds are still not available to ICTA researchers, equipment is not yet on-site, and the soil laboratory is currently not operational. Despite these predicaments, however, experimentation has continued, and bean data were collected at two sites during three growing seasons. The continuation of field experimentation in the face of adversity is largely attributable to the enthusiasm and skill of the ICTA scientists, who diverted resources from other projects to ensure uninterrupted data collection.

Considerable progress has been made regarding the whole-farm model. A crop sequencer has been constructed, and farm economics are in the process of being added to the system.

Puerto Rico

With assistance from J.W. Jones of the University of Florida, F.H. Beinroth of the University of Puerto Rico developed a project proposal titled "Computer Systems for Enhancing Agricultural Decision Making in the Caribbean" and presented it to the Caribbean Basin Advisory Group (CBAG) of the USDA/CRS Special Research Grants, Tropical and Subtropical Program (Section 406). The project was approved for a three-year period beginning July 1, 1989 and assigned a total budget of $133,000. F.H. Beinroth and J.W. Jones are the principal investigators.

The project purpose is to develop an agricultural decision support system that integrates innovative computer technology such as a Geographic Information System (ARC/INFO), and advanced data base management system (dBASE4), crop simulation models, and a knowledge-based expert system. Three areas of western Puerto Rico were selected for the application and demonstration of the technology in consideration of their environmental diversity, and 1:20,000 soil maps of these areas were digitized. As the bean model is used in the system, a minimum data set experiment was conducted to validate the model for the region. Efforts to link the spatial data bases with DSSAT have been initiated and the general structure of a system named the Agricultural and Environmental Geographic Information System (AEGIS) has been designed.

Results to date indicate that the objectives of the project can be accomplished during the life of the project. This will provide an excellent illustration of the application and applicability of IBSNAT technology.

Bolivia

In January 1988, the Agricultural Development Officer (ADO) at the U.S. AID Mission in Bolivia invited IBSNAT to send a representative to La Paz to discuss the possible utilization of IBSNAT technology in Bolivia. The visit was made in March 1988 and resulted in the preparation of a detailed project proposal titled "New Tools for Bolivia's Agriculture—A Decision Support System for Managing Natural Resources for Sustainable Agriculture in Bolivia." The proposal was submitted to U.S. AID/Bolivia in April 1988. It met with a favorable response and was under consideration as part of a larger agricultural development project that was then in the design stage. In March 1989, the project was informed by U.S. AID/Bolivia that, regrettably, the proposal could not be funded as the allocated budget had been reassigned to other, presumably drug-related, areas.

More DSSAT Applications

In addition to the projects conducted with external support under the IBSNAT umbrella, there are various instances where DSSAT or the IBSNAT models are used by other organizations or projects in their endeavors.

Under the auspices of the *American Soybean Association*, a group of soybean modelers from seven states of the United States recently adopted IBSNAT's standardized input/output data structures as the norm for a project in which at least four soybean models will be tested. The modelers not only adopted the file structures but also made some suggestions for their improvement.

Another example is the *Predictive Assessment Network for Ecological and Agricultural Responses to Human Activities (PAN-EARTH)*, a project of Cornell University's Global Environment Program. This research project involves an interna-

tional network of physical and biological scientists who are investigating potential effects of global environmental change on the biological systems of selected case study countries and regions. PAN-EARTH selected the IBSNAT crop models because they can be calibrated to virtually any location with appropriate inputs of soil, meteorology, and cultivar data. PAN-EARTH has acquired the IBNSAT models for wheat, maize, soybean, peanut, sorghum, and millet and will also use the rice and cassava models once they are released.

The *Environmental Protection Agency (EPA)* is addressing similar issues in the EPA/AID International Agriculture Project in which IBSNAT is a major collaborator. The project, which is managed by C. Rosenzweig of the Goddard Institute for Space Studies, Columbia University, is using the crop models installed in DSSAT in an attempt to simulate the changes greenhouse warming trends could have on crop production and trade.

The project includes countries which are either important exporters or importers of food, or whose food production is currently or projected to be vulnerable to climate change. Countries participating in the study include, Australia, Bangladesh, Canada, China, Costa Rica, Egypt, France, Indonesia, Kenya, Mali, Mexico, Niger, Pakistan, the Philippines, Thailand, the United Kingdom, the United States, the Soviet Union, and Zimbabwe.

DSSAT Applications

DSSAT places in the users' hands the immense computational power and memory of computers, combined with the experience and knowledge needed to diagnose, interpret, and prescribe solutions to site-specific problems. Today changes are so rapid that we can no longer afford to conduct only trial-and-error field experiments. Solutions found in this manner take so long to test that they are often obsolete by the time they are found. IBSNAT is striving to help create systems based solutions through development of its Decision Support System for Agrotechnology Transfer.

DSSAT was designed primarily for user groups in agriculture, but owing to its break with traditional ways of diagnosing and prescribing solutions, it has been adopted by other types of users. The emergence of issues which require assessment of conditions that may occur in the future, call for the type of problem solving capabilities DSSAT has.

Predicting Sustainability Under "Greenhouse" Conditions

The EPA and U.S. AID are using DSSAT to assess and predict the effects of greenhouse warming and increased CO_2 levels on sustainable agriculture. Cornell University's PAN-EARTH Project is also using DSSAT for its global climate change studies.

Land and Resource Use Planning

Soil survey information and the mapping capabilities of Geographic Information Systems combined with the simulation and predictive qualities of DSSAT will offer increasingly sophisticated and accurate land and resource use planning.

Suggesting Agrotechnology Packages

A large number of agrotechnology packages may be devised and evaluated interactively, using the strategy evaluation programs in DSSAT. Systems simulation allows for more screening of large ranges of potential management systems, and varietal testing of cultivars through crop simulations of multi-year performances.

Pest Crop Modeling

Modelers are working on ways to link pest crop interaction modules with DSSAT. By coupling these components, systems simulation can more accurately describe the interactions between pests, disease, and crop performance.

These are just a few examples of what DSSAT, with its generic models and modular components, may be able to accomplish. DSSAT's generic attributes are the very ones that give it its power; for in a quickly changing world, power and flexibility must be linked.

Scientists participating in the project have been asked to define geographical boundaries of the major agroproduction regions of their country, provide observed climate data for sites within these regions, compile inputs necessary, and run the crop models for 50-year simulations using the baseline data and climatic change scenarios provided by EPA. The goal of the project is to produce a consistent set of crop modeling results from all participating countries so that adaptive responses may be generated.

An interdisciplinary research project formed in Florida, *Application of Integrated Agrotechnology for Crop Production and Environmental Quality Protection (APINAT)*, has adopted DSSAT to improve the procedures extension specialists recommendations of water and fertilizer management techniques for field crops, potatoes, and citrus. Research and extension faculty from six departments at four locations in Florida are involved. G. Kidder from the University of Florida visited the IBSNAT Project in Hawaii for six months in order to learn DSSAT and prepare a training program on the use of DSSAT for agricultural professionals.

The recently established *International Nursery for Modeling of Bean Growth and Development* adopted IBSNAT's minimum data set concept and the BEANGRO model for a project designed to test adaptability of cultivars to new environments and predict the performance and yield under those conditions. Collaborators of this network will collect data sets across a wide range of environmental conditions. These data will be used for testing the bean model and for developing genetic coefficients.

Scientists of the *Food and Technology Center for the Asian and Pacific Region (FFTC/ASPAC)* performed a very systematic and successful calibration and validation of the CERES-maize model for Taiwan. As a consequence, the maize model is now operational for practical application in that country.

These examples of DSSAT and IBSNAT model applications may suffice to indicate how IBSNAT technology can be applied in various scenarios and for different purposes. The project derives satisfaction from the fact that scientists from other organizations find it propitious to utilize IBSNAT's DSSAT and crop models.

IBSNAT Networks

As the project has evolved, four kinds of networks have emerged.

1. A network of data generators for model validation.
2. A network of modelers and system scientists.
3. A network of DSSAT users.
4. Regional networks.

While the first two networks were established simultaneously during the implementation phase of the project, the third is a more recent development. Although each of the networks has a distinct purpose and focus, their memberships overlap.

The IBSNAT Network of Data Generators

The purpose of this prototype network is to produce the field and laboratory data required to build and validate the crop simulation models. To allow the design of universally applicable models and their worldwide testing, this network should, ideally, include most of the major agroecological zones of the tropics and subtropics; hence the term "benchmark sites" in the project title. Although this goal could not be completely achieved for logistic and financial reasons, the project has nevertheless succeeded in consolidating an impressive array of experiment sites into a data generating network of wide environmental diversity (Table 1).

Collectively, the collaborators have produced a total of 134 minimum data sets, almost exclusively with their own funds. Several scientists from these institutions have participated in IBSNAT organized training workshops. Recently, collaborators in Fiji and Thailand independently conducted workshops to train local staff in collecting the minimum data set (MDS) and entering the data into DSSAT.

Inevitably, the level of activity has not been constant and equal across the network as is reflected in the quantity and quality of the MDS which have been generated. For example, Panama, was an active early collaborator but has now

Collaborators and Users of DSSAT

vanished from the IBSNAT scene, and others, like the USDA/ARS Tropical Agricultural Research Station in Puerto Rico, have joined the network only recently. The underlying reason for this predicament is that collaboration is entirely voluntary and IBSNAT has no control over resource allocation and prioritization of effort among its cooperators. Given the scarcity of funds in the developing countries, many of the collaborators have been unable to produce complete data sets. In addition, soil characterization and weather data, particularly solar radiation, are frequently not available to the field experimenters. Consequently, many of the submitted minimum data sets are incomplete. The number of individuals and research organizations expressing interest in collaboration has been increasing.

Country	Kind of Agricultural Research Center	Agency
Australia	National	CSIRO
Burundi	National	University of Burundi
Colombia	International	CIAT
Costa Rica	Regional	CATIE
Fiji	National	MPI
	National	University of the South Pacific
Guam	Regional	University of Guam
Guatemala	National	ICTA
India	International	ICRISAT
	State	Punjab Agric. University
	State	Tamilnadu Agric. University
Indonesia	National	AARD/CSR
Jordan	National	University of Jordan
Malaysia	National	MARDI
New Zealand	National	DSIR
Pakistan	National	PARC/NARC
Philippines	International	IRRI
	National	PCARRD
Puerto Rico	National	USDA/ARS/TARS
Syria	International	ICARDA
	Regional	ACSAD
Taiwan	International	AVRDC
	Regional	FFTC/ASPAC
	National	Nat'l. Chung Hsing University
Thailand	National	Dept. of Land Development Agriculture
United States	International	IFDC, (Alabama)
(Florida)	State	University of Florida
(Hawaii)	State	University of Hawaii
Venezuela	National	FONIAP
Zambia	National	University of Zambia

Table 1
IBSNAT Project network of data generating collaborators.

The IBSNAT Network of Modelers & System Scientists

It was recognized early in the project that no single institution could effectively deal with all aspects of the projected activities. The project therefore set out to enlist the best scientists, wherever they could be located. The project systematically selected a team of scientists to form an interdisciplinary and international network of modelers and systems scientists. Formal agreements between IBSNAT and the following institutions were established:

- *Michigan State University*: to develop and validate the cereal models;
- *University of Florida*: to develop the grain legume models and a decision support system;
- *International Fertilizer Development Center (IFDC)*: to develop cereal models;
- *The Edinburgh School of Agriculture*: to develop a whole farm model; and
- *The University of Guelph*: (Ontario, Canada) to define genetic coefficients.

Table 2 summarizes the institutions and their area of involvement in the software generation component of the IBSNAT Project.

Institution/Country	Subject Matter Area
Michigan State University, MI, U.S.A.	Cereal models
University of Florida, FL, U.S.A.	Grain legume models Decision support system
Edinburgh School of Agriculture, U.K.	Whole-farm models
IFDC, AL, U.S.A.	Cereal models
CIAT, Colombia	Bean model
ICRISAT, India	Peanut model
Cornell University, N.Y., U.S.A.	Potato model Data base management system
INRA, France	Data base management system
USDA/ARS,WA, U.S.A.	Root crops model
USDA/ARS, TX, U.S.A.	Maize model Minimum data set
Dept. of Agriculture, Thailand	Cassava model
University of South Pacific, Fiji	Aroid model
University of Queenland, Australia	Cassava model

Table 2
Institutions collaborating with IBSNAT in software generation.

The IBSNAT Network of DSSAT Users

Version 2.1 of IBSNAT's Decision Support System for Agrotechnology Transfer (DSSAT) released in 1989, has since been distributed, to about 130 institutions and individuals from around the world. The network formed by this group is growing at a rate of one per week. To facilitate feedback for users, a questionnaire survey was mailed out in May, 1990 (see Appendix B for list of users). IBSNAT's newsletter, *Agrotechnology Transfer*, will serve to keep users updated on common concerns expressed by them and actions taken to improve DSSAT.

The IBSNAT Regional Networks

As agricultural practices, products and problems are usually the same in agroecologically and culturally similar areas, the network approach holds particular promise for successful implementation in such regions. The project has therefore long fostered the notion of establishing regional networks that tailor the IBSNAT philosophy and methodology to the environmental, agro-production, and socio-economic conditions of a region.

Efforts to this effect were undertaken, with various degrees of success, in Southeast Asia, Oceania, Central America, and the Arab countries.

Asean Benchmark Sites Network for Agrotechnology Transfer (ABSNAT)

A project proposal for ABSNAT was prepared by IBSNAT and ASEAN country representatives at an IBSNAT-sponsored meeting held in Manila, Philippines, in March, 1985. The project objectives were to increase research efficiency and to render research results more readily available to ASEAN farmers by transferring agrotechnology as well as solving agricultural problems through systems-based research.

Acting in behalf of the proposed members of the network, the Philippine Council for Agriculture and Resources Research and Development (PCARRD) submitted the proposal to the ASEAN Committee on Food, Agriculture and Forestry (COFAF) in May 1985. COFAF apparently approved the proposal, but its subsequent fate remains unclear. Efforts to clarify the issue by correspondence have not been successful. In retrospect, the proposal should have been sent to high level policy makers in each of the represented countries before submission to COFAF.

Oceania Benchmark Sites Network for Agrotechnology Transfer (OBSNAT)

The project proposal for OBSNAT was prepared, with IBSNAT inputs, by the New Zealand Department of Scientific and Industrial Research (NZDSIR) and submitted to the Permanent Heads of Agriculture and Livestock Production (PHAPS) of the South Pacific Commission (SPC) in November, 1984. The proposal was in principle approved, but NZDSIR and the Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM) were commissioned to conduct a feasibility study. In June 1989 an OBSNAT workshop was held at SPC headquarters in Noumea, New Caledonia, which was attended by two IBSNAT representatives. During this meeting, which was financed mainly by ORSTOM, the project's course of action was discussed and outlined. It was later decided that OBSNAT implementation should follow a phased approach and comprise two components: the Pacific Agricultural Information System (OBSNAT:PAIS) and the Agronomic Research Programme (OBSNAT:ARP). A detailed proposal for OBSNAT:PAIS has been developed. With the appointment of an OBSNAT program manager by the South Pacific Commission, OBSNAT will become operational.

Discussions were held with executives of the Centro Agronomico Tropical de Investigacion y Esenañza (CATIE) in Turrialba, Costa Rica, regarding the establishment of a regional IBSNAT-linked network in Central America, tentatively named the CATIE/IBSNAT Red de Transferencia de Agrotenologia (RETA). The project was asked to present this idea to CATIE's boards of directors to generate high-level support for a subsequent proposal. Because of political unrest in the region, however, the board meeting was cancelled twice and has now been postponed indefinitely. If and when it takes place, the project will make the presentation, provided travel funds are available.

Initial discussions were also held with the director and staff of the Arab Center for the Study of Arid zones and Dry Lands (ACSAD) in Damascus, Syria, regarding the establishment of an IBSNAT network in the member countries of ACSAD. The matter is now pending but will be further pursued if the opportunity arises to visit ACSAD.

Utilization and Dissemination

Workshops Held or Attended by IBSNAT

Workshop on Agroclimatology of Asian Grain Legume Growing Areas and Regional Legumes Networks.

Place: Patancheru, India
Date: 5–17 December 1988
Purpose: The second week of the workshop was comprised of training sessions where lectures on the DBMS, the minimum data set, PNUTGRO, and IBSNAT and their use were presented.
IBSNAT Personnel: J.W. Jones

Western Regional Soil Survey Work Planning Conference

Place: Maui Community College, Maui, Hawaii
Date: 13–17 June 1989
Sponsors: University of Hawaii, College of Tropical Agriculture and Human Resources (CTAHR); University of Hawaii, Department of Agronomy and Soil Science; U.S. Department of Agriculture Soil Conservation Service (USDA/SCS).
Purpose: To meet and discuss and present papers under the following general headings: a) "Our Role in the Pacific Basin," b) "Performance of Crop Pasture, and Forest Lands." The Decision Support System for Agrotechnology Transfer (DSSAT V.2.1) was demonstrated by G Y. Tsuji, IBSNAT. Emphasis was placed on a uniform and standard soil data base.

South Pacific Commission Workshop/ OBSNAT

Place: Noumea, New Caledonia
Date: 3–18 June 1989
Purpose: A technical proposal to implement the Oceanic Benchmark Sites Network for Agrotechnology Transfer (OBSNAT) was presented to the Directors of Agriculture at the meeting of the South Pacific Commission. The proposal was for a six-year program that provides an opportunity for each of the 20 member island nations and territories to participate. To accommodate participation, four agroenvironments were identified as representative of the insular nature of potential OBSNAT members.
IBSNAT Personnel:
G.Y. Tsuji, University of Hawaii
G. Uehara, University of Hawaii

REDCA-CATIE Meeting

Place: Tegucigalpa, Honduras
Date: 30 August–1 September 1989
Purpose: To introduce and represent IBSNAT concepts and methodology and demonstrate the use of DSSAT and the crop simulation models.
IBSNAT Personnel/Collaborators:
G. Hoogenboom, University of Georgia
J. Arze, CATIE

Workshop on Modeling Pest-Crop Interactions

Place: Honolulu, Hawaii
Date: 7–10 January 1990
Purpose: The workshop objectives were to provide a forum for the exchange of concepts, methodology and information on simulation of pest effects on crop growth and development. The workshop also strove to encourage an active sharing of computer techniques to link pest models to crop and other models. The workshop was successful in its objectives, and was attended by 33 participants from 12 countries who managed individual sponsorship from their respective institutions in order to attend the workshop.
IBSNAT Personnel:
J.T. Ritchie, Michigan State University
U. Singh, IFDC

G.Y. Tsuji, University of Hawaii
P. Teng, University of Hawaii
H. Pinnschmidt, University of Hawaii
L.A. Hunt, University of Guelph, Ontario
R. Caldwell, University of Hawaii
E.A. Graser, University of Hawaii

Participants of the Workshop on Modeling Pest-Crop Interactions.

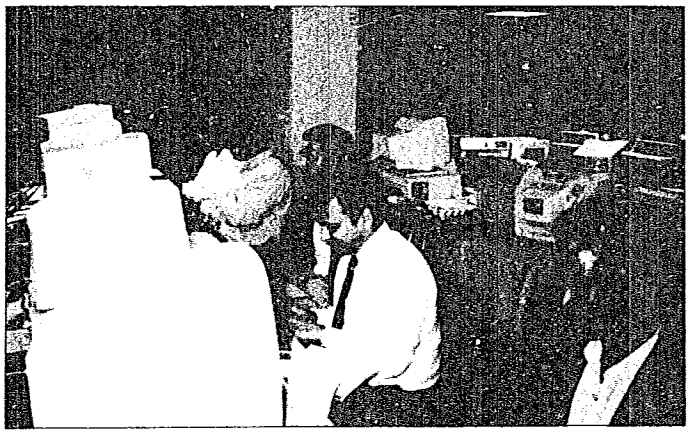
International Climate Change and Crop Modeling Workshop

Place: Washington, D.C.

Date: 27 January to 2 February 1990

Purpose: This workshop began the basework of an extensive study which will address the issues of global climate change and its effect on agriculture worldwide. This workshop included an overview of the Environmental Protection Agency/U.S. Aid International Agriculture Project, and introduced participants to DSSAT and the IBSNAT crop models. Researchers were asked to define geographical boundaries of the major production regions of their country, provide observed climate data for these regions, and run crop models for 50-year simulations using the baseline observed data and climate change scenarios provided by the EPA.

IBSNAT Personnel: D. C. Godwin, IFDC
J. W. Jones, University of Florida
J.T. Ritchie, Michigan State University
G. Hoogenboom, University of Georgia
D. Imamura, University of Hawaii
U. Singh, IFDC



Using DSSAT at the Climate Change & Crop Modeling Workshop.

Training Workshops

Place: Thailand

Date: 5–13 August 1987

Purpose: The workshop introduced IBSNAT concepts, crop modeling, data management, and field methodology. The workshop also included field trips to maize experiments and trained participants on the collection of the IBSNAT minimum data set, and the use of microcomputers. A post-workshop evaluation determined that participants felt they had gained needed experience. Many of the participants stated they would like a much longer follow-up workshop.

Training Workshop on Sorghum and Pearl Millet Modeling

Place: Patancheru, India

Date: 12–19 October 1988

Purpose: To a) understand plant physiological processes to model growth of sorghum and pearl millet; b) compare common principles of cereal crop growth models currently available; c) discuss coupling of nitrogen subroutine in CERES crop models; and d) review data base management systems.

IBSNAT Personnel:

J.T. Ritchie, Michigan State University, IBSNAT
D.C. Godwin, IFDC
U. Singh, IFDC
J.L. Monteith, ICRISAT
B.C.G. Gunasekera, ICRISAT
S.M. Virmani, ICRISAT
J.R. Burford, ICRISAT
J.W. Estes, ICRISAT
J.M. Peacock, ICRISAT
D.L. Oswalt, ICRISAT
G. Alagarswamy, ICRISAT
T.J. Rego, ICRISAT
A.K.S. Huda, ICRISAT

Training Course on Agrotechnology Transfer in Bangladesh

Place: Dhaka, Bangladesh
Date: 13–27 January 1989
Purpose: Conduct training course on Decision Support System for Agrotechnology Transfer in Bangladesh.
IBSNAT Personnel:

U. Singh, IFDC
A. Tang, University of Hawaii
P.K. Thornton, Edinburgh School of Agriculture
G. Uehara, University of Hawaii
G. Tsuji, University of Hawii

Institutions Represented:

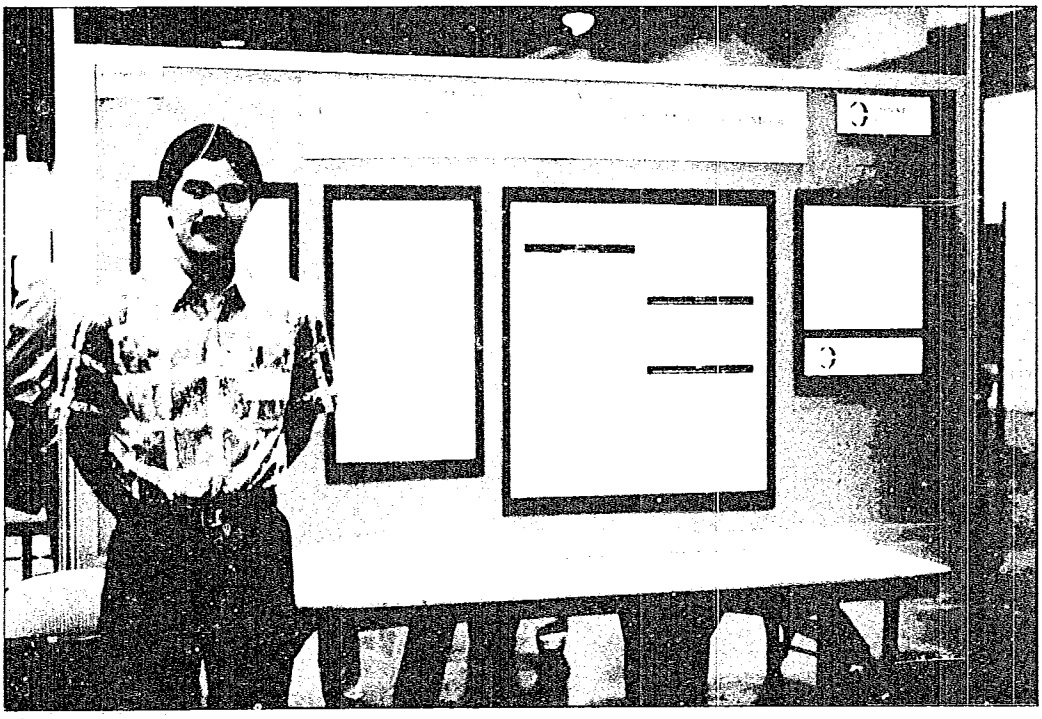
Bangladesh Agricultural Research Council
Bangladesh Forest Research Institute
Bangladesh Institute of Nuclear Agriculture
Bangladesh Jute Research Institute
Bangladesh Tea Research Institute
Dhaka University, Bangladesh
Department of Agricultural Extension, Bangladesh
Soil Resources Development Institute, Bangladesh
Space Research and Remote Sensing Organization (SPARRSO), Bangladesh

Training Program on Computer Simulation for Crop Growth and Fertilizer Responses

Place: Muscle Shoals, Alabama
Date: 15–26 May 1989
Purpose: In this workshop, participants learned how a comprehensive simulation model of crop growth and nutrient dynamics is constructed and how this can be applied to real world problems. The CERES models were demonstrated, the data base management system was explained, and application of the models to fertilizer cropping and environmental problems was demonstrated. Experts from IFDC and IBSNAT formed the faculty.

PAN-EARTH Sub-Saharan Africa Workshop

Place: Saly, Senegal
Date: 11–15 September 1989
Purpose: The workshop focused on the effects of global climate changes on the agriculture and ecology of the countries of sub-Saharan Africa. Workshop participants included scientists from 13 African countries, as well as Japan, Venezuela and the United States. In addition to reports on the participants' presentations and the text of papers, the workshop also provided updated



Richard Ogoshi presented his poster on genetic coefficients at the IBSNAT Symposium at the 81st Annual Meeting of the Society of Agronomy.

evaluations of climatological models and methodologies for evaluating ecological and agricultural effects of global climate change. The IBSNAT crop models were presented and training sessions held on how to use the models and DSSAT.

IBSNAT Personnel:
G. Hoogenboom, University of Georgia

PAN-EARTH Venezuela Case Study: PAN-EARTH/FONAIAP Workshop on Crop Model Training and Calibration

Place: Maracay, Venezuela
Date: 13–16 November 1989
Purpose: This workshop was primarily a technical workshop on crop model training and calibration. At the workshop, Venezuelan scientists were introduced to the concepts of the IBSNAT Project, and DSSAT. Extensive training sessions on the use of DSSAT and the IBSNAT crop models followed, and calibration was begun for the maize model in Venezuela. DSSAT will be used extensively by the PAN-EARTH Project.

IBSNAT Personnel:
G. Hoogenboom, University of Georgia
J. Comerma, FONIAP

Symposia Held or Attended by IBSNAT

International Symposium on Rice Production on Acid Soils of the Tropics

Place: Kandy, Sri Lanka
Date: 26–30 June 1989
Purpose: The purpose of this symposium was to review achievements and identify priorities, opportunities, and constraints for rice production on acid soils of the tropics. Additionally, the purpose was to assure the rice growing countries of the tropics an active role in research on acid soils and to foster an awareness among scientists, students, and policy makers of the importance and urgency of this work.

IBSNAT Symposium: The Decision Support System for Agrotechnology Transfer

Place: Las Vegas, Nevada at the 81st Annual Meeting of the American Society of Agronomy.
Date: 16–18 October 1989
Purpose: The symposium served as a forum for IBSNAT scientists to present papers and posters on IBSNAT's newly released Decision Support System for Agrotechnology Transfer (DSSAT V.2.1), its description, operation, and some applications.

Individual Training

Several visitors have come to the IBSNAT offices to receive training on DSSAT and the crop models. They are sponsored by their respective institutions and often stay for months, receiving extensive help as they familiarize themselves with the system. A list of these visiting colleagues who came to IBSNAT during the report period follows:

Dr. G. Kidder, University of Florida, APINAT Project

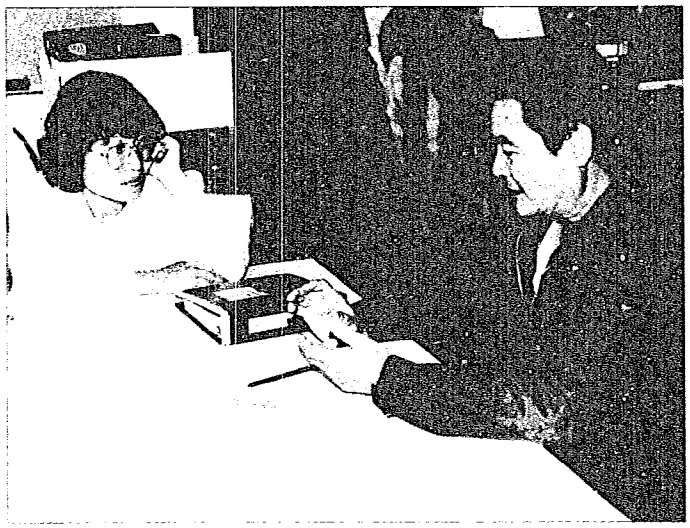
Dr. B. Singh, Punjab Agricultural University, Ludhiana, India

Dr. P. Singh, ICRISAT, India

Dr. R.N. Dukov, Institute of Hydrology and Meteorology, Bulgaria

Dr. Chi-ling Chen, Taiwan Agricultural Research Institute, Taiwan, Republic of China

Dr. I P.G. Widjaja-Adhi, Center for Soil Research and Climatology, Bogor, Indonesia



Dr. G. Uehara discusses DSSAT with visiting colleague Dr. Chi-ling Chen.

Appendix A

Institution Acronyms

Code	Name
AARD	Agency for Agricultural Research and Development (Jakarta, Indonesia)
ABSNAT	ASEAN Benchmark Sites Network for Agrotechnology Transfer
ACSAD	Arab Center for Studies of Arid Zones and Dry Lands (Damascus, Syria)
AID/S&T/AGR/RN	Agency for International Development, Bureau for Science and Technology, Office of Agriculture, Renewable Natural Resources (Washington, D.C., USA)
APINAT	Application of Integrated Agrotechnology for Crop Protection and Environmental Quality Protection, (Gainesville, Florida, U.S.A.)
ARS	Agricultural Research Service (Temple, Texas, USA)
ASEAN	Association of Southeast Asian Nations
AVRDC	Asian Vegetable Research and Development Center (Taiwan, Republic of China)
BARC	Bangladesh Agricultural Research Council
CARDI	Caribbean Agricultural Research and Development Institute
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza (Turrialba, Costa Rica)
CBAG	Caribbean Basin Advisory Group
CEPGL	Commission Economique des Pays du Grande Lac
CGPRT	Regional Research and Development Centre for Coarse Grains, Pulses, Roots and Tubers
CIAT	Centro Internacional de Agricultura Tropical (Cali, Colombia)
CIMMYT	Centro de Investigacion y Mejoramiento de Maiz y Trigo
CIP	Centro Internacional de la Papa [International Potato Center](Lima, Peru)
COFAF	Committee on Food, Agriculture, and Forestry (ASEAN)
CRIDA	Central Research Institute for Dryland Agriculture (Hyderabad, India)
CSIRO	Commonwealth Scientific and Industrial Research Organization (Brisbane, Australia)
CSAR	Centre for Soil and Agroclimate Research (Bogor, Indonesia)
DLD	Department of Land Development (Bangkok, Thailand)
DSIR	Department of Scientific and Industrial Research (Lower Hutt, New Zealand)
DTEC	Department of Technical and Economic Cooperation
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária
ESCAP	Economic and Social Commission for Asia and the Pacific
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization (United Nations, Rome, Italy)
/UNDP	United Nations Development Program
F/FRED	Forestry, Fuelwood Research and Development

FFTC/	Food and Fertilizer Technology Center for the Asian and ASPAC Pacific Region (Taipei, Taiwan, Republic of China)
FONAIAP-CENIAP	Fondo Nacional de Investigaciones Agropecuárias–Centro Nacional de Investigaciones Agropecuárias (Venezuela)
IARI	Indian Agricultural Research Institute
IBSNAT	International Benchmark Sites Network for Agrotechnology Transfer (Honolulu, Hawaii, USA)
ICARDA	International Center for Agricultural Research in the Dry Areas (Aleppo, Syria)
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics (Hyderabad, India)
ICTA	Instituto de Ciencia y Tecnologia Agricola
IFDC	International Fertilizer Development Center (Muscle Shoals, Alabama, USA)
IITA	International Institute for Tropical Agriculture (Ibadan, Nigeria)
INRA	Institut National de la Recherche Agronomique (Toulouse, France)
IRA	Institut de la Recherche Agronomique (Yaounde, Cameroon)
IRAZ	Institut de Recherche Agronomique et Zootechnique (Burundi)
IRRI	International Rice Research Institute (Manila, Philippines)
MARDI	Malaysian Agricultural Research and Development Institute (Malaysia)
MFAD	Manpower for Agricultural Development
MPI	Ministry of Primary Industries (Suva, Fiji)
NZDSIR	New Zealand Department of Scientific and Industrial Research
OAU/STRC—SAFGRAD	Organization of African Unity/ Scientific Technical and Research Commission—Semi-Arid Food Grain Research and Development
OBSNAT	Oceania Benchmark Sites Network for Agrotechnology Transfer
/ARP	Agronomic Research Programme
/CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Development
/PAIS	Pacific Agricultural Information System
ORSTOM	Office de la Recherche Scientifique et Technique Outre-Mer
PAN-EARTH	Predictive Assessment Network for Ecological and Agricultural Responses to Human Activities
PARC	Pakistan Agricultural Research Council (Islamabad, Pakistan)
PCARRD	Philippine Council for Agriculture and Resources Research and Development (Manila, Philippines)
PHAPS	Permanent Heads of Agriculture and Livestock Production (New Zealand)
PSTC	Program in Science and Technology Cooperation
RETA	Red de Transferencia de Agrotecnologia
SCS	Soil Conservation Service
SMSS	Soil Management Support Services (Washington, D.C., USA)
SPC	South Pacific Commission (New Caledonia)
U.S. AID	United States Agency for International Development
USDA/ARS	United States Department of Agriculture, Agricultural Research Service
/SCS	United States Department of Agriculture, Soil Conservation Service (Washington, D.C., USA)
/NSSL	National Soil Survey Laboratory (SCS) (Lincoln, Nebraska, USA)
/TARS	Tropical Agricultural Research Station

Appendix B

List of DSSAT Users

Country	User
Argentina	Osvaldo E. Sala, Departmento de Ecologia
Australia	Trevor H. Booth, CSIRO Forestry and Forest Products, Canberra R. Ferraris, CSIRO, University of Queensland, St. Lucia Steve Harrison, University of Queensland, St. Lucia B. A. Keating, CSIRO, University of Queensland, St. Lucia R. L. McCown, CSIRO, Division of Tropical Crops & Pastures Errol D. Reid, University of Queensland, St. Lucia J. S. Russel, CSIRO Division of Tropical Crops & Pastures Robert White, CSIRO, Division of Water Resources, Griffith, NSW
Bangladesh	Z. Karim, Bangladesh Agricultural Research Council, Dhaka
Belgium	J. Feyen, Center for Irrigation Engineering
Brazil	Otavio Siqueira, EMBRAPA
Burkina-Faso	Taye Bezuneh, OAU/STRC-SAFGRAD
Cameroon	Joseph Bindzi-Tsala, IRA, Yaounde
Canada	Gaetan Bourgeois, Agriculture Canada Research Station Michael Brklacich, Land Resource Research Centre S. E. Weaver, Agriculture Canada
Colombia	Ricardo R. Guerrero, Honomeros Columbo Venezolanos Jeffrey W. White, CIAT, Cali, Colombia
Costa Rica	Francisco Leopoldo Merino Cisneros, CATIE Guiselle Hidalgo, Universidad Estadel a Distancia
Egypt	Helmy M. Eid, Soils & Water Research Institute, University of Alexandria
Fiji	Hemant Kumar Prasad, University of Hawaii, Fiji
France	Richard Delecolle, INRA, Station de Bioclimatologie Ghislain Gosse, INRA, Station de Bioclimatologie Martine Guerif, INRA, Station de Bioclimatologie
Germany	Bruce E. Allison, University of Hohenheim

Guatemala	Carlos E. Heer, Instituto de Ciencia y Tecnologia Ag.
Guyana	Leslie Anthony Simpson, National Agricultural Research Institute
India	N. V. K. Chakravarty, Indian Agricultural Research Institute M. B. Rajegowda, University of Agric. Meteorology Sciences Gangadhar D. Rao, Central Research Institute for Dryland Potnis Sharad Sadashir, Center of Advance Studies in Agricultural Meteorology Piara Singh, ICRISAT S. K. Sinha, Water Technology Centre
Indonesia	Istiqlal Amien, Center for Soil Research, Bogor J. W. Taco Bottema, United Nations, ESCAP CGPRT Centre Abdul Karim Makarim, BORIF, Bogor
Israel	Eshel Bresler, Institute of Soil and Water J. Lomas, Israel Meteorological Service
Japan	Hiroshi Seino, National Institute of Agro-Environmental Sciences
Kenya	Mick O'Neill, Mid America International Agricultural Consortium
Kuwait	Mohammed S. Albahouh, Kuwait Institute for Scientific Research
Malawi	Alex R. Saka, Chitedze Research Station
Malaysia	Abdul Rashid Ahmad, MARDI, Soil Science Unit Aminuddin Bin Yusoff, Central Research Laboratory Division (MARDI)
Mali	Moussa Traore, Institute of Rural Economy, Bamako
Mexico	Mark Bell, CIMMYT
Mozambique	Elaine Kelly, U.S. AID/Mozambique
The Netherlands	Gerrit Hiemstra, Meteo Consult B.V. M. Pietesse, Duyvis Recter B.V.
New Zealand	Bruce B. Trangmar, DSIR T. Williams, Horticultural Research Centre
Niger	M. V. K. Sivakumar, ICRISAT
Nigeria	Mwenja Gichuru, IITA
Norway	Haauon A. Magnus, Norwegian Plant Protection Institute
Philippines	Carlos S. Basilio, University of the Philippines at Los Banos Crisanto R. Escano, Philippine Council for Agriculture and Natural Resources Research and Development, Los Banos
Saudi Arabia	Osama Yousuf Sabr
Tahiti	Charles L. Garnier, Service Economic Rural

Taiwan	Chi-ling Chen, Taiwan Agricultural Research Institute Chen Fang Lin, National Chung Hsing University, Taichung
Thailand	David Delgado, Agricultural & Natural Resource Development, U.S. AID/ Bangkok J. A. Gartner, Asian Institute of Technology Attachai Jintrawet, University of Hawaii, (Khon Kaen, Thailand) M.L. Chakranopakhun Tongyai, Department of Agriculture Taweesak Vearsilp, Department of Land Development
Trinidad	St. Clair Forde, CARDI
United Kingdom	J. Barry Dent, Edinburgh School of Agriculture Thomas E. Downing, University of Birmingham D. H. Sutton, AFRC Institute of Engineering Research
United States	David Anderson, USDA/SCS John Barrett, USDA/ARS Allie Blair, New Mexico State University Ken Boote, University of Florida David Bridges, University of Georgia Israel Broner, Colorado State University Foster Cady, F/FRED Project, University of Hawaii Andy Clark, University of Maryland Wendell P. Cropper Jr., University of Florida Bruce R. Curry, University of Florida Craig L. Dobbins, Purdue University Warren J. Enger, Ronco Consulting Corp., Washington, D.C. Shu Geng, University of California Davis Ricardo Goenaga, USDA/ARS/TARS, Mayaguez, Puerto Rico R. J. Hanks, Utah State University Dan Hardesty, Washington State University Mark A. Harwell, Cornell University Heermann, Colorado State University Tom Hodges, USDA/ARS, Prosser, Washington Roy Jenne, National Center for Atmospheric Research Allan Jones, Blackland Research Center, Texas A&M, Temple, Texas William J. Jorns, Kansas State University Gerald Kidder, University of Florida Diana Liverman, Pennsylvania State University Harry P. Mapp, Oklahoma State University Derrel L. Martin, University of Nebraska Mari Marutani, University of Guam Susan Miyasaka, Hawaii Branch Station Olin Moore, High Plains Consulting Company, Texas Jon Ochs, Eureka Farm, Washington Luis Perez, University of Puerto Rico Gary Peterson, Colorado State University Ata Qureshi, Climate Institute, Washington, D.C. H. Reed, University of Maryland Kevin D. Robbins, Louisiana State University Pierre C. Robert, University of Minnesota Abelardo Rodriguez, Tarleton State University Cynthia Rosenzweig, Goddard Institute for Space Studies, Columbia University Sally Schneider, North Carolina State University Earl Stegman, North Dakota State University

	Janice Thies, NIFTAL Project, University of Hawaii A. Weiss, University of Nebraska-Lincoln Mary Whittaker, Stanford University Gail Wilkerson, North Carolina State University
Uruguay	Walter E. Baethgen, FAO-UNDP
Venezuela	Donja Beg, Estacion Experimental Yaracuy Francisco Blanco Juan A. Comerma, FONAIAP-CENIAP Luisa De Zilva, Estacion Experimental Guanipa Miguel L. Acevedo, Universidad De Los Andes
Zimbabwe	Paul Muchena, Plant Protection Research Institute

Appendix C

Bibliography of IBSNAT Publications

Newsletter

Agrotechnology Transfer (1987-1990)
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Appendix D

Review Panel Members

IBSNAT Project Review: July 1990
Five scientists who are distinguished by their academic and professional excellence have agreed to review the IBSNAT Project in July 1990. They are as follows:

Natural Resources
Dr. Johan Bouma, Department of Soil Science and Geology at the Agricultural University, Wageningen, The Netherlands

Meteorology
Dr. Ray Jansen, Agrometeorologist, NOAA Dept. of Commerce, National Weather Service (retired), Bedford, Texas

Plant Pathology
Dr. David MacKenzie, National Biological Impact Assessment Program, CSRS-USDA, Washington, D.C. (Chairperson of the panel)

Crop Science
Dr. Dale Moss, Department of Crop Science, Oregon State University, Corvallis, Oregon

Economics
Dr. Truman Philips, Director of the Food Protection Agency, University of Guelph, Ontario, Canada

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