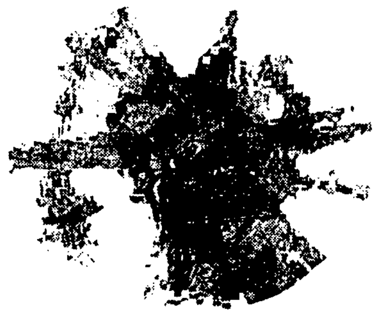
THE IBSNAT DECADE



The end of a project feels like a beginning...
---Frank Gehry

The IBSNAT Decade

Ten Years of Endeavor at the Frontier of Science and Technology

International Benchmark Sites Network for Agrotechnology Transfer
Department of Agronomy and Soil Science
College of Tropical Agriculture and Human Resources
University of Hawaii, Honolulu, Hawaii

Acknowledgements

The IBSNAT decade would not have been possible without the support, guidance, goodwill, achievement and plain hard work provided by scientists, researchers, farmers, administrators, technicians and staff of numerous institutions, organizations and companies, the whole of which not only spanned the globe but also ranged across international, national and private domains. In this report, our intent was to include, either by name and group affiliation or in photo studies, all those who have contributed through these ten years. If we have missed any one or any group, our profound apologies. To all of you, our heartfelt thanks and grateful appreciation.

One final word of special appreciation is necessary for two individuals who provided continuous encouragement and support for IBSNAT throughout the past decade: T.S. Gill, Chief, Division of Renewable Natural Resources, Office of Agriculture, USAID; and N.P. Kefford, Dean, College of Tropical Agriculture and Human Resources, University of Hawaii.

IBSNAT, The International Benchmark Sites Network for Agrotechnology Transfer,is a network consisting of the contractor (University of Hawaii), its subcontractors and many global collaborators. Together they have created a network of national, regional, and international agricultural research for the transfer of agrotechnology among global partners in both developed and lesser developed countries.

From 1982 to 1987, IBSNAT was a program of the U.S. Agency for International Development under a cost-reimbursement Contract, No. DAN-4054-C-00-2071-00, with the University of Hawaii. From 1987 to 1993, the contract was replaced with a Cooperative Agreement, No. DAN-4054-A-00-7081-00, between the University of Hawaii and USAID.

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Editors: Gordon Y. Tsuji & Sharon Balas

Design: Sharon Balas

Production: Sharon Balas & Karen Y. Nakama

Original artwork, page i: Matthew J. Thornton

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Executive Summary

One of the great tragedies of science and technology is that the large body of specialized knowledge which scientists know and take for granted is not accessible to those who need it most. Because of this, critical personal and policy decisions which can affect human lives and well-being are made without the benefit of this knowledge.

With this knowledge crisis in mind, the organizers of the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) project set forth as their goal in 1982, a plan to enable clients in the agricultural community to apply relevant knowledge to assess the benefits and risks of adopting new and untried practices and policies, and therefore to enable them to make better choices for themselves and society.

Recent events make these choices even more critical. Choices influenced by the dynamism in global politics to global climate can lead to changes which head in unexpected directions. Such changes imply that what was true in the past may no longer apply, and warn us that site-specific, empirical knowledge acquired through generations of trial and error can no longer be afforded nor used with confidence to prepare for the future. The rapid obsolescence of empirical knowledge further suggests that to secure agricultural sustainablity, investments must be made in the acquisition of process-based knowledge. This knowledge base can then be used repeatedly to diagnose problems and prescribe alternative remedies to improve the performance of a system over time and space.

At the close of the project in 1993, IBSNAT's major accomplishments included (i) a functional, computerized product called DSSAT for **D**ecision **S**upport **S**ystem for **A**grotechnology **T**ransfer which incorporates available process-based knowledge in models and data bases and (ii) the establishment of a global network of systems developers and systems users.

The approach taken by IBSNAT is based on the premise that it is less expensive, faster, and more reliable to study systems using models than to experiment with the system itself. IBSNAT focused its efforts on three objectives by concentrating its resources on activities under each.

- *DECISION TOOL* The DSSAT is a program shell that links three major elements—crop simulation models, a data base management system, and a management/risk assessment program—into a single integrated system. Version 2.1 of DSSAT was released in 1989 with crop models for wheat, maize, soybean, and peanut. Crop models for rice, sorghum, millet, barley, dry bean, potato, cassava, and aroids were subsequently added to versions 2.1 and 3.0.

- *NETWORK* The DSSAT is the end-product of a synthesis process involving systems developers from the Universities of Edinburgh (Scotland), Florida, Georgia, Guelph (Canada), Hawaii, and Puerto Rico, Michigan State University, the International Fertilizer Development Center, and the U.S. Department of Agriculture's Soil Conservation Service and Agricultural Research Service. Validation of DSSAT and its crop models was accomplished through a global network of benchmark sites involving systems users operating in diverse biophysical and socio-economic environments. Standard procedures to describe sites and soils and to record observations of weather and crops for validation were established with the *minimum data set* concept described by Nix (1984) and adopted by IBSNAT.
- *ACCEPTANCE* More than 500 copies of DSSAT have been distributed since 1989 and nearly 1000 individuals have participated in training courses and workshops on DSSAT and systems research. Responses received from a recent survey of users, and printed throughout this report as quotes, reflect DSSAT's utility and acceptance. DSSAT was used at national and global levels in studies organized by the U.S. EPA and AID on the impact of global climate change on food production and trade; and by scientists at field and farm levels in a number of countries in Eastern and Central Europe, Africa, Asia, Latin America, and the Pacific on sustaining crop productivity.

In summary, IBSNAT provided a means to capture, condense and synthesize existing knowledge into a compact, portable decision support tool that is useful to diagnose problems and evaluate alternative ways to deal with them to attain objectives specified by the user. The systems approach provides an innovative, cost-effective way to respond to the myriad of "what if" questions that will have to be answered in a timely manner to transform agriculture as we know it today into one that is consistent with the concept of sustainable development.

Summary Sheet

Project Title:

International Benchmark Sites Network for Agrotechnology Transfer

Agreement Number:

DAN-4054-A-00-7081-00

Project No. 936-4054

Contractor:

Department of Agronomy and Soil Science
College of Tropical Agriculture and Human Resources
University of Hawaii at Manoa
2500 Dole Street, Krauss Hall 22
Honolulu, Hawaii, U.S.A. 96822

Principal Investigator:

Goro Uehara, University of Hawaii

Associate Principal Investigator:

Friedrich H. Beinroth
Department of Agronomy and Soils
University of Puerto Rico
Mayaguez, Puerto Rico

Program Monitor and Funding Agency:

Tejpal S. Gill
Renewable Natural Resources
Office of Agriculture
Bureau for Science and Technology
Agency for International Development
Washington, D.C. 20523

Contract Period:

1 September 1982 to 31 August 1993

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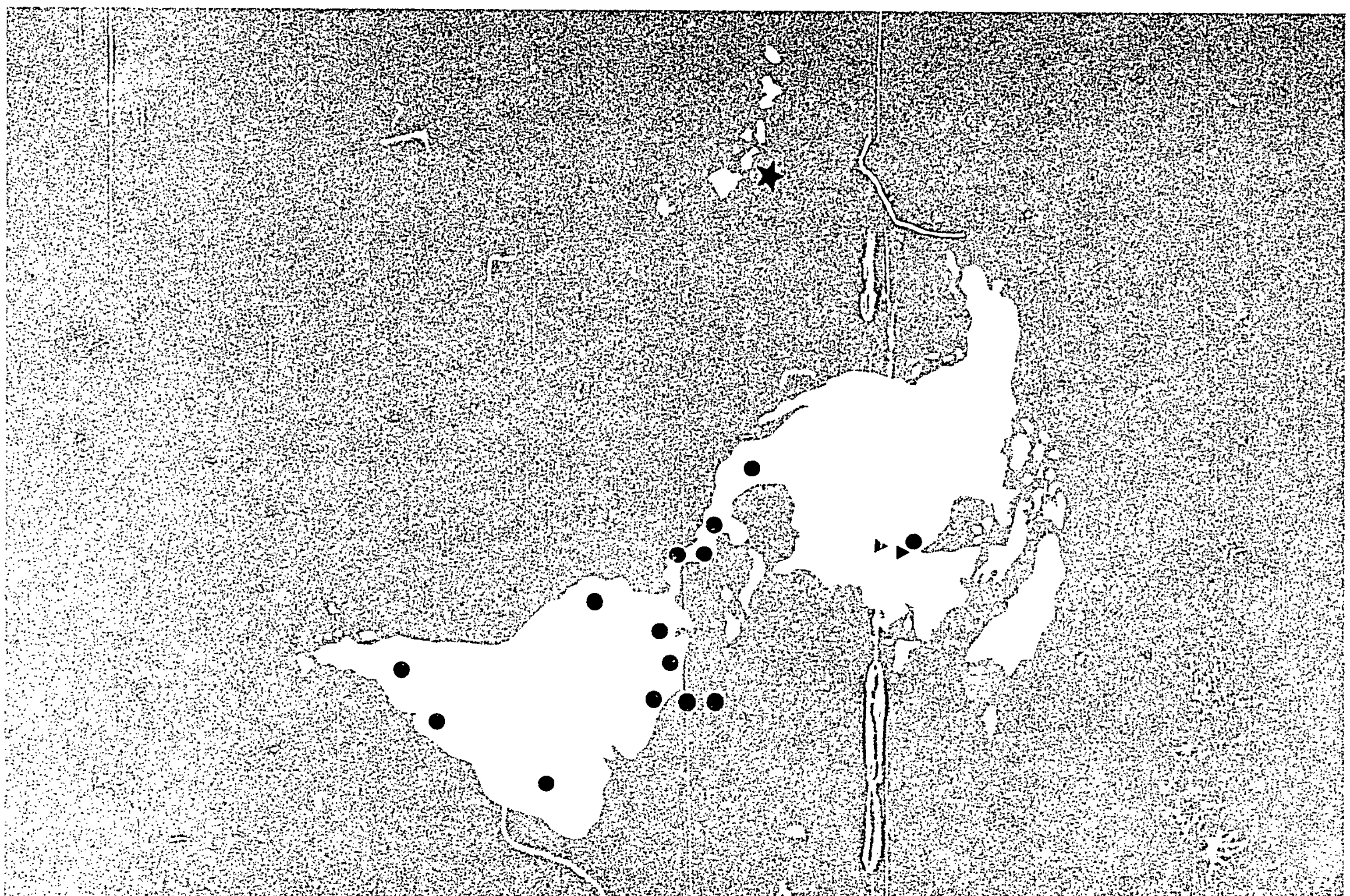
IBSNAT Network Map



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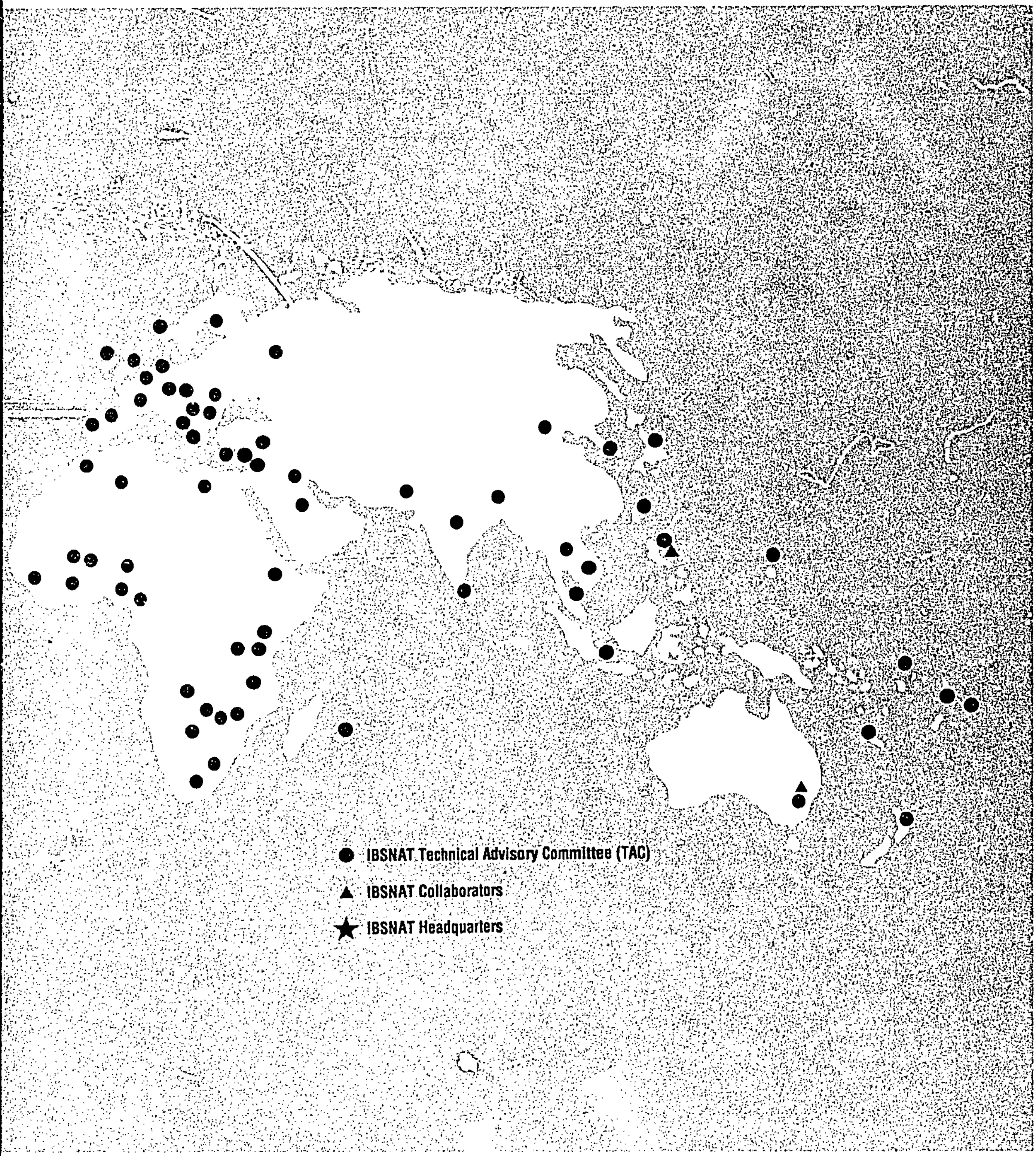
IBSNAT Technical Advisory Committee (TAC)
IBSNAT Collaborators
IBSNAT Headquarters

Introduction

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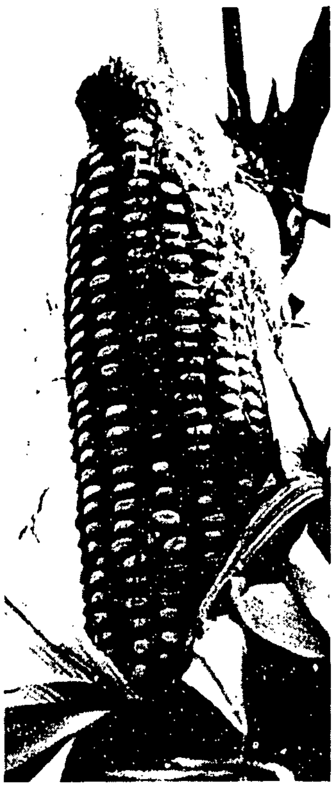


Overview & Impact

Science and technology have generated a wealth of information, but the functional knowledge necessary to support decision making is not accessible to those who need it most. IBSNAT was designed to help remedy this situation by effectively accelerating the process of knowledge dissemination in order to provide decision makers with alternative scenarios of potential outcomes.

Systems scientists use models as a means to capture, condense and organize knowledge. Models are the means by which knowledge about systems and their performance is made portable and accessible to users whose livelihood and welfare depend on this performance.

When IBSNAT was first established, a number of individuals and groups already had functional, dynamic, process-based crop simulation models ready for global testing. Several within this group believed that field testing of the models, preferably in an international network of benchmark research sites, would expose imperfections and allow the models to be refined. Thus the intent of IBSNAT, from the beginning, was not to develop models, but to enable existing modeling groups to demonstrate the utility of their models by demonstrating their capability to simulate outcomes of alternative crop production strategies anywhere in the world. As products of systems synthesis and analysis, functional models are important only insofar as they enable decision makers to generate the desired information with which to support decision making.

Farming systems research and development programs have demonstrated repeatedly that accessibility to promising new crops, crop cultivars, products or practices does not guarantee their adoption by client groups. What farmers need in addition to the innovations is convincing evidence that an innovation will improve farm performance in a way specified by them. But conducting on-farm trials to determine the suitability of a particular innovation defeats the purpose of research by reducing it to a trial-and-error exercise.

The principal aim of IBSNAT was to enable a broad range of users from farm advisors to policy makers to apply scientific knowledge to assess, in a matter of hours, at no cost or risk to the user, how adoption of a specific technology might affect systems performance. The *ex ante* analysis would be conducted in response to "what if" questions posed by the technology adopter. Answers to whole sets of "what if" questions would be the means by which the appropriateness of an innovation would be judged, and the decision to adopt or reject it ultimately made. Ten years ago the key question was whether answers to "what if" questions raised by farmers or policy makers might not be generated more efficiently by models than by on-farm or on-station trials.

Evidence for the potential utility of crop simulation models appeared over ten years ago when the United States Department of Agriculture's Agricultural Research Service crop modeling group in Temple, Texas demonstrated that its maize model could predict grain yields of field experiments conducted over several years in Hawaii, Indonesia and the Philippines. What was remarkable about the results was the ability of the model to account for, and explain, large yield variances associated with differences in climate and rates of nitrogen fertilizer application. What was even more remarkable was the model's ability to predict yields in tropical environments never before visited by the model. But the capacity to make predictions depended not only on accessibility to models, but just as critically, on accessibility to soil and climate data with which to drive the models. Thus, the concept of a minimum data set (MDS) for model validation and application became an important guiding principle for IBSNAT from its inception in 1983 to the present.

Minimum Data Set

The main purpose of IBSNAT's inaugural meeting at the International Crop Research Institute for Semi-Arid Tropics (ICRISAT) in Hyderabad, India in March 1983 was to specify the minimum amount of environmental, crop, and management data a model user would need to validate and apply existing crop models. The concept of a Minimum Data Set (MDS) was borrowed from earlier attempts by Australian scientists to initiate a similar effort. These earlier attempts did not go beyond the conceptual stage for lack of demonstrated utility of crop models and the scarcity of wholly operational crop models (Nix, 1984).

"...the functional knowledge necessary to support decision making is not accessible to those who need it most."

One of the key tasks for participan'~ at the first IBSNAT meeting at ICRISAT headquarters in Hyderabad, India was identifying the MDS for selected crops; in this case, for sorghum.

The Hyderabad meeting accomplished its two principal objectives. It identified crops for IBSNAT to focus on and reached agreement on the minimum set of crop, soil, weather and management data with which to simulate growth and development of the recommended crops. The long-term aim of the project was to develop a solid foundation for dealing with the soil-plant-atmosphere continuum so that strong links between the biophysical and socio-economic aspects of farming systems could later be forged. The participants recommended that the scope of work be limited to ten food crops including four cereals (maize, rice, sorghum, and wheat), three grain legumes (dry bean, groundnut, and soybean), and three root crops (aroid, cassava, and potato). Millet and barley were later added to this list. The minimum data set was published as Technical Report No. 1 (IBSNAT, 1984) and revised in 1986 (IBSNAT, 1986), and again two years later (IBSNAT, 1988).

Reaching agreement on the MDS was a major achievement for IBSNAT. Fortunately, the state of crop models existing at the time enabled the participants to focus on data needed by the models. By 1983, most crop models were operating on a daily time step and considerable convergence in their data requirements had already occurred. Thus, the MDS was largely predetermined by the models themselves. Even so, it took great restraint on the part of even the

I have a deal with the GIS for the land reform prognosis in Russia. The DSSAT crop models show that this approach is the best and fastest for the Russians. Now a first step in the Federal GIS for the land reform support, based on DSSAT crop models, is ready. The Supreme Council and Highest Economical Council supports the application of this methodology for the main agricultural regions.

---A.L. Badenko, Russia

modelers to keep the data set at the lowest possible minimum. There was great temptation, for example, to add relative humidity, wind velocity and direction, and pan evaporation to the weather MDS of daily maximum and minimum air temperature, solar radiation and rainfall.

In the beginning what was important was not so much the number and kinds of variables that were included in the MDS, but the simple fact that an MDS, imperfect as it was, existed. That the initial set was flawed is evidenced by the number of revisions it has undergone. The MDS is imperfect now and will always be imperfect because knowledge of the processes scientists are trying to simulate is imperfect. But the simple fact that an MDS existed gave a sense of unity and coherence to a dispersed and decentralized group operating out of more than fifteen countries.

In the final analysis it was the utilitarian goals of IBSNAT that determined the size and nature of the MDS. It was reasoned that a large and complex MDS would merely add to the burden of data acquisition in the developing countries. There was full agreement among all involved that IBSNAT would not assemble decision aids, however powerful they might be, which would be rejected by the very clients they were meant for simply because the input data to use them were unavailable or too difficult and costly to obtain.

Participants at IBSNAT training course collecting maize biomass as part of the MDS.

The Participants

A unique feature of IBSNAT has been the role played by the participating scientist in the design, management and implementation of its activities. IBSNAT quickly evolved into a participatory effort out of practical necessity. Unlike projects that deal with a single crop, or component such as soil, water or climate, IBSNAT, designed as a systems project, was intended to deal with many crops and all relevant biophysical and socioeconomic aspects of agricultural systems. The task was to find suitable individuals to lead sub-programs to make up the whole.

J.T. Ritchie and H.A. Nix.

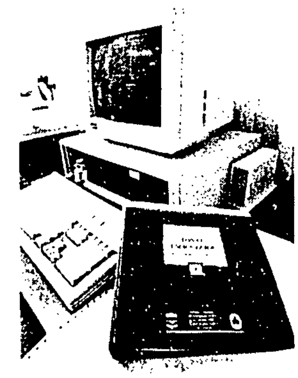
The first two participants, J.T. Ritchie and H.A. Nix, were selected by the principal investigator, but thereafter, all others were jointly identified and selected by the existing group. This method of inviting new participants into the group had two advantages. First the group as a whole provided a larger base from which to choose competent candidates, and second, the close and intimate working relations required for interdisciplinary work made it imperative that a new member was the choice of the group rather than an individual.

One danger of forming research teams in this way is that it tends to bring together individuals who think alike, and run the risk of reaching consensus on a flawed concept. True interdisciplinary teams, however, are composed of individuals with such diverse backgrounds and training that some convergence in thinking, particularly with respect to agreement on project goals, research methodology, and client orientation is not only desirable but necessary. A strong commitment to a client-oriented effort, driven and guided by client-needs, was a key element shared by team members.

This commitment has probably been the single characteristic that has united and sustained the IBSNAT team members. They had long realized that the problems faced by clients ranging from farmers to policy makers were not disciplinary problems but systems problems that could only be diagnosed and solved through interdisciplinary efforts. Another characteristic of the participants was their willingness to adjust their on-going programs to accommodate project goals and objective, thereby greatly leveraging the overall efforts. The incentive to operate in this way came from knowledge that the value and quality of the product assembled by the team would far exceed anything a single member working alone could produce. The participants of IBSNAT were, therefore, not individuals who needed additional resources to do research, but leaders of on-going research programs who were themselves looking for opportunities to work in a more integrated manner with workers in other disciplines. IBSNAT provided them with this opportunity.

Accomplishments

IBSNAT focused on the creation of a single integrated product called the Decision Support System for Agrotechnology Transfer (DSSAT, IBSNAT 1989). DSSAT is a computer software that is designed to enable a user to match the biological requirements of crops to the physical characteristic of land to attain objectives specified by the user. The system consists of (1) a data base management system to enter, store and retrieve the minimum set of soil, crop, weather and management data to validate and apply crop simulation models, (2) a set of validated crop models to simulate outcomes of genotype by environment by management interactions, and (3) application programs that enable the user to conduct agronomic experiments in the computer. A single experiment may contain as many as 15 treatment combinations, and may be simulated for up to 50 consecutive years using historical or estimated weather data to assess long-term performances in a way that cannot be done within one or two years of on-farm or on-station trials. Whole probability distribution of outcome of alternative agronomic, economic and environmental strategies are analyzed and displayed in tables and graphs for easy comparison.



Since agriculture deals with a problem domain that is nearly infinite, a DSSAT that attempts to address all problems for all users will not be practical, possible or even desirable. On the other hand, DSSAT should be able to accommodate the range of problems and conditions encountered on a single farm and allow the farmer to assess alternative combinations of management practices for the crops, soils and weather patterns of a particular farm. DSSAT also uses the same minimum set of soil, crop and weather data to evaluate alternative management practices, irrespective of agroecological zone. Lastly, DSSAT can also be used as an effective training aid for university students, agricultural advisors and policy makers.

"True interdisciplinary teams...are composed of individuals with such diverse backgrounds and training that some convergence in thinking...is not only desirable but necessary."

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Lessons Learned

IBSNAT learned that better integration of effort offers the easiest and most cost-effective way to increase research efficiency at this time. Unfortunately most research institutions are organized and administered in a way that fosters continued reliance on disciplinary research for prestige and scholarly excellence. The reward systems, and the research and publication standards set by disciplinary societies also contribute to perpetuation of the existing situation.

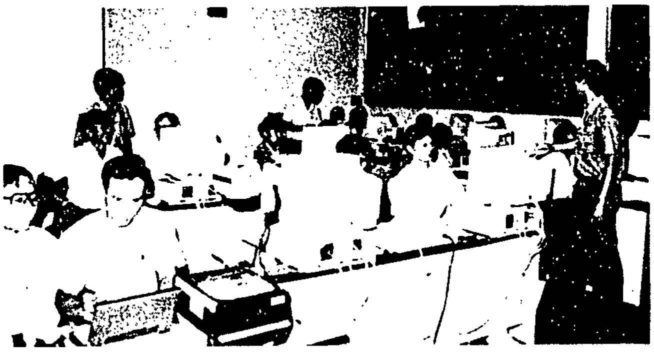
There exists, however, in nearly every institution, pockets of systems-oriented researchers who are ready and eager to join interdisciplinary teams. While they represent a small fraction of the total scientific community, and occur in numbers too small to field interdisciplinary teams within any single institution, they constitute a large, under-utilized resource internationally. These individuals have the following characteristics:

- They are mission- and goal-oriented.
- They are committed to systems-based interdisciplinary research.
- Their research priorities are set by client needs.
- They respond to client needs by producing user-friendly decision aids designed to enable clients to diagnose and solve problems on their own.
- They are product-oriented.
- They are process-oriented and know the value of basic research.
- They tend to share a common vision of the purpose of research.
- They are eager to form networks that enable them to attain higher goals which are otherwise unattainable.

The IBSNAT experience demonstrates that establishment of multi-disciplinary, international, collaborative research networks composed of individuals with the above characteristics is not only possible and worthwhile, but essential for dealing with systems problems.

Future Needs

Decision support systems, however powerful or reliable, serve no useful purpose unless they are used to improve decision making. Although much needs to be done to improve existing models and other decision aids, two other factors prevent their widespread use. First, the minimum data set for soils, crops and weather needed to apply the models and decision aids is not generally available to users. A major task for the future is to compile and organize existing data for each country and region, and to design, plan and implement a global program to fill missing data gaps. Because development of data bases is not as exciting as model development, researchers and policy makers must not make the error of neglecting the former.



Training group at Chiang Mai, Thailand.

The second need is to train a critical number of farm advisers, researchers, educators, administrators and policy makers to use the new decision aids. To make a difference, a critical number of users in every part of the world must choose to replace unsound practices and policies with a new, more productive and environmentally sustainable set. The time is ripe to develop a global plan to train people to use the knowledge captured in decision aids to make better choices now, to ensure a better future.

While there is widespread agreement that a systems approach based on interdisciplinary effort is needed to address agricultural and environmental issues, large scale implementation of this approach is constrained by the inability of the development community to field the necessary interdisciplinary teams. This situation largely stems from the disciplinary and commodity orientation of most research organizations. In spite of this, most institutions have a small number of researchers who are strongly inclined towards systems-based research. On an international scale, this group represents a large, underutilized resource which can be mobilized to respond to complex tasks that require interdisciplinary action. The IBSNAT experience indicates that the fielding of international interdisciplinary teams is not only possible, but highly productive and cost-effective.

"The time is ripe to develop a global plan to train people to use the knowledge captured in decision aids to make better choices now, to ensure a better future."

Rationale

The Earth's land resources are finite. But the number of people they must support continues to grow rapidly. Agriculture is thus confronting a problem that will soon become critical and intensify until population growth approaches zero.

The agricultural sector has responded to this challenge by mounting a massive research effort that includes thousands of traditional field experiments conducted around the world. Notwithstanding the enormous amount of time, capital and effort spent on this research, however, it is improbable that it will suffice to meet the challenge. There are several reasons for this.

First, experiments are conducted at a particular point in time and space and the results generated are therefore site- and season-specific and thus may or may not apply elsewhere. Second, conventional agricultural

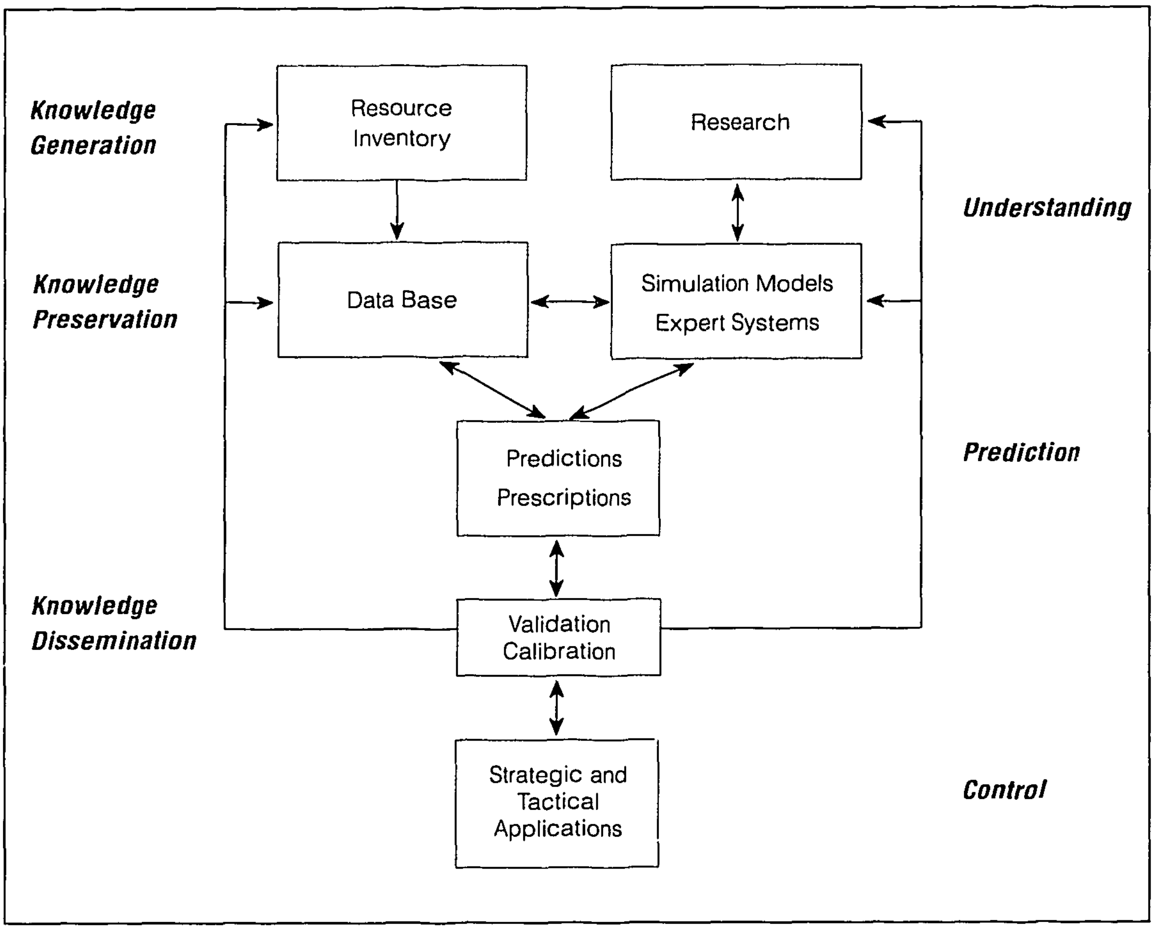
research is time-consuming, and it is unlikely, therefore, that implementable results are generated within the time frame dictated by demographic patterns. And third, agricultural research is often lacking where it is needed most, for example, in the developing countries of the tropics.

The transfer of agrotechnology has been proposed as the solution to this problem. This process involves the transfer of material, such as a seed, or information and knowledge, such as a management practice, to new locations. The transference may be accomplished by trial and error, statistical methods, analogy of agroenvironments, or by systems analysis and simulation.

Transfer by trial and error is clearly ineffective, and statistical methods are suited primarily for interpolation rather than extrapolation. The analogue approach, on the other hand, is useful, but it is qualitative and can obviously be applied only in situations where experience for a particular recipient agroenvironment has been generated elsewhere. Given the immense diversity of agroecosystems, an unrealistic amount of research in many places and at various seasons would be required to make this approach fully operational.

The systems approach is based on the *understanding* of how the components of a system interact. Applied to crop production, the systems approach simulates the genotype by environment by management interactions and *predicts* the performance of a production system in response to the controlling factors of weather and management practices. Databases, crop and soil simulation models, expert systems, and analytical and application programs can be integrated in a decision support systems to predict and, hence, *control* outcomes. This portable system, then, becomes the vehicle for the transfer and deployment of the fundamental knowledge residing in the software.

IBSNAT's decision to adopt the systems approach marked a significant departure from the logic that was the basis for an earlier soil-based agrotechnology transfer program, The Benchmark Soils Project. The transition from soil to site, from a part of the system to the whole system, reflects a conceptual quantum jump from linear thinking to a holistic perspective.



IBSNAT's framework for agrotechnology transfer.

Time has proven this decision correct. In fact, the relevance of this rationale has been reinforced by recent developments on the environmental scene. As it is becoming evident that the notion of sustainable development is not just an option but an imperative, it is also becoming evident that a shift from the traditional *post facto* approach to an anticipatory *ex ante* approach is needed to adequately address the new issues and agendas resulting from a growing environmental awareness and responsibility. Thus, agriculture has not only to provide food, fibre, fuel and income for ever more people, but it has to do so without degrading critical life support systems such as ground water and biodiversity.

The Rio Declaration of the United Nations Conference on Environment and Development in Rio de Janeiro, Brazil in June of 1992, stressed that the "Essential Means" to achieve Agenda 21 include "Scientific Cooperation and Technology Transfer" and "Information for Decision Making." It also emphasized that actions are needed "...to enhance scientific understanding [which] will require development and greater application of the more effective and efficient predictive tools now available, such as...computer modeling...national and international observation, and collection research networks should be established to compile data and information for the predictive modeling and assessment of environmental change."

It is reassuring that the concepts and visions advanced by IBSNAT for the past decade are now advocated by the United Nations.

"...it is becoming evident that the notion of sustainable agriculture is not just an option but an imperative..."

Goal, Objectives & Approach

Goal

The goal of IBSNAT was 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 so that the environment and its biodiversity are conserved.

Objectives

To achieve its goal, IBSNAT established 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 level;
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 decision support systems through case studies.

Approach

IBSNAT was based on the premise that a holistic approach is not only desirable but necessary to deal with the complexity of agricultural systems and the human causes and consequences of environmental change. A further premise was that models are contemporary tools to capture, organize and utilize knowledge and the means to make knowledge about systems and their performance portable and accessible.

The basic strategy to translate this premise into an action program was to establish a global network of scientists collaborating in the development and validation of models, incorporate the models into a decision support system and demonstrate the validity of the system in application studies.

The network of collaborators included modelers, systems scientists and researchers who conducted field experiments to collect the "minimum data sets" (MDS) for testing and validation of the crop models. The concept of the MDS was developed by Australian scientists and adopted by IBSNAT as the minimum soil, crop, weather and management data needed to simulate growth and development of the selected crops. The modelers used these data sets to construct the crop simulation models. Systems scientists combined the models with databases and application programs and developed a decision support system.

Training and dissemination efforts, directed mainly at IBSNAT's target clientele in the developing countries, were a critical component.

As IBSNAT evolved, it became obvious that constant adjustments in the project strategy were needed to accommodate advances in information science and computer technology. These developments opened up new avenues for research that yielded solutions that could not have been anticipated when the IBSNAT concept was originally developed. Examples of unexpected activity include the areas of pest and disease management, genetic coefficients, cropping systems and geographic information systems. Flexibility and dynamism therefore were the chief characteristics of IBSNAT's management team and were encouraged by the funding agency.

To ensure the highest professional standards and scientific integrity, and for guidance and counsel, the IBSNAT Technical Advisory Committee (TAC) was established. This committee constituted an exceptional pool of talent, expertise and vision and proved to be an invaluable asset in the IBSNAT decade of endeavor.

Production crew from Australia's television series, "Beyond 2000," filming IBSNAT's innovative genetic coefficient experiment on Maui for a program on "Global Farming."

Management

Management by objectives and outputs was the strategy implemented by IBSNAT. In order to achieve its stated objectives, outputs associated with each objective were targeted for completion by defining activities, tasks, and agents in annual work plans. Each output had some measurable indicator of progress towards milestone events.

The IBSNAT project was programmed to achieve its three stated objectives by accomplishing six outputs and a number of sub-outputs. In the annual workplan, activities associated with each output were outlined and responsible individuals identified to carry out specified tasks. Hence, progress towards attaining project objectives were measured by relating milestone events achieved in completing tasks and activities under each of the six outputs. Available fiscal and human resources could then be re-allocated as necessary to support key activities in the annually developed and updated work plans.

The six outputs recognized by IBSNAT are listed below:

Output 1	Database Management System
Output 2	Decision Aids
Output 3	DSSAT User Application Software
Output 4	Collaborative Research Networks
Output 5	Applications/Demonstrations
Output 6	Acceptance

The first three outputs are described under the heading "Products" in this report and are the three essential components of the DSSAT software. Accomplishments under the remaining three outputs are described in similarly identified sections in this report.

Management of the IBSNAT project involved the coordination and harnessing of available human and fiscal resources to achieve project objectives. Planning to merge scientific visions with fiscal realities required interaction of IBSNAT's principal investigator, its core staff and its subcontractors with the Technical Advisory Committee and the Management Review Group (MRG). Annual technical work plans were developed in consultation with the Technical Advisory Committee. The work plans and associated budgetary plans for fiscal support of activities were then merged and reviewed by the MRG for implementation.

The Research Corporation of the University of Hawaii (RCUH) served as the facilitating group for all expenditures and accounting of funds, including personnel matters.

Fiscal Support

The IBSNAT project was initially established as a cost-reimbursement contract between the U.S. Agency for International Development (USAID) and the University of Hawaii in 1982 for a period of 5 years for $5.1 million. Of that total, $4.3 million was actually awarded by USAID under the contract.

A cooperative agreement subsequently replaced that contract in 1987. Under this latter arrangement, the University of Hawaii, through RCUH, was required to document cost-sharing in an amount equivalent to 25% of the funds provided by USAID. The projected budget for this 5-year agreement was $5.4 million and was the amount awarded. The University of Hawaii contributed in excess of $1.35 million, including faculty and staff time, over that same period.

Leveraging of available resources was a key ingredient to the success of IBSNAT. Participants in the IBSNAT network used their own time and resources to generate and contribute data sets to develop, calibrate, and validate the crop models in DSSAT and to test DSSAT itself. Their contribution cannot be underestimated. For every dollar spent by USAID, we estimated a matching amount of nearly five times or more was spent by collaborators. Networking and a common goal to develop a decision tool or product resulted in a synergism embodied in IBSNAT collaboration.

Management Team

Groups involved in the management and implementation of IBSNAT activities are described in the following paragraphs.

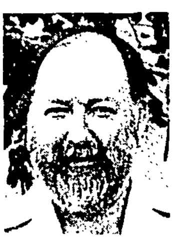
Technical Advisory Committee

The IBSNAT project was guided by its Technical Advisory Committee (TAC) of six internationally recognized scientists from varied disciplines and backgrounds to develop an interdisciplinary systems approach to agrotechnology transfer. Originally consisting of four members in 1984, the group added two additional members in recognition of the scope of disciplines necessary to achieve IBSNAT's objectives.


J.A. Comerma


J.B. Dent


L.A. Hunt


H.A. Nix


P.S. Teng


J.T. Ritchie

J.T. Ritchie of Michigan State University served as chairman of the TAC from its inception in 1985. He occupies the Homer Nolin Chair in the Soil and Crop Science Department at MSU. Members of the TAC represented a number of disciplines and a number of countries.

TAC Member	Discipline	Organization	Country
J.A. Comerma	Pedalogy	FONAIAP-CENIAP	Venezuela
J.B. Dent	Economist	Edinburgh University	Scotland
L.A. Hunt	Plant Genetics	University of Guelph	Canada
H.A. Nix	Ecology/Environment	Australian National University	Australia
P.S. Teng	Plant Pathology	IRRI	Philippines
J.T. Ritchie (Chairman)	Soil Science	Michigan State University	USA

Members of TAC provided the vision and the leadership to establish an international collaborative research network capable of making a difference in sustainable land management and agricultural development. Their vision was based on the premise that it would be more efficient to improve agroecosystems performance using validated simulation models than by experimenting with the system itself. And they reasoned that the development and validation of such models would require an international team effort. The TAC was not an oversight group but a participatory group.

Management Review Group

By establishing a cooperative agreement between the contracting agency, USAID, and the contractor, the University of Hawaii, a Management Review Group (MRG) was organized to oversee and approve annual workplans under this agreement. The MRG was composed of T. S. Gill, Chief of the Renewable Natural Resources Division, Office of Agriculture, Bureau for Science and Technology, USAID/Washington; M. R. Smith, Assistant Director, Hawaii Institute for Agriculture and Human Resources, University of Hawaii; and the principal investigator of IBSNAT, G. Uehara, University of Hawaii. The MRG met annually as part of the review process.

Core Staff

Coordination and monitoring of activities and tasks within the network were the responsibilities of the principal investigator and a core staff (varying between 5 to 10 members) located at the University of Hawaii. The responsibilities of this staff were to provide technical, communications, and logistical support to subcontractors, members of the IBSNAT network, and both the contractor and contracting agency. As part of the cooperative agreement, the principal investigator's salary was provided for by the University of Hawaii. All other core staff were compensated with funds from USAID.

V. AhLoy.

Core staff members, past and present, are listed below:

Administrative/ Project Officers	A. E. Chang	L. E. Higa
	R.K.L. Melton	
Fiscal Specialists	S. Sakumoto	A. Shimamura
	C. Kerley	
Secretary	N. Murabayashi	L.Mukai
	S. Sato	P. McKemy
Computer Programmers	C. P. Y. Chan	A. Denault
	A. C. Tang	H. Chan
	D. Imamura	
Editors	J. Palacio	R. Moulun
	S. Balas	
Publications Specialists	V. Pecsok	A. Miyata
	E. Kim	K. Nakama
	L. Raine	
Graphics	P. Choy	S. Yuu
Technical and Field Staff	A. E. Chu	R. Ogoshi
	P. C. Ching	V. Ah Loy
	B. G. Cagauan, Jr.	R. Jacintho
	L.A. Manrique	T. Jacintho
	U. Singh	M.I Tarpley
	H.O. Pinnschmidt	
Principal Investigator	G. Uehara	
Project Manager	G. Y. Tsuji	

Subcontractors

Subcontractors played a crucial role in IBSNAT. All subcontracts entered into were primarily related to model development, calibration and validation. Funds provided through subcontracts allowed each subcontractor to supplement ongoing research on model development, and in many cases, the employment of one or more post-doctoral researchers through IBSNAT accelerated the development and validation of crop models for installation in DSSAT.

At the time IBSNAT was established in 1982, functional models for testing were available for wheat, maize and soybean. By the time DSSAT was released in 1989, there were four validated models available, with the addition of one for peanut. Since then, eight models have been added.

The development of DSSAT involved all subcontractors and the University of Georgia through G. Hoogenboom. While each may have been involved in the development of a particular model or application of the model, they were all involved at different levels in the design and development of DSSAT.

Subcontractor	Contacts	Product
University of Florida	J. W. Jones K. Boote G.Hoogenboom	SOYGRO, PNUTGRO, DSSAT, AEGIS, BEANGRO
University of Guelph	L. Anthony Hunt	GenCalc, SUBSTOR-Cassava, DSSAT
Michigan State University	J. T. Ritchie	CERES-Maize, Wheat, Sorghum, Millet, Barley, SUBSTOR-Potato
University of Puerto Rico	F. H. Beinroth	SUBSTOR-Aroids, AEGIS
University of Edinburgh	J. B. Dent	Whole Farm Systems
International Fertilizer Development Center	P. K. Thornton D. C. Godwin U. Singh W. T. Bowen	CERES-Rice, Sorghum, SUBSTOR-Aroids, Nitrogen, Phosphorus, DSSAT
International Rice Research Institute	P. S. Teng H. O. Pinnschmidt	Rice Blast Module

IBSNAT collaborators, with training staff, attending courses at the University of Hawaii.

Products

Crop Models

DSSAT v2.1

DSSAT v2.5

DSSAT v3

Crop Models

At its inaugural meeting at ICRISAT in 1983, principals of IBSNAT met with a multi-disciplinary group of scientists to explore common interests in developing a new strategy to accelerate the process of agrotechnology transfer. This innovative strategy involved the integration of traditional trial-and-error research and analog transfer methods with a systems approach. Systems analysis and simulation to facilitate the transfer of agrotechnology required the adoption of technological advances of both the computer and information sciences. That meant crop simulation models would have a central role in the success of IBSNAT.

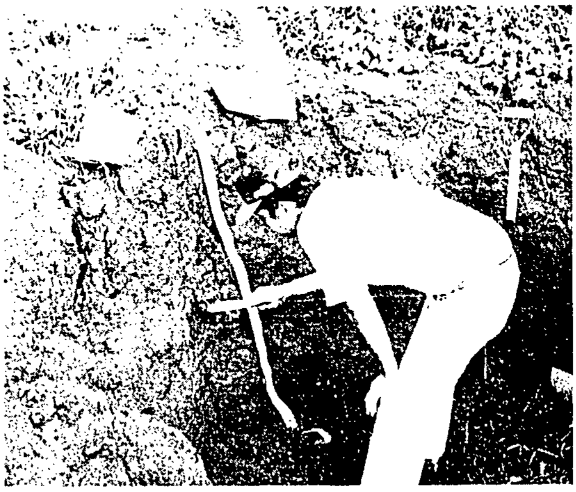
Of the the major food crops initially identified at that first meeting at ICRISAT, only three had functional crop models: CERES-Wheat, CERES-Maize, and SOYGRO. These three models eventually provided the common foundation and structure from which other crop models would be developed. The number of crops and crop models developed by IBSNAT eventually increased to 12 – barley, rice, sorghum, millet, peanut, dry bean, potato, aroid and cassava.

These models were designed to have global applications, and thus have been constructed to be independent of, and be able to accommodate, differences in locations, seasons, crop cultivars and management systems.

The IBSNAT crop models are mathematical representations of daily biological and physical processes and are used to predict harvestable yield, plant growth and development, nitrogen dynamics and water balance in response

Minimum weather data sets were routinely monitored in Rayong, Thailand.

to controlled (management) and uncontrolled (weather) variables.



All of the IBSNAT models simulate the effects of weather, soil, water, cultivar and nitrogen dynamics in the soil and the crop, on crop growth and yield.

When provided with the specific minimum data sets of soil, crop, weather and management , the accommodating characteristics of IBSNAT crop models enable the prediction of performance for any crop production system at any location and season. In order to predict a crop's potential, IBSNAT crop models require the following information.

1. The daily weather data consisting of maximum and minimum air temperatures, solar radiation and precipitation.
2. The standard soil description including data of key soil properties as a function of depth.
3. Information on sowing date, plant population, amounts and dates of irrigation and amounts and dates of N-fertilizer.
4. Genetic information related to maturity type, photoperiod sensitivity and yield components needed to evaluate optimum efficiencies within the constraints of weather and soil.

IBSNAT's intent was to use simulation models to assess crop performance in locations where the crops had never been grown, thus enabling users to assess the suitability of particular lands for specific crops, estimate productivity of the land and prescribe soil and crop management practices to obtain optimum production for specified conditions.

Inputs and outputs to the crop models have been standardized and documented (IBSNAT 1986, 1990), to increase the efficiency of sharing data, to allow the introduction of other crop models and to allow application programs in the IBSNAT Decision Support System for Agrotechnology Transfer (DSSAT, IBSNAT 1989) to be used with any of the crop models.

"Genetic coefficients make it possible for models to predict the performance of diverse cultivars on a global scale, independent of location, season and management."

Cereal Models: Wheat, Maize, Barley, Sorghum, Millet and Rice

CERES-Wheat developed by:
D.C. Godwin, IFDC & CSIRO;
J.T. Ritchie, Michigan State University.

CERES-Maize developed by:
J.T. Ritchie, MSU;
C.A. Jones, Texas A&M University;
J. Kiniry, ARS/USDA, Temple, TX.

CERES-Barley developed by:
J.T. Ritchie, MSU;
B.S. Johnson, MSU;
S. Otter-Nacke, MSU.

CERES-Sorghum developed by:
J.T. Ritchie, MSU;
U.Singh, IFDC;
G. Alagarswamy, ICRISAT;
G. Rao, ICAR (India).

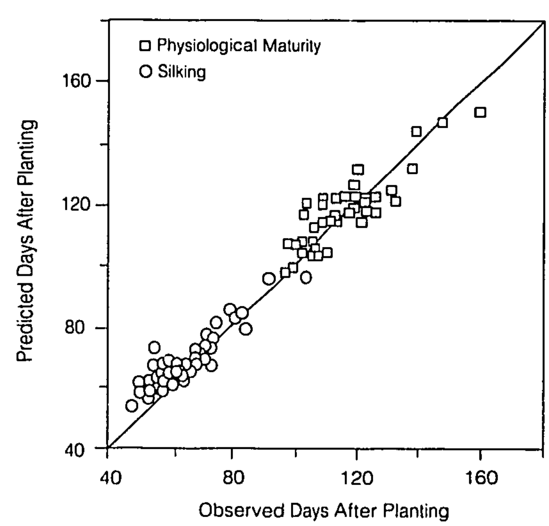
CERES-Millet developed by:
J.T. Ritchie, MSU;
Y. Ramakrishna, ICAR (India).

CERES-Rice developed by:
U. Singh, IFDC;
J.T. Ritchie, MSU;
D.C. Godwin, IFDC & CSIRO.

The cereal, or CERES (Crop-Environment Resource Synthesis), family of crop models is used in DSSAT to predict the performance of six grain crops. All six of these models are designed to use a minimum set of soil, weather, genetic and management information. The models 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.

The CERES models use a minimum of readily available weather, soil and variety-specific genetic inputs. To simulate growth, development and yield, the models take into account the following processes:

- Phenological development, especially as it is affected by genotype and weather. The models simulate the effects of photoperiod and temperature on the timing of panicle initiation and the duration of each major growth stage;
- Extension growth of leaves, stems and roots;



Testing CERES-Maize in the tropics for predicting phenology.

* Biomass accumulation and partitioning, especially as phenological development affects the development and growth of vegetative and reproductive organs;
* Water balance that simulates the daily evaporation, runoff, percolation and crop water uptake under fully irrigated conditions, and rainfed conditions;
* Soil nitrogen transformations associated with mineralization/immobilization, urea hydrolysis, nitrification, denitrification, ammonia volatilization, losses of N associated with runoff and percolation, and uptake and utilization of N by the crop.

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

CERES-Rice

The CERES-Rice model has the same features and characteristics as those described for the other CERES models. It differs from them, however, in that it can also simulate the establishment of a rice crop from dry sowing, pregerminated seeding to transplanting. In particular, it differs in the following ways:

* Provision has been made within the model to calculate an effect of transplanting shock on crop duration;
* Water balance also simulates crop water uptake under intermittent flooding and drying and fully upland conditions where the soil is never flooded.
* In addition, the nitrogen submodel of the CERES-Rice model simulates transformations of nitrogen in the plant in both upland and lowland conditions. The model simulates the effects of nitrogen deficiency on photosynthesis, leaf area development, tillering, senescence and remobilization of nitrogen during grain filling.

With data from experiments that were conducted during the 1980s, the rice model predicted quite well, with coefficient of determination between predicted and observed ranging from 0.8 to 0.9.

---I. Amien, Indonesia

[We] study and validate CERES-Rice for upland rice in Northern Thailand in order to evaluate the potential yield and appropriate management in the area.

---S. Jongkaewwattana, Thailand

Grain Legume Models: Soybean, Peanut and Dry Bean

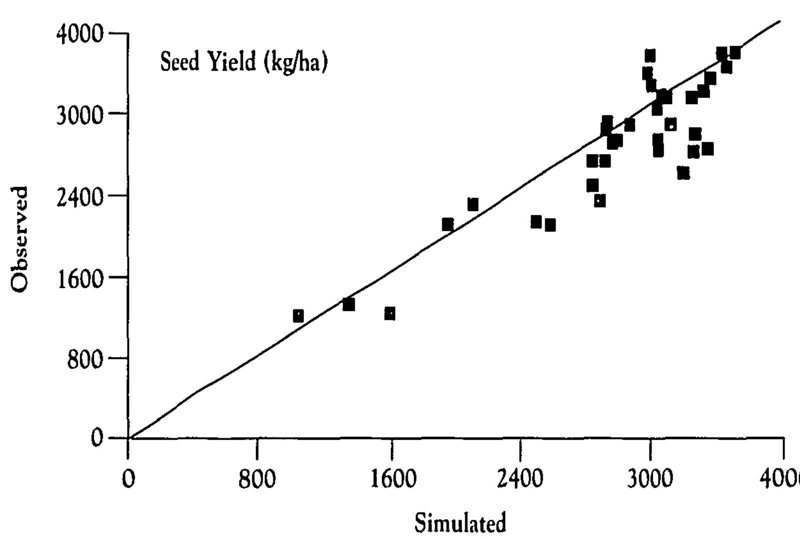
SOYGRO developed by:
J.W. Jones, University of Florida;
G. Wilkerson, North Carolina State Univ;
S.S. Jagtap, IITA.

PNUTGRO developed by:
K.J. Boote, UF;
G. Hoogenboom, University of Georgia, Griffin;
J.W. Jones, UF.

BEANGRO developed by:
G. Hoogenboom, UG, Griffin;
J.W. Jones, UF;
K.J. Boote, UF.

The grain legume, or GRO, models are also 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. As in the CERES models, a one dimensional soil-water model simulates water availability to the plants based on processes of runoff, percolation and redistribution of water. Thus, soil characteristics and weather data are required inputs. The models are also sensitive to planting date, row and plant spacings and irrigation management options.



Observed vs. simulated seed yield from SOYGRO for Bragg and Cobb soybean varieties growing in Gainesville, FL., 1976-1984, over a wide range of irrigation treatments.

Some of the applications of the GRO models are:

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

Users can input their own soil, weather and management data, as well as their own measured crop growth data from experiments or from farmer fields for testing or validating the model for their own conditions. Experiments can be simulated and compared in tabular and graphical forms with measured data. Scientists can easily conduct sensitivity analyses by interactively selecting combinations of soils, weather, cultivar and management factors. And users can conduct risk analysis studies by simulating many cropping seasons over time and space by varying weather and soil inputs.

To predict the performance of a cultivar planted on the same day at different locations, at differing elevations and different mean air temperatures, the IBSNAT crop models must be versatile and accurate. Here, T. and R. Jacintho, IBSNAT agrotechnicians, take daily measurements of soybean which was grown at one of three research stations, Kuiaha, Haleakala and Olinda Stations, located at three different elevations, on the island of Maui, Hawaii, USA.

Root Crop Models: Cassava, Aroid and Potato

The root crop, or SUBSTOR (Subterranean Storage), models are process-oriented computer models which simulate above and below ground growth and development of the vegetative and reproductive states for cassava, aroid and potato. Cassava and aroids are the only two crops of the twelve selected by IBSNAT that are grown exclusively in the tropics and subtropics. Because of the limited amount of available reported and recorded data, development and validation of crop models for both were somewhat handicapped. For cassava, data sets from CIAT were especially helpful in model development. For aroids, two crop cultivars, taro and tanier, were selected over other types for model development because of more readily available data sets from Fiji, Hawaii and Puerto Rico.

SUBSTOR-Cassava Model

SUBSTOR-Cassava developed by: R.B. Matthews, University of Guelph/IRRI;

The SUBSTOR-Cassava model for DSSAT v3 describes the growth of cassava (*Manihot esculenta* L. Crantzor) for a range of environments. Potential dry matter production is calculated from the existing leaf area, and is modified by effects of light, temperature, water stress and vapor pressure deficit. Leaf and stem growth are assumed to be the dominant sinks for assimilate, with fibrous roots receiving a decreasing fraction of that allocated to the shoot, adjusted when this is limiting. The storage roots receive any remaining assimilate. The same water balance model found in both IBSNAT CERES and GRO models is used to estimate water status. No attempt was made to include nitrogen dynamics because of the paucity of data in the literature.

It is intended, however, to modify the existing nitrogen subroutines used in other

IBSNAT crop models for inclusion in a subsequent version of the model.

Three growth phases are arbitrarily defined for present purposes:

- Planting to emergence;
- Emergence to first branching (the switch to the reproductive phase);
- First branching to maturity or final harvest. Subsequent branchings may occur during this stage.

Phenological development of the crop is described by assuming that there were two independent "clocks" - one accounting for vegetative development and the other for reproductive development. Rate of vegetative development (i.e., progression towards the stage at which leaf appearance is effectively zero) is influenced by temperature and water stress, while rate of reproductive development (progression towards branching) is influenced by both of these factors, as well as photoperiod. Vegetative aspects may also be influenced by photoperiod, but this is not incorporated at present.

The concept of the "development day" is used as the unit of each time scale. This is equivalent to chronological days at the optimum temperature and photoperiod, with no water or nutrient stresses operative. Suboptimal conditions may reduce the daily rate of progression. A characteristic number of developmental days must be reached before entering into a succeeding phase. The model was validated with the limited number of available datasets. For these, good agreement between simulated and measured values was found for a range of genotypes in a range of environments. Further validation is necessary, however, before widespread application. The factors controlling leaf size and times of branching were identified as areas in which there is a scarcity of knowledge, and to which future cassava physiology research should be directed.

The cassava model will be used as a research tool of the Multiple Cropping Center of Chiang Mai University and in the Department of Agriculture, Thailand. The Khon Kaen Field Crop Research Center will be the key institution in this regard.

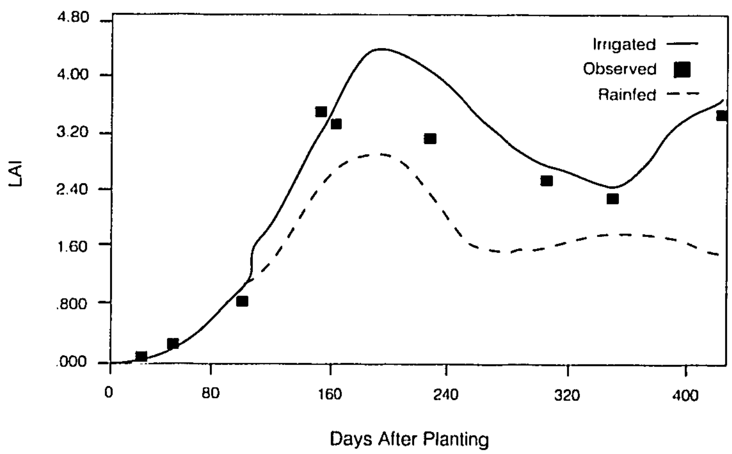
----A. Jintrawet, Thailand

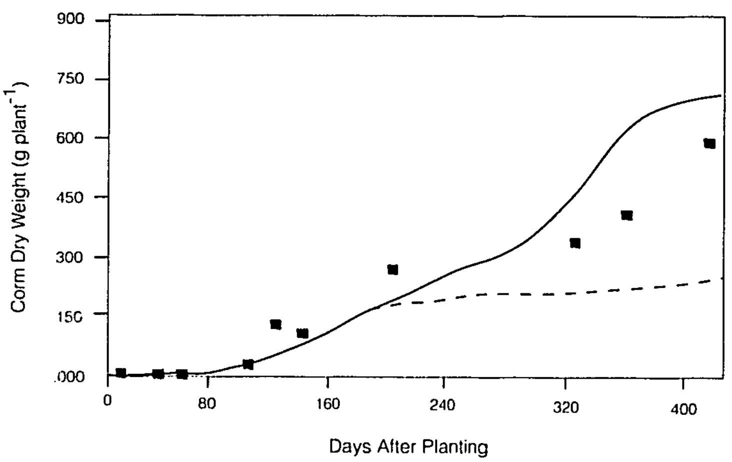
SUBSTOR-Aroid Model

SUBSTOR-Aroids developed by:
U. Singh, IRRI/IFDC;
H. Prasad, University of Hawaii, Sprad;
R. Goenaga, ARS/TARS, Mayaguez, PR.

SUBSTOR-Aroid is a dynamic crop growth model that simulates the growth and development of taro and tanier on a daily basis from planting to harvest. Development of the SUBSTOR-Aroid model has focused on a cultivar commonly grown in the Pacific, Caribbean, tropics of Africa and southeast Asia, known as taro (Colocasia esculenta). The model can simulate plant growth for any of the following methods of planting: transplanting, direct planting of petiole-corm cuttings or hulis, and direct planting of mini-sets or buds.

The model is designed to simulate growth and development of aroids 1) at potential productivity or 2) limited only by the availability of water. The nitrogen version of the model is currently under development. The water balance model used in the IBSNAT models is also used in SUBSTOR-Aroid. It has an added lowland component with the ability to simulate a flooded field with a bund.





Simulated response of LAI and total corm growth to irrigated and rainfed treatments. Observed data is for irrigated treatments for taro variety, Bun Long.

This is the first attempt to develop a model for a tropical root crop with a predominantly subsistence base. Edible aroids, particularly taro and tanier, have considerable untapped potential as a food and energy source. SUBSTOR-Aroid can realistically capture the differences between taro and tanier, as well as the effects of varieties, weather conditions and irrigation regimes.

Data sets for model calibration and validation are limited. They are now being generated by researchers with the Tropical Agricultural Research Station (TARS) of the ARS/USDA 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 IFDC. The USDA/ARS/TARS effort in Puerto Rico is a major one and should substantially accelerate model development.

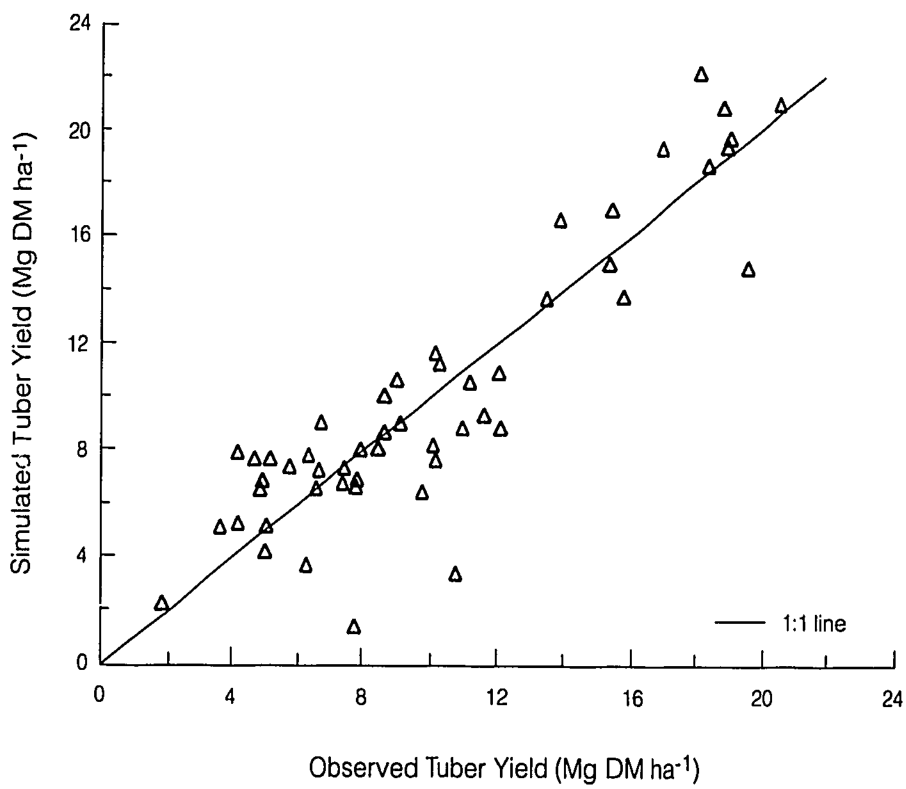
Taro (Colocasia esculenta) is a commonly grown aroid in the Pacific, the Caribbean, and Southeast Asia.

I have conducted field experiments with tanier (Xanthosoma spp.) and taro (Colocasia spp.). Data from these experiments have been used to generate coefficients needed for model development.

SUBSTOR-Potato Model

SUBSTOR-Potato developed by:
T.S. Griffin, MSU;
B.S. Johnson, MSU;
J.T. Ritchie, MSU.

The SUBSTOR-Potato model was developed as a CERES-type crop model and thus uses capacity type models of soil water and soil N dynamics that are used in other CERES-type models. SUBSTOR-Potato is a dynamic computer model which simulates growth and development of the potato crop over a wide geographical range and for different cultivars, and includes a new approach to incorporating temperature and photoperiod effects on tuber initiation. It also simulates growth using a capacity model for carbon fixation constrained by radiation, high temperatures, nitrogen deficit and soil water stress.



Simulated versus observed tuber yield for potato cultivars grown in 10 different locations.

The general approach taken to simulate phenological development was to incorporate both temperature and photoperiod effects. The integration of climatic effects, the extrapolation of linear tuber bulking to define tuber initiation and the recognition of cultivar differences, which are features unique to this model, represent a new approach to modeling potato development. This approach takes into account the obvious effects of photoperiod on delaying or hastening tuber initiation. It also recognizes that cultivars are distinctly different in their response to climate, though it is realized that refinement of the cultivar-specific genetic coefficients are likely. Furthermore, this approach greatly simplifies the simulation of tuber initiation, although this may change as the physiological basis and control factors for tuber initiation are clarified.

The validation set for SUBSTOR-Potato included a wide arrange of geographical regions, cultivars and management intensities (e.g., irrigation, N fertilization). Because of the diversity of these data, however, model validation was intentionally limited in several ways. First, a formal sensitivity analysis was not conducted because the inclusion of diverse data in the validation set seemed to make such analyses redundant. The second limitation is the scope of validation specifically for plant stress factors. Although the validation set inherently addresses the effects of N and soil water stresses on development, growth and yield, validation statistics on plant-soil N (or water) balance were not included because most data sets did not include sufficient soil and plant N analyses to adequately evaluate the nitrogen subroutines in the model. Thus, the SUBSTOR-Potato model validation may be considered preliminary, but the model has great potential for simulating potato growth and for evaluating potential changes in management in many regions.

The crop models have been used to compute the different suitability of soils using different scenarios (amount of available water for irrigation).

---J. Boixadera, Spain

Other Crop Models

In 1983, ten crops were identified by participants in the first IBSNAT symposium as major food crops for which crop models should be developed. Two additional crops were subsequently added. These food crops are categorized as cereals, grain legumes and root crops. During the decade, many have asked if tree crops, both fruit-bearing or leguminous fuelwood and vegetable crops, could be added to the IBSNAT list. IBSNAT's response has been an affirmative one. In many instances, requesters were advised of the kind of support IBSNAT could provide to assist in developing a new or adopting an existing model to conform to the input and output formats of IBSNAT crop models.

Several examples of reported crop models bearing the IBSNAT input/output file structures include the following:

Crop	Model Developers
Sunflower	F. Villalobos, Cordoba, Spain
	A.J. Hall, Buenos Aires, Argentina
	J.T. Ritchie, MSU
Sugarcane	G. Inman-Bamber, South African Sugar Association (SASA), Natal, South Africa
	G. Kiker, J.W. Jones, Florida, USA
Pineapple	D. Bartholomew, Hawaii, USA
	J. Zhang, Hawaii, USA
	E. Malezeiux, CIRAD, Paris, France
Cotton	B. Kimball, ARS/Phoenix, USA

The sunflower model was developed with support from J.T. Ritchie of IBSNAT and Michigan State. An operational version of the model will be made available for installation in DSSAT v2.1 and can be validated for application by DSSAT users. R. Dukov of Bulgaria has provided data sets to IBSNAT for calibration and validation tests with varieties grown there.

Models for sugarcane and pineapple were developed using the IBSNAT/CERES framework. Both are plantation-type agricultural cash crops and are grown extensively in tropical and subtropical areas. The sugarcane model developed by Inman-Bamber and Kiker have been named CANEGRO v1 and v3, respectively. The Australian version is being developed as a module in CSIRO's APSIM (Agricultural Productivity Simulator). APSIM has many features common to DSSAT, including a common database for all modules.

The cotton model is being used in the FACE (Free-Air CO2 Enrichment) project of the International Geosphere/Biosphere Program (IGBP).

S. Meeker of CSIRO reported a pigeon pea model was developed by Australian scientists after attending an IBSNAT training course at ICRISAT in India in 1988. SOYGRO was used as a "template." The IBSNAT crop model structure was also used to initiate development of a crop model for peas by the Research Institute of Soil Science and Agricultural Chemistry (RISSAC) of the Hungarian Academy of Sciences; G. Hoogenboom cooperated on this effort in 1992.

I am working on adaptation of the already developed IBSNAT models of maize, wheat, soybean, peanut and dry bean in conditions of Bulgaria... for... the sunflower model.

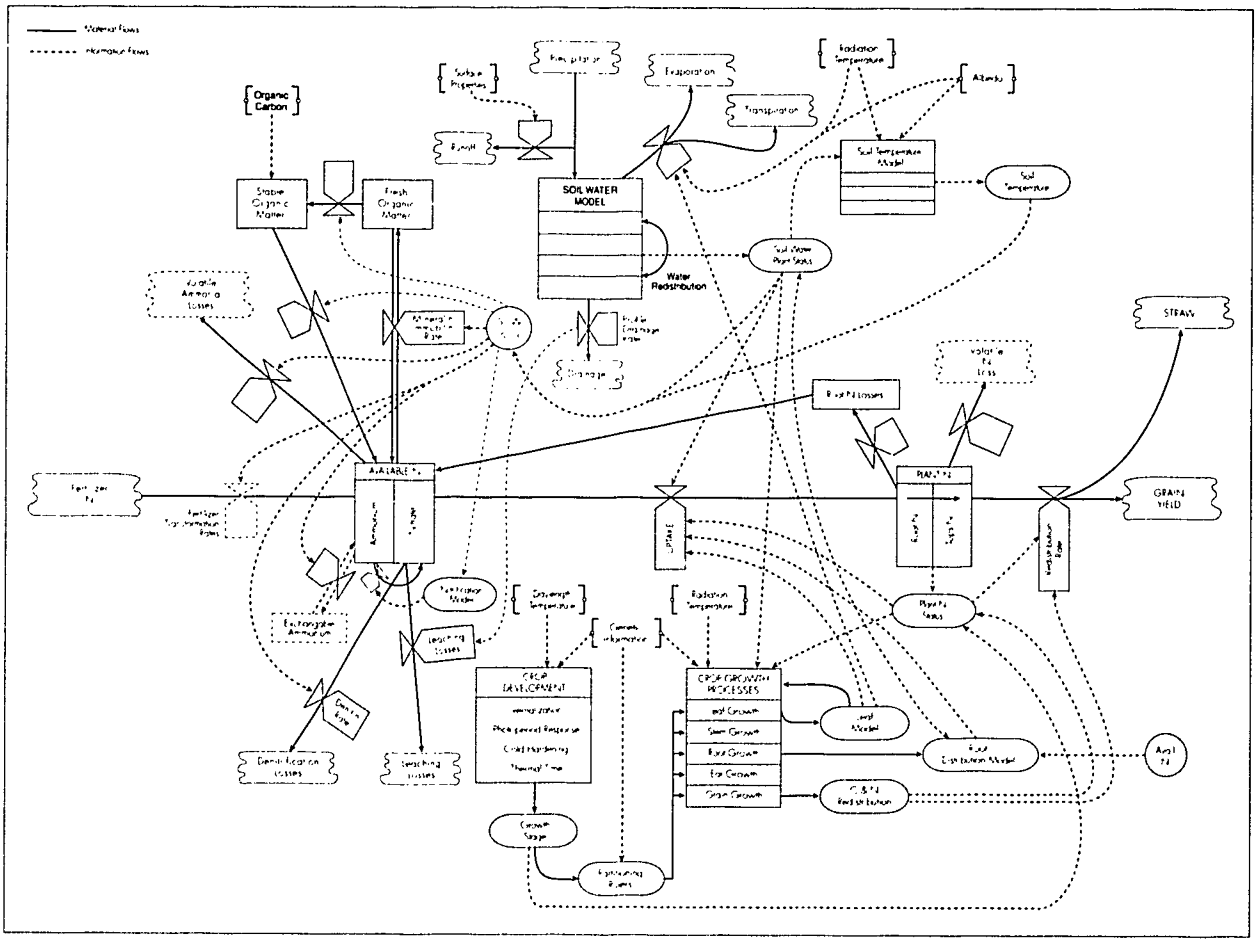
---R.N. Dukov, Bulgaria

Crop Model Nutrient Subroutines

Nitrogen Dynamics: CERES Models

CERES Nitrogen Module
developed by:
D.C. Godwin, IFDC;
U. Singh, IFDC;
P.K. Thornton, IFDC.

The nitrogen submodel of the CERES crop models is designed to interact with the Ritchie 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 lengtl density, soil-water availability, and plant nitrogen demand.



Systems diagram of the nitrogen model for non-flooded conditions.

In the CERES-Rice model, two processes are described: upland and lowland. The upland N model simulates the processes of turnover of soil organic matter and crop residues and the associated mineralization and/or immobilization, urea hydrolysis, movement of urea and nitrate with drainage and evaporation, nitrification, and denitrification, losses of N associated with runoff and percolation, the uptake and utilization of N by the crop, 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.

The lowland rice model uses three components: the floodwater, a thin oxidized soil layer and the bulk of the soil mass that is reduced when flooded. The soil N transformations can take place in puddled and nonpuddled soils. The N model 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.

The model simulates nitrification and denitrification as simple first order rate processes. Nitrification is an aerobic process and does not normally occur in flooded, reduced soil. In the model, when the soil is flooded, nitrification calculations are performed only for the oxidized layer. Under upland conditions or in drained soil, nitrification is simulated in all soil layers.

Denitrification occurs under anaerobic conditions. In the procedure, indices for temperature, water-filled pore space (as a surrogate for oxygen supply) and soil soluble carbon are used to modify denitrification rate.

Testing of the simulation of crop response to nitrogen has been extensive. Summary testing of CERES-Wheat against 233 observed data indicate 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.

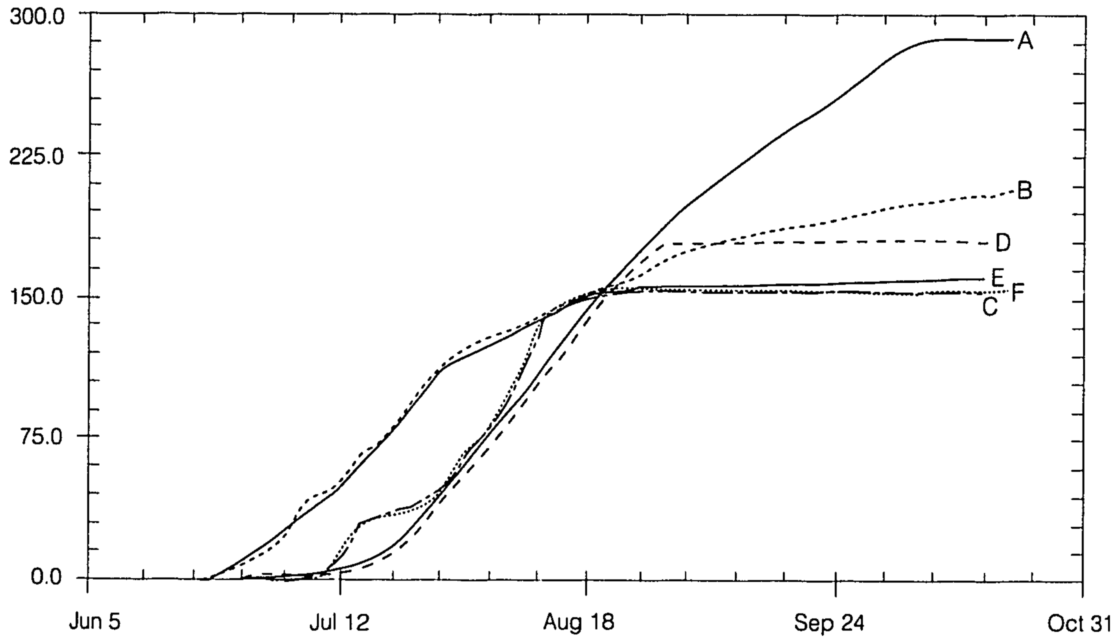
We have been using the CERES-Wheat N model to study the response to N fertilizer in dry, wet and normal years in South Eastern Australia.

---K.J. Bheenick, Mauritius

Nitrogen Dynamics: GRO Models

GRO Nitrogen Module developed by:
G. Hoogenboom, UG, Griffin;
J.W. Jones, UF;
P. Singleton, NifTAL, UH;
W.T. Bowen, IFDC.

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 to simulate nitrogen uptake, fixation, and remobilization or leaching. 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 nitrogen fixation, nodule growth and nodule initiation. The subroutine also accounts for the depressing effect of high fertilizer nitrogen on biological nitrogen fixation. Calibration and validation of the nitrogen fixation function of the model is being carried out in cooperation with the NifTAL Project.



(1.00)	N FIXED kg/ha	-	IRRIGATED	A
(0.100000)	N UPTAKE kg/ha	-	IRRIGATED	B
(0.100000)	N LEACH kg/ha	-	IRRIGATED	C
(1.00)	N FIXED kg/ha	-	NON - IRRIGATED	D
(0.100000)	N UPTAKE kg/ha	-	NON - IRRIGATED	E
(0.100000)	N LEACH kg/ha	-	NON - IRRIGATED	F

Simulated results of nitrogen fixation, uptake and leaching for irrigated and non-irrigated soybeans planted on June 5.

Phosphorus Dynamics: All Models

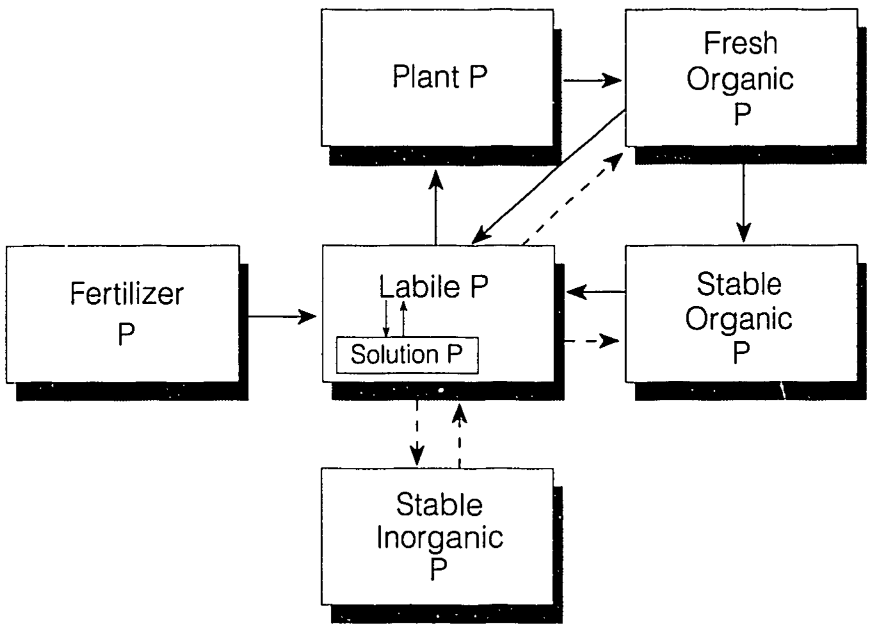
A phosphorus submodel of the IBSNAT crop models is under development at IFDC, This submodel will be closely coupled to the water balance, nitrogen balance and plant growth routines. The submodel simulates absorption and desorption of soil phosphorus, organic phosphorus turnover and the dissolution of 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 Module developed by:
U. Singh, IFDC/IRRI;
W.T. Bowen, IFDC;
D. Hellums, IFDC.

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 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 tissues. The deficiency dernand, on the other hand, is the amount of phosphorus required to raise the actual phosphorus concentration to a critical phosphorus concentration.

The phosphorus supply for each layer is calculated using soil



Phosphorous pools and their relationships in the IBSNAT models.

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.

Programming and testing of routines for simulating phosphorus dynamics in plant and soil will continue at IFDC. Working versions of these routines will initially be coupled to CERES-Maize, SOYGRO and BEANGRO for testing. As with the soil water balance and nitrogen dynamics submodels, the phosphorus submodel will be programmed for coupling to each crop model.

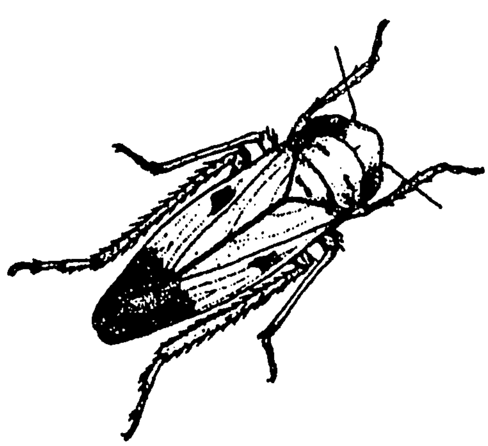
Pest-Crop Coupling

Rice Pest Link developed by:
P.S. Teng, IRRI;
H.O. Pinnschmidt, IRRI.

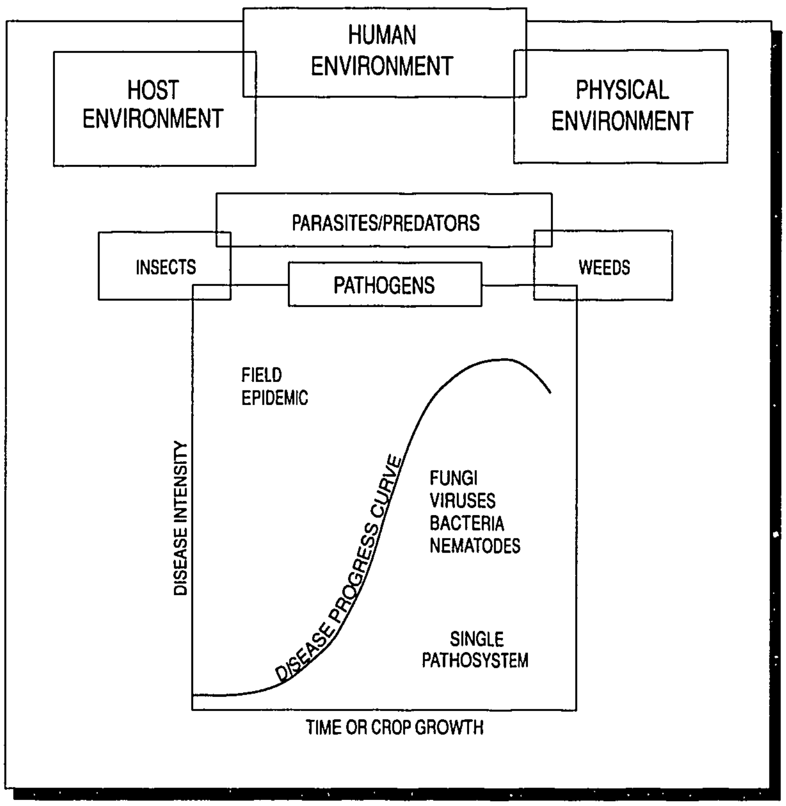
Grain Legume Pest Link developed by:
W. Batchelor, UF;
K.J. Boote, UF;
J.W. Jones, UF.

IBSNAT has developed a generic pest coupling approach that allows the input of scouting information on pest infestation levels or damage. Although it has become obvious over the years that IBSNAT crop models are only capable of predicting yield in situations that are relatively pest-free, it has become equally obvious that highly mechanistic simulators of pest population dynamics, while being excellent tools for understanding pests, require difficult-to-obtain regional level inputs. For example, there is a low probability of success for an insect population dynamics model to predict *a priori* insect populations during the season from an initial pest input and seasonal weather. The difficulty is not necessarily with the model, but with seasonal influxes of migrating insects dependent on numerous factors, and on highly variable mortality factors.

Many pest management decisions are based on periodic (i.e., weekly) sampling of pest populations or plant damage caused by pests. If a given pest population or damage is above a threshold, some pest control action, such as pesticide application, is made. Sometimes referred to as "scouting reports," the data collected during these periodic field surveys could be used as feedback information to adjust pest simulators to allow for improved predictions of pest populations for the next few weeks, and forecasting when the thresholds would be exceeded.



Alternatively, scouting data could be used as direct input into crop models. Using this approach, scouting data on pest numbers or damage to the crop are input into crop models in order to predict yield reduction from pests. Damage is described in terms of either observed damage or observed pest numbers rather than being generated using independent pest models. The user is required to maintain time course data describing pest related damage or particular pest levels. This information is typically collected through pest scouting. Pest levels are converted to damage in a pest coupling routine using feeding rate coefficients which can be a function of pest stage. Once the timing and amount of damage are ascertained, the damage is applied to the proper variables in the crop models. Using this approach, pest damage can be simulated on a real time basis.



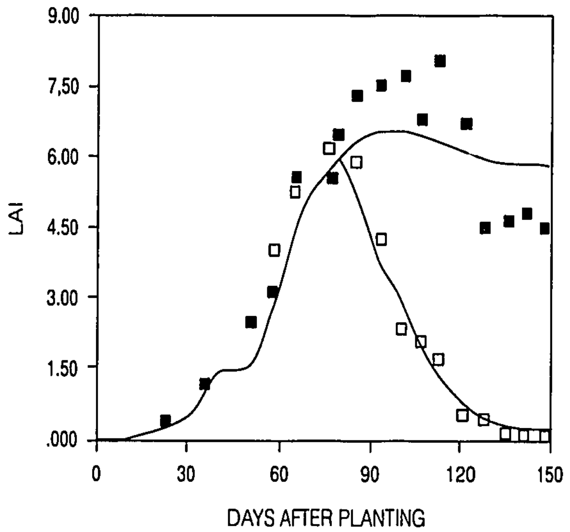
Schematic representation of the operational environment for a disease epidemic (Teng, 1985).

Generic Damage Types and Coupling Points

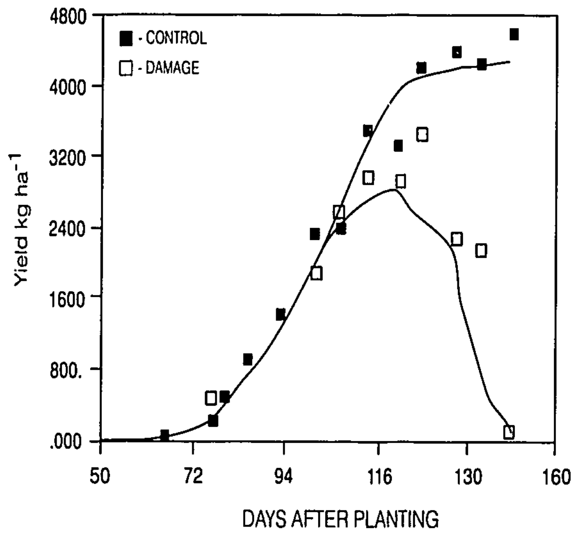
In order to develop a generic framework for applying damage to crop models, selected damage types have been identified and defined, and linkage between the damage and the crop determined. Boote et al. (1983) have developed a general classification scheme for pests affecting row crops.

We are using the wheat crop model (CERES) to incorporate disease data for North Carolina (powdery mildew and leaf rust).

---S. Leath/C. Garcia, North Carolina



Simulated and observed leaf area index for peanut with and without late leafspot disease (Bourgeois et al., 1991).



Simulated and observed seed yield for peanut with and without late leafspot disease (Bourgeois et al., 1991).

They define tissue consumers as pests that consume leaf, seed, shell, stem, or root tissue. Stand reducers are defined as pests that reduce the number of plants, while assimilate sappers are pests that consume assimilate from host cells while leaving the cells intact. They also defined other categories of pest damage.

Pest Damage Type	**Type Plant Damage Mechanism (or Coupling Point in Crop Model)**	**Units**
Tissue Consumption	leaf mass	g leaf/m2
	leaf area	m2 leaf/m2
	stem mass	g stem/m2
	root mass	g root/cm2
	root length	cm root/cm2
	root length volume	cm root/cm3
	seed mass	g seed/m2
	seed number	no. seed/m2
	shell mass	g shell/m2
	shell number	no. shell/m2
Stand Reduction	whole plant number	no. plants/m2
Assimilate Consumption	daily carbohydrate supply	g CH_2O/m2

List of coupling points or plant damage types to be included in the CERES and GRO models in DSSAT v3.

A coupling point in a crop model is a variable to which a specific damage type is applied. Coupling points can be state variables such as leaf, stem, seed, shell, or root mass, as well as rate variables such as daily photosynthetic rate or rate of tissue senescence. In some cases, coupling points may be other variables such as leaf area index or seed number. Using this definition, researchers identified several of the major damage types and associated coupling points caused by pests in soybean, rice and peanut.


Effects of downey mildew on maize.

Damage Input Structure—Pest Damage Files

A general structure was developed by Batchelor et al. (1991) to organize and facilitate input of pest damage into crop models. Two data files were defined for this purpose. The first file, the pest progress file, maintains a record of observed pest or damage levels in a given field. Pest populations can be obtained from field scouting reports commonly used in both commercial and research fields.

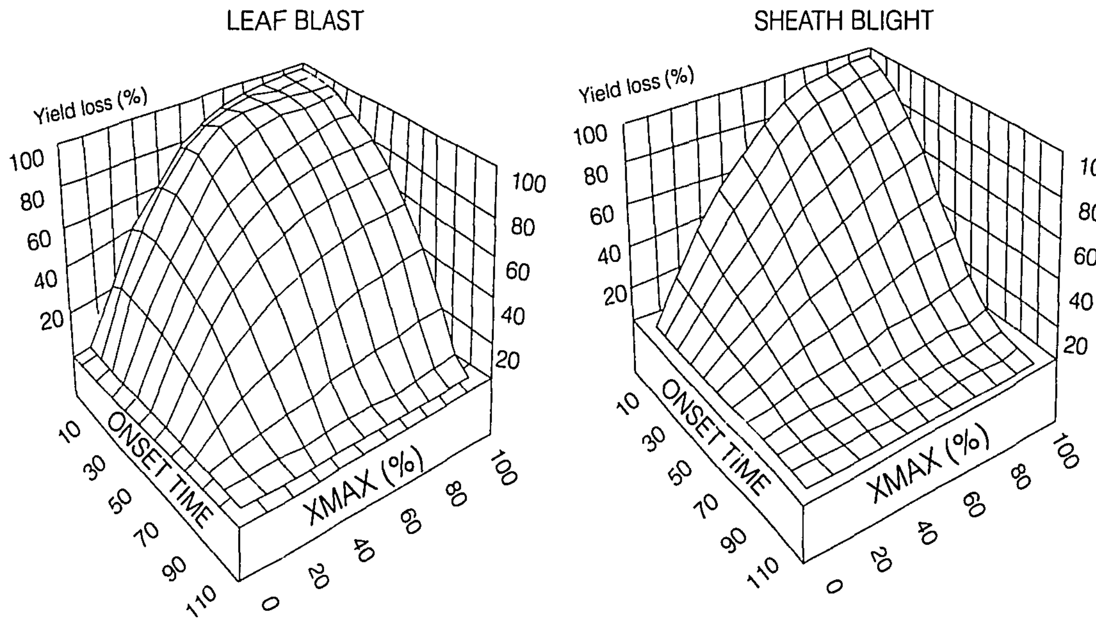
The pest coefficient file is analogous to the genetic coefficient file in the crop models. It is a permanent file which would be developed by specialists such as entomologists or pathologists who are familiar with particular pest types. This file contains characteristics of particular pests including feeding rates, coupling points, and feeding site preferences.

Information in this file combined with the DSSAT minimum experimental data set (observation date, type of pest or damage, and density, (IBSNAT, 1989)) can be combined to compute a specific damage amount or rate on each observed damage date. Pest information from the coefficient and progress files are then read in at the beginning of the simulation. The pest/damage levels are linearly interpolated between observation dates in the daily growth loop in the crop model, and potential damage rates calculated for each coupling point.

Applying Damage to Crop Growth Models

A set of crop model variables was selected as pest coupling points for implementing pest damage in the CERES and GRO models. Damage is applied to

I feel DSSAT has tremendous potential if pest and disease models can be produced....
---J.A. Mulliken, Nebraska



Simulated yield loss resulting from pest scenarios for leaf blast and sheath blight (Pinnschmidt et al., 1990).

these variables according to the types and amount of pests or damage in the pest progress file. Related variables in the crop models are also modified because of their association with the primary variables listed below. For example, if leaf mass is consumed, leaf area index should be reduced, as well as the amount of protein and nitrogen stored in the leaves. This structure was designed to account for all subsequent damage effects for any valid damage input.

The structure of the pest-crop link allows insect population levels or observed damage levels from routine scouting data to be input into a pest pro-gress file. Insect population levels are then converted into damage rates for plant parts and applied to the crop models. Because this structure is generic, insect population and damage rates could also be generated by pest models or estimated by experts.

The damage routines give the models the flexibility to effectively simulate different combinations of pest levels on different dates. Overall, the model gave good agreement with measured data.

This link will extend the practical applications of crop models to a broad range of problems that occur in the real worlo. It is hoped that this module, linked with crop models, will be able to assist researchers in developing and improving decision aids for pest-crop management.

Genetic Coefficients

For a crop model to be truly generic –that is, capable of accurately simulating growth and development of any genotype at any location in any season– it must contain functional relationships that specify how a given genotype will interact with a given environment. The IBSNAT approach to development of truly generic crop models is to use a set of notational coefficients that specify the genotype x environment interaction. These are termed genetic coefficients. Genetic coefficients are, in essence, the behavioral fingerprint of a crop cultivar. They summarize, quantitatively, how a particular cultivar responds to an array of environmental factors, such as maximum and minimum temperature, daylength and soil water and nitrogen contents, and make it possible for models to predict the performance of diverse cultivars on a global scale, independent of location, season and management.

Genetic Coefficient Concept developed and implemented by:
L.A. Hunt, University of Guelph;
J.T. Ritchie, MSU;
S. Parajasingham, University of Guelph;
R.M. Ogoshi, UH.

The number of genetic coefficients in a crop model varies from model to model, depending upon the number of key phenological and morphological processes required to accurately simulate cultivar x environment interactions. For example, there are five coefficients for maize. These are designated P1, P2, P5, G2, and G3. The letters P and G stand for phasic (phenology) and growth, respectively. The biological meanings of these five are as follows.

- P1 – Duration (expressed in degree days above a base temperature of 8° C) of the phase during which the plant is not responsive to change in day length. This corresponds to the period from emergence to the end of the juvenile phase.
- P2 – Extent to which development (expressed as days from emergence to a specific development stage such as tassel initiation) is delayed when the plants are grown in a daylength one hour longer than the optimum (12.5 hours).
- P5 – Degree days above a base of 8° C from silking to physiological maturity.
- G2 – Maximum possible number of kernels per plant.
- G3 – Kernel filling rate during the linear grain filling stage when conditions are optimum.

[We are] working on determining the genetic coefficients of two of our local maize varieties CGR52 and R201?. Once these are derived, DSSAT is to be used in assessing risk in dryland maize production and management options to minimize this risk.

---Z. Shamudzarira, Zimbabwe

Determination of Genetic Coefficients

In general, genetic coefficients for a cultivar can be determined in the field or in a controlled environment setting. In a controlled environment chamber, the factor of interest (e.g., daylength or temperature) can be varied while all other factors are kept constant. Photoperiod, vernalization, and juvenile stage coefficients are more precisely obtained in this way. Most model users, however, do not have access to controlled environment chambers, and therefore, IBSNAT developed methods for obtaining these genetic coefficients under field conditions. By selecting sites and times of year and/or increasing daylight hours using artificial lighting, it is possible to determine the coefficients in the field. Data obtained in these experiments are then summarized in terms of the functional relationships used in the model structure as genetic coefficients.

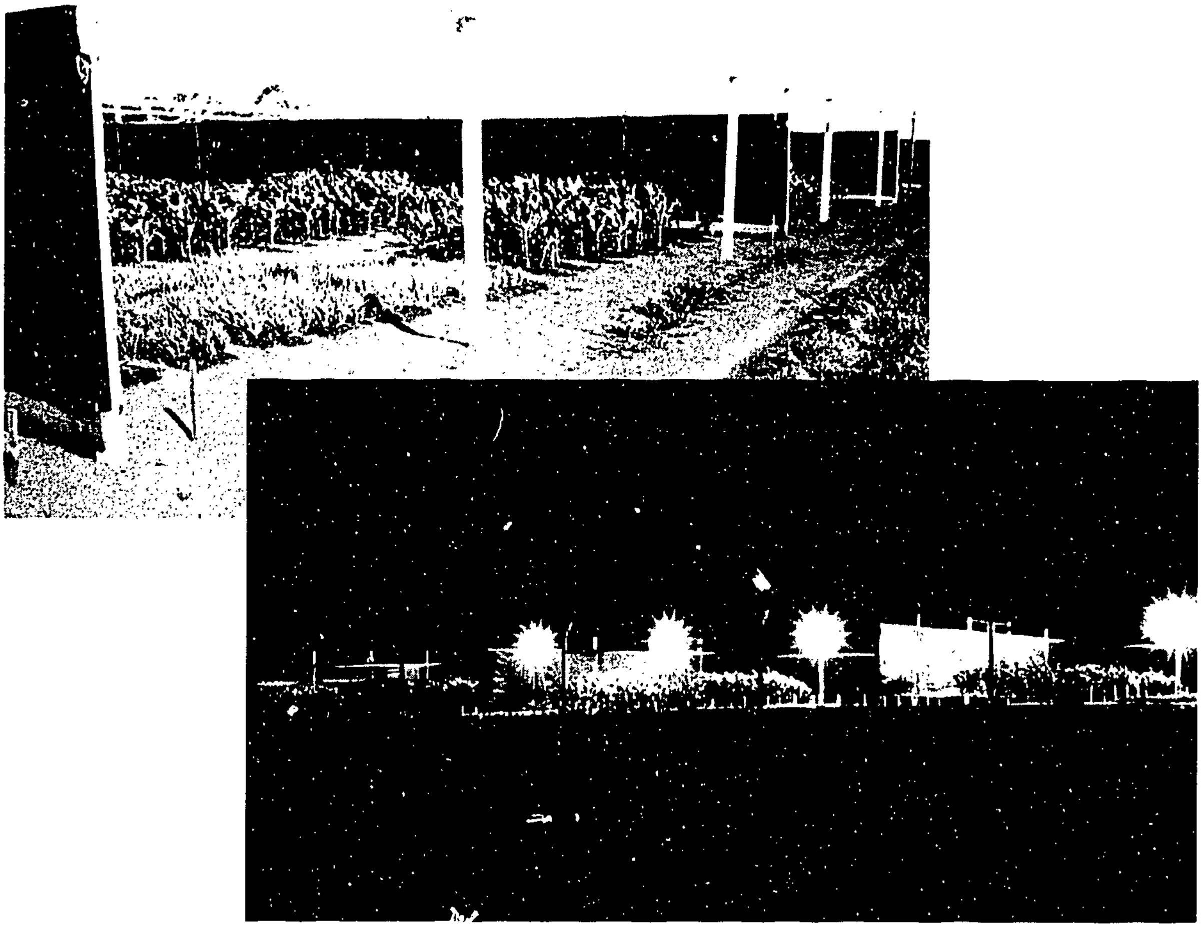
Estimation of Genetic Coefficients

When the genetic coefficients for a cultivar are not known, these can be estimated by (1) using a number of minimum data sets in which dates of phenological events and yield components (e.g., grain number and grain weight) have been determined, and (2) running the appropriate crop model over several iterations with these data sets to assess the precision of simulated events with observed.

For example, the genetic coefficients P1, juvenile phase, and P5, grain filling phase, for the IBSNAT/CERES Maize Model can be estimated if dates for 50 percent tassel initiation, silking, and physiological maturity are known. With two different planting times (summer and winter), P2, the photoperiod coefficient, can be estimated, and the P1 value further refined.

The actual process of obtaining "accuracy of fit" genetic coefficients involves running the model with approximate coefficients for the cultivar in question, and comparing model output with actual data.

The genetic coefficient values obtained in this way will most likely work for dates of planting similar to those in the field minimum data set and in the region where the measured dates were obtained. If several planting dates or locations or years are available in a data set for this cultivar, the genetic coefficient values for each situation can be estimated.



in 1987, IBSNAT conducted an initial photoperiod experiment at its Haleakala, Maui site to study the effects of extended daylight treatments on the maize cultivar, "Pioneer X304C." As shown in these two photos of four plots (the top is the day view; the bottom, the night view), photoperiod was extended with artificial lighting to create daylengths of 14, 17 and 20 hours with one plot receiving only natural sunlight. Each plot was separated by 100% saran shade cloth.

Applications and Future Directions

The genetic coefficients used in the IBSNAT crop models are coefficients 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. Whether this is so is a moot point, and one that requires further

Coefficients	Codes	Values
A. Development Aspects		
Juvenile Phase	VARTHR (3)	(0-15.0 days†)
Photoperiod Sensitivity	VARTH	(1-32 days; ratio)
Critical Night Length	VARNO	(6.0-13.0 h)
Pod Growth Duration	VARTHR (6)	(5.0-9.0 days†)
Grain Filling Duration	VARTHR (10)	37.0-47.0 days†)
B. Growth Aspects		
Leaf Size	TRIFOL	(0.25-0.45 days^{-1}†)
Leaf Specific Area	SIZELF	(150-200 cm^2)
Maximum Pod Production Rate	SLAVAR	(300-370 cm^2 g^{-1})
Pod Growth Rate	PODVAR	(150-250 m^{-2} day^{-1}†)
Grains/Pod	SHVAR	(9.0-25.0 mg day^{-1}†)
Grain Growth Rate	SDPDVR	(1.5-3.0)
	SDVAR	(5.0-12.0 mg day^{-1}†)

† *Under optimum temperature conditions*

Some genetic coefficients used in the IBSNAT SOYGRO model.

examination. Should it be proven, however, that the coefficients are functions of the environment in which the measurements were made, then redefinition of the coefficient(s) and recoding of the model(s) will be necessary.

Examination of the universality of coefficients currently used, and hence of the correctness of the understanding built into the models, is a task that will have to be undertaken with some urgency in the near future.

The coefficients currently used relate in varying degrees to the characteristics reported for specific cultivars by agencies responsible for cultivar testing. This relationship needs to be further developed, with the ultimate goal being a situation in which genetic coefficients and varietal characteristic tests become one and the same. To reach this situation, the way in which some coefficients are expressed may need to be changed, perhaps to a scaler base as has already been done for wheat. To help in this, crop models and DSSAT will be needed as analytical tools for application to cultivar test data by location.

Finally, the array of genetic coefficients currently used in IBSNAT crop models 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 pests, will have to be taken into account before model outputs can be used directly for decision making at the farm level. Incorporation of coefficients that relate to such aspects, along with further validation of the effectiveness of the coefficients currently incorporated, is essential if modeling approaches are to achieve their potential for bringing greater precision and economy into some of the decision making steps of agriculture.

We have used several crop models (wheat, maize, soybean) to evaluate irrigation strategies in Southern Spain. The wheat and soybean models have [also] been used to compare sowing dates and cultivars.

---F. Villalobos, Spain

A major milestone was achieved by IBSNAT with the integration of crop models, databases for weather, soil and crops and agrotechnology transfer application programs and their incorporation into a single computer software package, known as DSSAT (Decision Support System for Agrotechnolgy Transfer).

DSSAT v2.1 is a highly modular, menu-driven interactive software package, the components of which are linked by a memory-resident "Shell." It contains 11 functional crop models for maize, wheat , rice, sorghum, millet, barley, soybean,peanut, dry bean (Phaseolus v.) potato and aroids (taro/tanier). (Note: SUBSTOR-Cassava is available in DSSAT v3.) All the models are semi-mechanistic, have a daily time-step and include substantial biological detail, such as soil water balance and uptake, light interception, plant growth and development and nitrogen dynamics. Input routines are standardized so that the soil and weather databases can be shared between crop models. Outputs include time series of plant growth and environmental variables as well as end-of-season yield. The crop models are designed to have global application, i.e., to be independent of cultivar, location, season and management system.

DSSAT was designed for researchers to easily create "experiments" to simulate, on computers, outcomes of the complex interactions between various agricultural practices, soil and weather conditions and to suggest appropriate solutions to site specific problems. DSSAT relies heavily on simulation crop models to predict the performance of crops for making a wide range of decisions.

Two weather generation modules are included in DSSAT. These are designed to estimate the coefficients of a weather model from historical data from any site, and to generate synthetic weather sequences. One weather model, WGEN, requires daily maximum and minimum temperatures, solar radiation and precipitation for a period of at least five years; the other, WMAKER, relies on monthly means and standard deviations.

A "strategy generator" offers the user of DSSAT the choice of levels for a number of experimental factors. These include corp cultivar, planting date, planting density,row spacing, soil type, and irrigation and fertilizer strategy. "Strategy analysis" programs are available to derive cumulative relative frequencies of selected performance variables over the range of seasons generated. Performance variables include net return per hectare (defined as gross revenue per hectare less base production costs and expenditure on irrigation, fertilizer and seed), duration of growth stages, nitrogen and irrigation water stress and usage rates, and biomass and yield data.

DSSAT v2.1 – A Description

With DSSAT v2.1 users are able to (1) input, organize, and store data on crops, soils, and weather, (2) retrieve, analyze and display data, (3) validate and calibrate crop growth models, and (4) evaluate outcomes of different management practices at a site.

In DSSAT, a database management system (DBMS) is used to organize and store the minimum data sets, to provide user-friendly data entry and retrieval and to integrate data from several sources. Retrieval programs extract data from the centralized data base and create files for running the crop models. Outputs can be printed or graphically displayed and compared with experimental observations for validating the crop models and conducting sensitivity analyses. Application, or agrotechnology transfer, programs facilitate running crop models for different management practices over several seasons to determine the most promising and least risky combinations of management for various locations and soil types. Graphics programs allow users to easily plot simulated and observed crop and soil data and the results from strategy evaluation analyses. The Shell program provides access to the programs in DSSAT using pop-up menus.

The functions of DSSAT were selected primarily to support the use of crop simulation models in decision making applications. The utility of this system depends on the ability of the crop models to provide realistic estimates of crop performance for a wide range of environment and management conditions and on the availability of the required data.

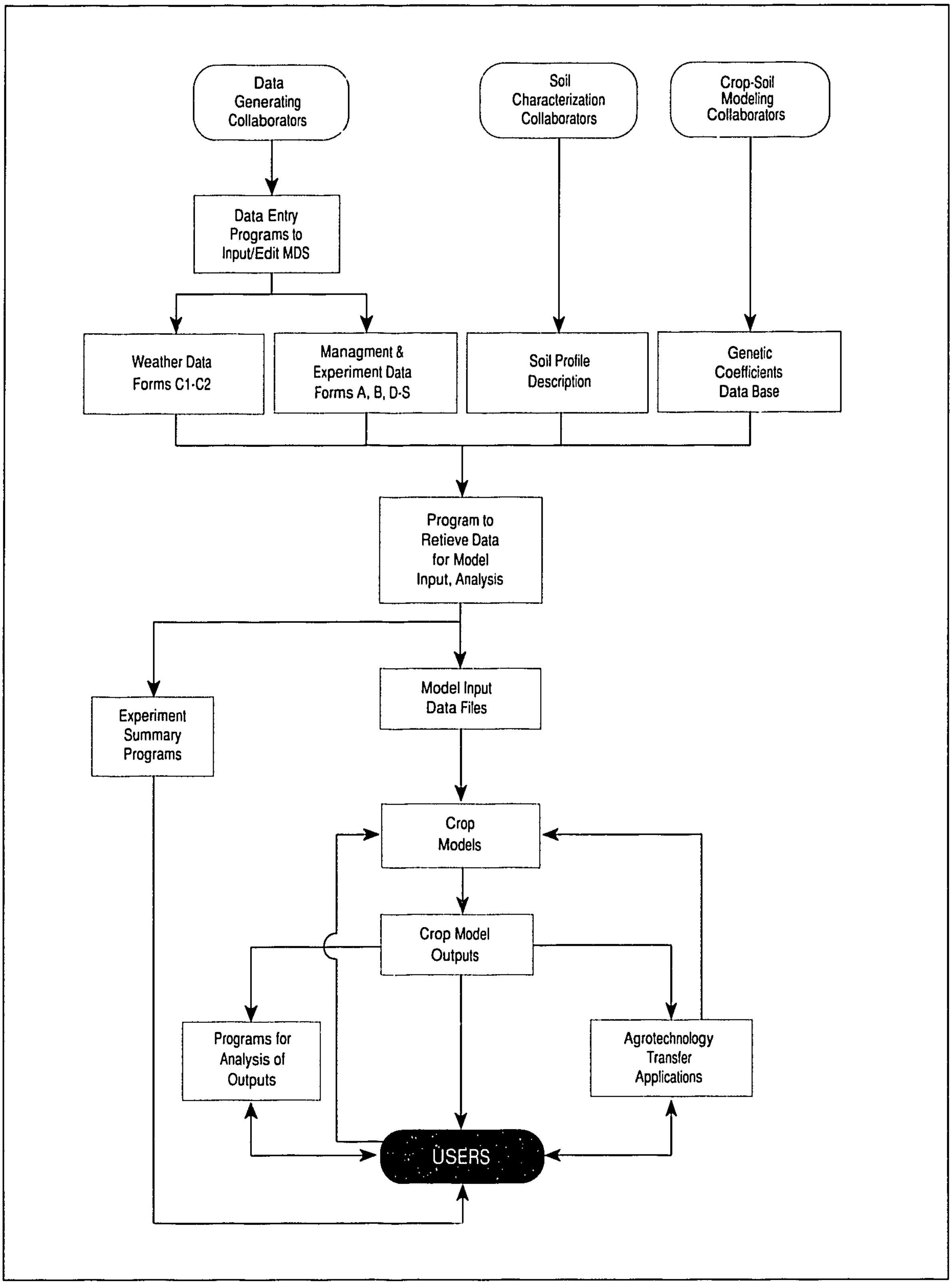
Management options, v2.1	**Variables availabe for analysis, v2.1**
Crop cultivar	Grain yield
Planting	Pod yield
Plant Population	Biomass
Row Spacing	Season length
Soil type	Reproductive season length
Irrigation	Seasonal rainfall
Fertilization (nitrogen)	Seasonal evapotranspiration
Initial conditions	Water stress, vegetative
Crop residue managment	Water stress, reproductive
	Number of irrigations
	Total amount of irrigation
	Number of nitrogen applications
	Nitrogen applied
	Nitrogen uptake
	Nitrogen leached
	Nitrogen stress, vegetative
	Nitrogen stress, reproductive
	Net returns

A listing of the options a user can choose in DSSAT v2.1 to create different management strategies and the simulated performance indicators that can be analyzed.

Source: Jones 1993

We have used DSSAT to determine the potential sorghum productivity in several agroecological regions of India...We have also used DSSAT to simulate nitrogen fertilizer rate scenarios for selected benchmark locations. This study involved estimating the risks involved in N fertilizer applications in drylands.

---G. Alagarswamy, India



Schematic drawing of DSSAT components.

The first release of DSSAT v2.1 (IBSNAT 1989) contained models of the following four crops: maize (CERES-Maize V2.10), wheat (CERES-Wheat V2.10), soybean (SOYGRO V5.42) and groundnut (PNUTGRO V1.02). Seven additional crop models have since been added: rice (CERES-Rice) drybean (BEANGRO V1.01), sorghum (CERES-Sorghum), millet (CERES-Millet), barley (CERES-Barley), potato (SUBSTOR-Potato) and aroids (SUBSTOR-Aroids). On a personal computer with a math co-processor they each require less than one minute to simulate one growing season.

Examples of genetic coefficients are the thermal or photo-thermal time required by a crop to reach a particular growth stage such as flowering or physiological maturity, sensitivity to photoperiod, and maximum number of seed per shell. A library of genetic coefficients is available for many varieties of the crops currently included in the DSSAT.

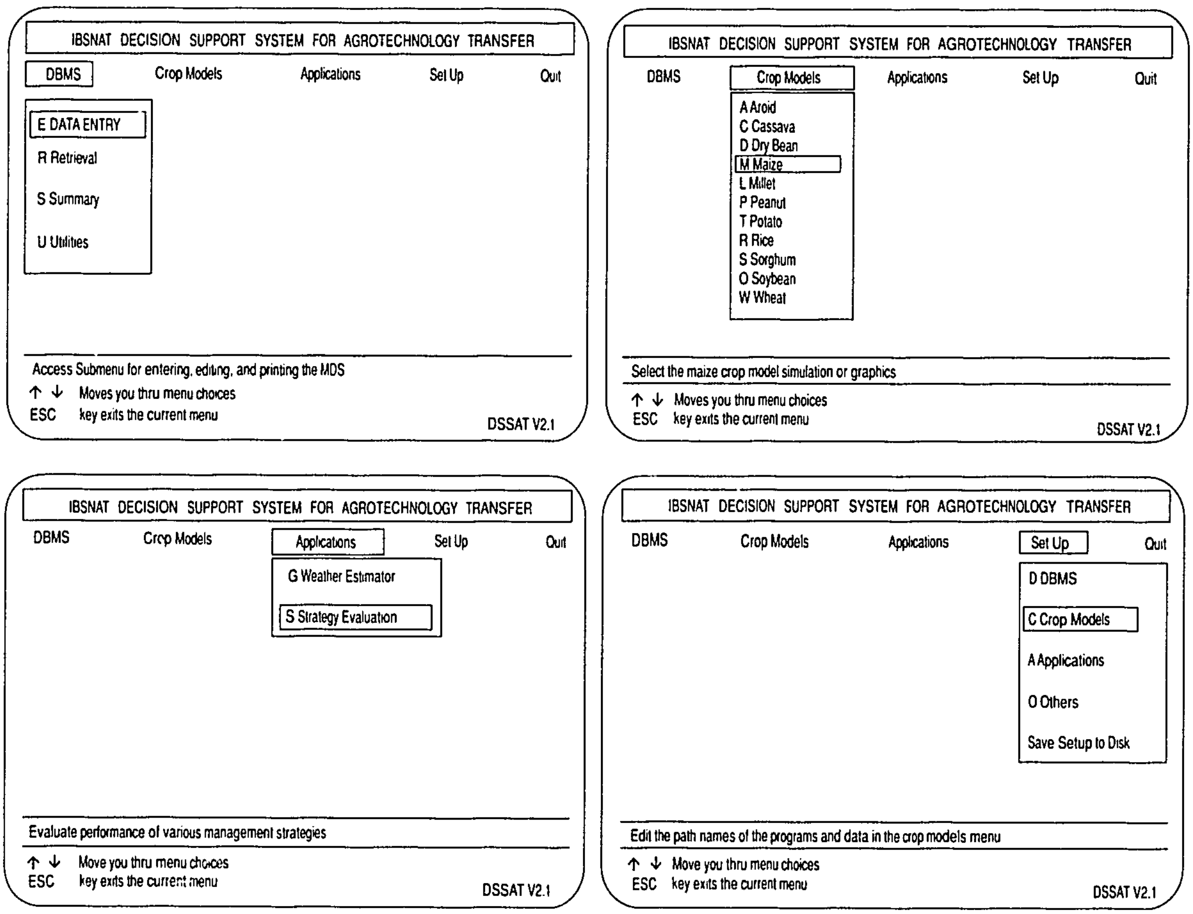
We have been using DSSAT to simulate rice performance under different crop management practices, comparing yields and identifying detrimental effects of crop water management [practices] used in rice production in Alaeoas State, in the San Francisco Basin.

The main goal is to identify restrictive points in the rice production systems and to make technicians from extension service aware of them and to correct them at the farm level, improving regional rice yields.

---Luiz C.G. Barros, Brazil

Shell

The DSSAT shell program enables users to access all of the program components contained in DSSAT. The Shell also includes an install program that automatically creates directories on the harddisk as specified by the user. A data file which specifies the path and name of each program and data component is also maintained. Users may change the location of any DSSAT component, and after any program is executed in DSSAT, control is returned to the DSSAT Shell.



The DSSAT Shell uses pop-up menus to guides users to its components. These are the main menu screen displays of the Shell which allow users to gain access to the DBMS, Crop Models, Applications programs and Set Up components of DSSAT.

Data Base Management System (DBMS)

T. Vearasilp of the Land Development Department of Thailand entering minimum weather data while at a field location.

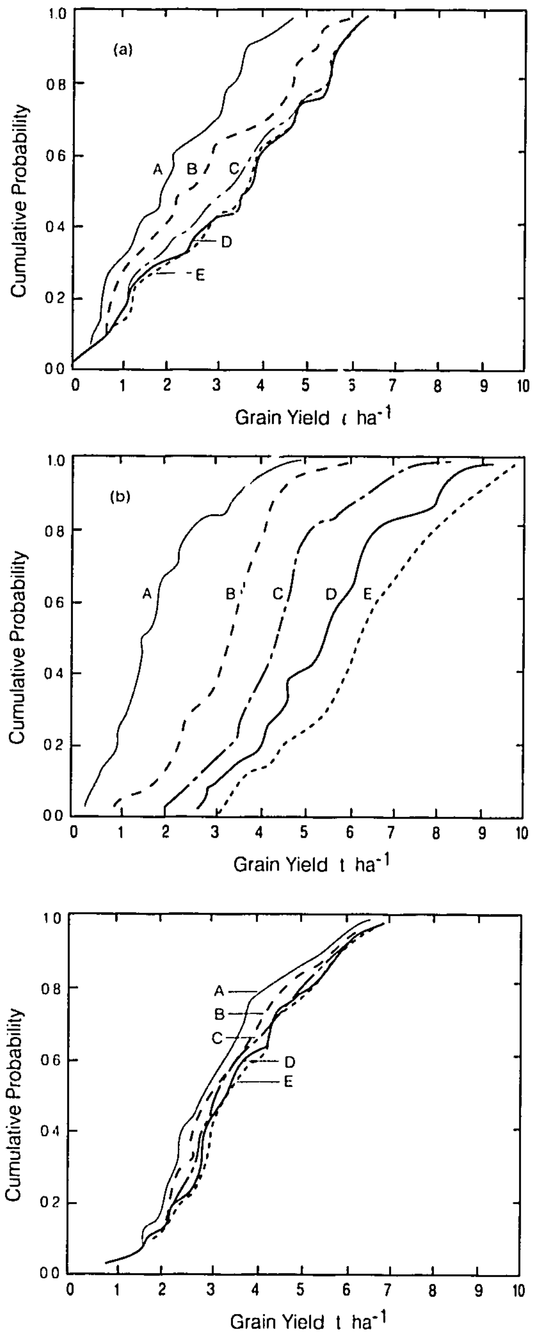
For validation, crop models are used to simulate crop responses under specific experimental conditions for which observed data are available. The MDS for validation consists of: 1) weather for the growing season during which the experiment was conducted, 2) soil properties, and 3) crop management and experimental data (IBSNAT 1988). Crop management data include planting date, dates when soil conditions were measured prior to planting, planting density, row spacing, planting depth, crop variety, irrigation and fertilizer practices. Programs link weather and experimental data with the crop models by creating crop model input files. The minimum required weather data includes latitude and longitude of the weather station and daily values of incoming solar radiation, maximum and minimum air temperatures and rainfall. Optional data include dry and wet bulb temperatures and wind speed.

Soils data in DSSAT are pedon characterization data by horizon with soil profile descriptions. Some of the key site information include soil classification, surface slope, color, permeability and drainage class. Soil horizon data include horizon depth (layer thickness), sand, silt, clay contents, 1/3 bar bulk density, organic carbon, pH, aluminum saturation, and root abundance information. A program uses these data to estimate parameters required for the soil water submodel (albedo, runoff curve number, upper limit of the first stage of soil evaporation, drainage coefficient and layer parameters of lower limit for plant growth, drained upper soil water limit, saturated soil water content, and relative root growth distribution). If data for a particular soil and site are not available in the data base, users can manually enter their data set through an interactive program and add it to the database.

The standard outputs from the DBMS include: 1) chronological listing of activities and events for an experiment including experimental operations, phenological events, sampling dates, and history of special events; 2) summary of preplant soil fertility and preplant soil water content for each layer, and 3) graphs of maximum and minimum air temperatures, rainfall, radiation, and degree-days on a 10-day or monthly basis.

Our primary interest in the application of DSSAT was to explore the possibility of introducing an energy crop while protecting the soil and securing a fair economic result.

---V. Sardo, Italy



Cumulative probability functions (CPFs) of simulated wheat grain yield for five nitrogen fertilizer rates (0,30,60,90 and 120 kg/ha for A,B,C,D and E respectively) at (a) Warooka, AUS, (b) Rothamsted, UK and (c) Topeka, USA (Godwin and Vlek, 1985).

Strategy Evaluation

The real power of the DSSAT for decision making lies in its ability to analyze many different management strategies. When a user is convinced that the model can accurately simulate local results, a more comprehensive analysis of crop performance can be conducted for different soil types, cultivars, planting dates, planting densities, and irrigation and fertilizer strategies to determine those practices that are most promising and least risky. The weather estimator and strategy evaluation programs in DSSAT establish the desired combinations of management practices, link the models to historical weather data or generate multiple years of weather data for the location, run the model(s), and analyze and present results to the user. The risk arising from rainfall variability is exposed in a way that could never be achieved with field experiments. Presentation of model outputs as cumulative probability functions (CPFs) allows this risk to be quantified, as, for example, the estimated probability of wheat yields for three different sites and five N-fertilizer rate, as shown in the figures on this page.

Limits to the experimental domain are imposed, ultimately, by the variables and their ranges as specified by the modeler. Choosing suitable combinations of factor levels allows the individual effects of factors on response variables, as well as interactions between factors, to be determined. For example, in the figures on this page, the strategy with a CPF to the right is considered the "best." For Rothamstead, grain yield significantly improved with increasing levels of N in comparison to the Warooka and Topeka sites.

It is clearly impossible to conduct field experiments for a large number of soil types, cultivars and management practices (such as the enormous number of alternative forms of intercropping) over a number of seasons. The DSSAT program has considerable potential for reducing the time and cost of evaluating agrotechnology packages designed for farmers in developing countries.

DSSAT can be used as a screening tool to minimize the number of variety trials, like those shown here in Hungary, which are necessary to determine the best-suited variety for a location.

Weather Estimators

Weather estimators (or generators) software, WGEN and WMAKER, developed by Richardson and Wright (1984) and Keller (1982), respectively, are included in DSSAT. Each estimator has two programs; one program to compute weather coefficients from historical weather data and the second program to generate weather data using these coefficients. The WGEN requires daily long-term historical data on maximum and minimum air temperatures, solar radiation, and precipitation, while WMAKER uses monthly means and standard deviations of potential evapotranspiration, average air temperature, precipitation, and number of wet days in a month.

DSSAT is the only coherent system we could find for training crop weather modelling Agrometerology professionals from developing countries, for national policy making and long-term productivity analyses.
---M. Meron, Israel

DSSAT ♦ v2.5

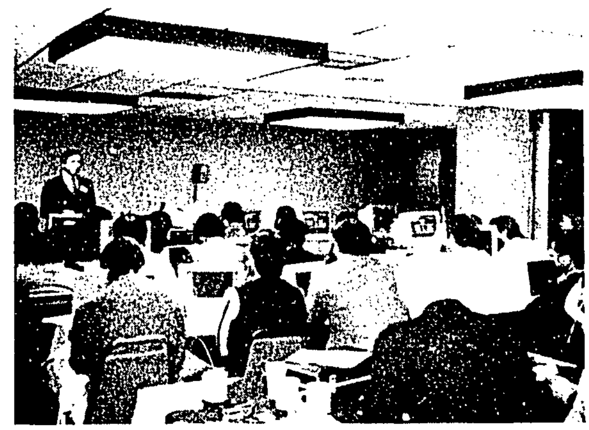
Global climate change and its impact on the world's marketplace are issues that require models to simulate potential outcomes. The U.S. Environmental Protection Agency (EPA) and USAID jointly supported such a study on the impact of future climate change on food production and trade. Several key countries and regions were identified by the principal leader of this study, Cynthia Rosenzweig of the Goddard Institute for Space Studies at Columbia University. To implement this study within a two-year time frame, the IBSNAT network was tapped as an immediate technical resource base for scientists from key locations and as a developer of a product to assess potential productivity through simulation. Crop models in version 2.1 of DSSAT were modified to accommodate the effect of doubling CO_2 levels in the atmosphere. This modified version of DSSAT was distributed to participants as version 2.5.

The response of agricultural systems to climate change is clearly one of the more significant global environmental problems that we face and the network of scientists in IBSNAT, with their expertise in crop growth modeling, could lend invaluable support to this research.

For this study, the daily canopy photosynthesis and transpiration sections of the CERES and GRO crop models in DSSAT v2.5 were modified to respond to changes in CO_2 concentration. The management sections of the models and the strategy evaluation program were expanded to include the option to modify weather data interactively.

During the two-year study, crop models for wheat, maize, rice, and soybeans were used extensively by participants from over 20 countries representing each continent as they arrived at country level assessments of the impact of increased temperatures and levels of carbon dioxide.

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 obtained from three different global circulation models (i.e., the Goddard Institute for Space Studies (GISS) model; the Geophysical Fluid Dynamics Laboratory (GFDL) model; and the United Kingdom British Meteorological Office (UKMO) model), which were provided by the EPA. Outcomes of crop productivity from DSSAT were used in an economic analysis to assess their impact on trade relative to growers and importers then and now.



A Global Climate Change meeting organized by USEPA and USAID.

Yield changes predicted from these studies in individual countries were to be used in two types of economic assessment: 1) global agricultural models to estimate changes in the production and trade of the crops of interest, and 2) studies of the magnitudes and nature of food deficits in regions that would be especially vulnerable to the predicted climate change. It was hoped that the study would enable agricultural program managers from each country to define adaptive policies or programs.

The goal was to produce a consistent set of crop modeling results from all countries involved in the project, identify effective adaptive responses and build awareness of the global climate change issue. Outputs from this effort were reported in a one-day symposium organized by Rosenzweig during the 1992 annual meeting of the American Society of Agronomy.

[used DSSAT in] assessment of climatic warming impact on Japanese crop production and adaption strategies. This study was carried out as part of the USEPA project entitled "Implications of Climate Change on World Crop Production and Trade."

---H. Seino, Japan

The basic concepts and purposes of DSSAT v3 are the same as those for DSSAT v2.1. Most of its components, however, are new. Changes have been made to create a more flexible system, to correct some deficiencies in the earlier version, and to add new features that facilitate more practical applications of the databases, models and analysis programs. DSSAT v3 is still field (or site) oriented, with weather, soil and experiment data linked to specific sites and dates of measurements.

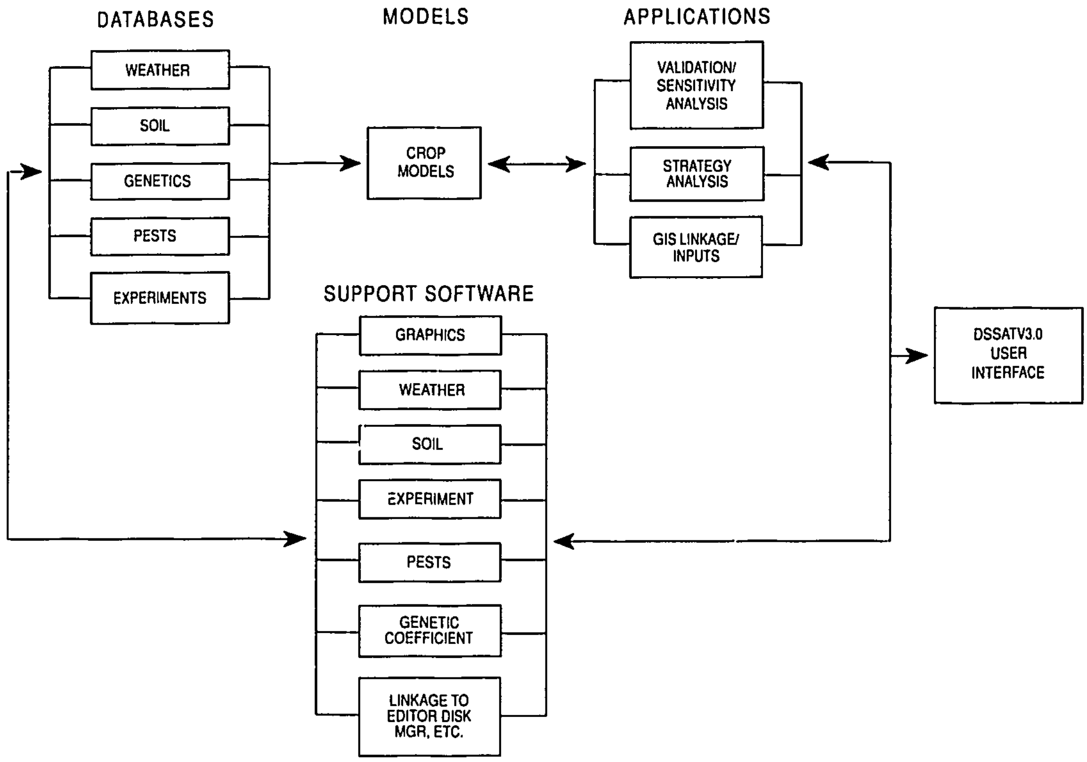
DSSAT v3 still allows users to simulate individual crop performance for recorded or hypothetical experiments and thus to conduct sensitivity analyses and validation comparisons in a convenient, easy to use framework. It allows users to define crop management strategies, to simulate the variability in performance due to year to year variability in weather, and to compare different management strategies. Moreover, it emphasizes the handling of data with additional utility programs which assist in data input and data application.

Overview of DSSAT v3

DSSAT v3.0 contains the IBSNAT crop models for cereals, grain legumes and root crops. An added option, Other Crops, was included to allow users to add any other models which conform to the input/output file formats of DSSAT. Those models which were in DSSAT v2.1 have been improved in several ways.

A new soil water model is completed and contains improved infiltration, redistribution and root water uptake calculations. Restrictions to percolation are included in soil inputs so that perched water tables can be simulated along with oxygen stress effects on root and crop growth processes. An option has been added to compute potential evapotranspiration using the Penman equation, which uses humidity and wind speed if those data are available.

All of the crops are sensitive to carbon dioxide concentrations so that climate change studies can be made. A soil phosphorus model is under development. Capabilities for automatic planting, harvesting, residue management and fertilizer applications are included in all models and DSSAT v3 can sequentially operate the models to simulate crop rotations and the long-term effects of cropping systems on soil N, organic matter and P availabilities.



Schematic of the main components of DSSAT v3.

Source: Jones 1993

In addition, the effects of pest damage to the crops can be simulated for various types of pest damage (e.g., insect feeding on different plant parts and disease destroying tissue or whole plants).

The Pacific Agriculture Information System (PAIS) aims to improve the access to and exploitation of agronomic information by Pacific Island Countries. As part of this, use will be made of crop models to predict crop performance...and...DSSAT provides a means to do this.

---P.B.S. Hart, Fiji

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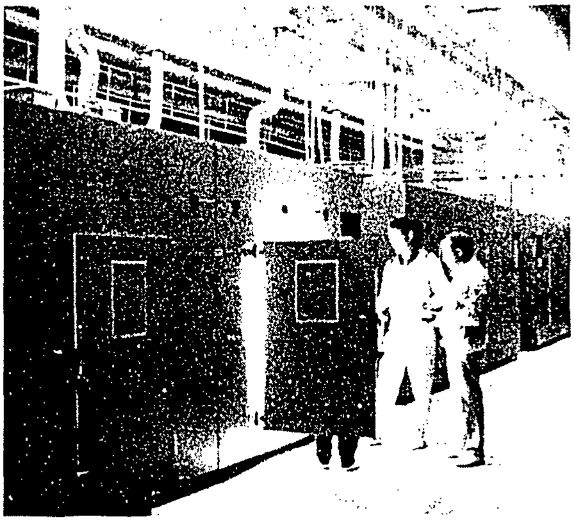
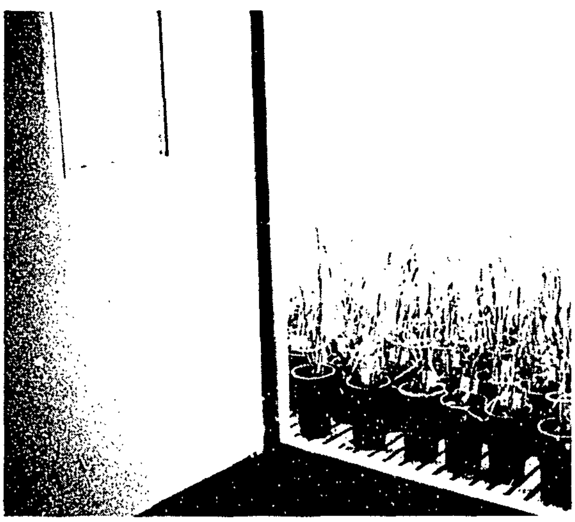




Growth chambers with controlled environments, like these shown here in Martonvásár, Hungary, have been used to determine genetic coefficients.

A program is included to assist users in estimating genetic coefficients for each crop using data from variety trials and other field experiments. DSSAT v3 contains support software to enable users to create, maintain, search, edit and display data required for the models and application programs.

The addition of these new crop model features resulted in a need for additional model inputs. Therefore, the standard input/output data and their formats have been modified. An added feature in all the crop models allows subsets of the inputs to be used when certain factors are not to be included in an analysis. For example, the soil inputs for the phosphorus model do not have to be input if there are no limitations in production due to this factor, and the phosphorus submodel would not be run in this case. Climate change and pest inputs may also be excluded if desired. Because of the major changes in inputs and outputs, a program in DSSAT v3 will allow users to convert DSSAT v2.1 model inputs to formats for the new DSSAT.

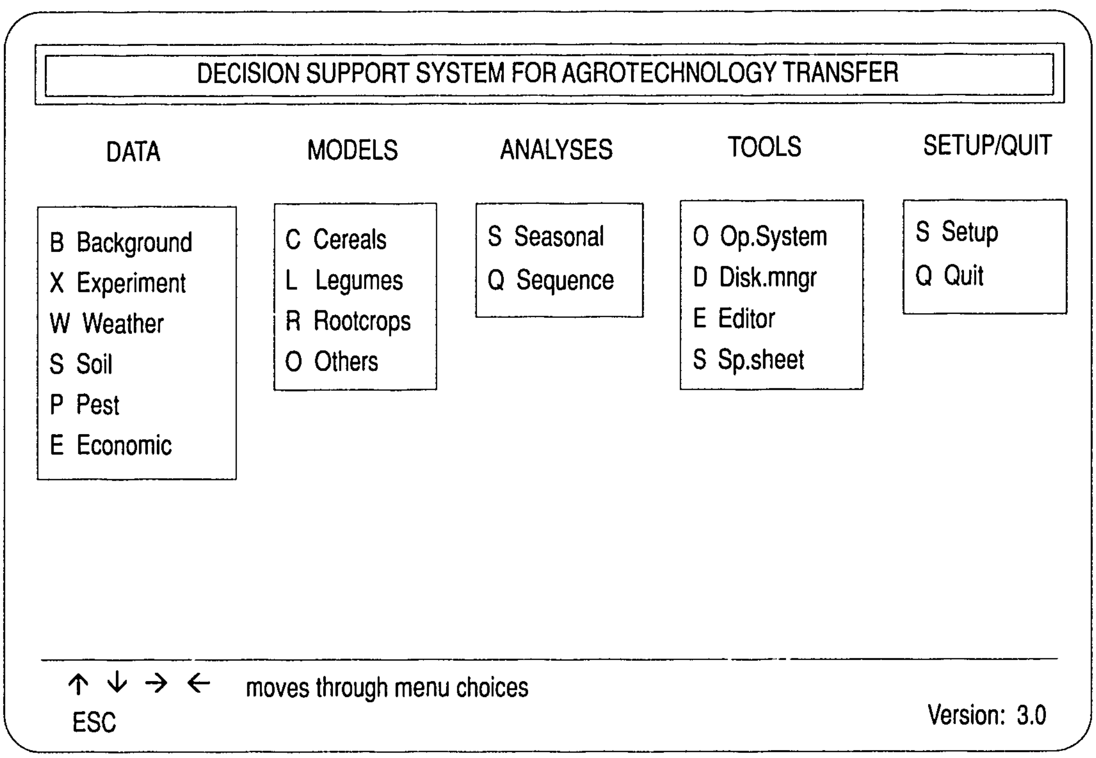
The strategy evaluation program has been revised to analyze long-term crop rotations in which soil conditions will carry over from one crop to the next. Improved capabilities for handling weather data (importing, reformatting, cleaning, filling missing data) have been developed. Improvements have also been made in the graphics programs and data base management system to adapt to the new formats and features of the data and models, respectively.

Shell

The DSSAT v3 Shell, which displays the user-selectable DSSAT main menu items, is similar to the DSSAT v2.1 Shell with additions and changes for accessing DSSAT v3's new and improved features. The formats and files for each of these types of data, however, have been changed to facilitate new applications that were not previously available. One major change is that data are now stored in ASCII files so users can access and manipulate them more easily than was the case in version 2.1 where data were stored in dBase files. In DSSAT v3, temporary dBase files are created and placed on the screen to make it easier for users to search for data or information contained in these files.

The Shell has five menu items, each with various options, which allow access to DSSAT's weather, soil and experiment data (DATA), crop models (MODELS), application programs, directories and management (ANALYSES), editing tools (TOOLS) and setup options (SETUP/QUIT).

A program, entitled "Convert," to convert DSSAT v2.1 ASCII model input files to DSSAT v3 formats for management input, soil and weather data is accessed from the Shell, Under DATA and Experiments, as is a new experiment entry pro-



The DSSAT v3 Shell with its five main menu items displayed, which give users access to its DATA, MODELS, ANALYSES, TOOLS and SETUP components.

gram, "XCreate," which enables users to create standard experiment details files used for model inputs.

The weather manager program, or "Weatherman," allows users to format weather data, fill in missing or out of range data values and simulate daily weather data if they are not available for a site. This new simulation feature allows users to input monthly data from published sources, such as FAO, and simulate crop performance.

A genetic coefficient calculation program, entitled "GenCalc," has been added, under DATA and Experiments, to assist users when they have cultivars that are not in the DSSAT genetic coefficients file.

Pest and Economic options are also accessed from the Shell, from which users can store and handle pest and economic data.

Crop Models

All the crop models in DSSAT v3 can be accessed for validation and sensitivity analysis purposes as is the case in DSSAT v2.1. Generally, all the DSSAT v3 crop models are operated from a single program which allows users to simulate experiments (using new data file structures) and conduct sensitivity analyses. The crop models have a more modular structure with a separate input module that processes the new files to reduce program size and complexity. This modular approach will provide flexibility for crop models developed by other groups with different input/output structures so they can be integrated into DSSAT v3.

A new crop model graphics program entitled "Wingraf" is also available. It is mouse-driven and creates plots of simulated and observed variables similar to the graphics package in DSSAT v2.1. This new program, however, is much more flexible and can output graphs to printers or to files for inserting into other software.

Also under each crop model section is an option for reviewing model inputs and outputs from simulation runs. This feature allows users to locate experiments, view them on the screen, or print them out to save for other purposes.

Crop Model Capabilities

The crop models in DSSAT v3 are versions created by modifying version 2.1 models. The cereal crop models were basically integrated into one program, referred to as the Generic CERES model, and it includes maize, wheat, sorghum, millet, rice and barley. These six cereal models were combined to run under a single set of code by incorporating the development and growth sections from each individual model into a single module with a single soil component. This new module uses the DSSAT v3 input/output file structures and formats and is fully compatible with the graphics program, genetic coefficient calculator, and season analysis programs found in DSSAT v3. The input file for genetic coefficients has been modified to adapt it to the genetic coefficient calculator program. Genetic coefficients for all cultivars in V2.1 have been converted and are available for simulation with the new crop model versions.

Peanut is one of the CROPGRO models contained in DSSAT v3.

The grain legume models (SOYGRO, PNUTGRO, and BEANGRO) now all operate using a generic grain legume model structure referred to as CROPGRO. These three models now include soil nitrogen balance (incorporated from CERES-Maize) and symbiotic nitrogen fixation. The phenology and photosynthesis components of these models were changed. Thus, the grain legume models in DSSAT v3 are considerably different from those found in v2.1.

The SUBSTOR models (aroid, cassava, potato) will also operate under a generic structure. This model will have similar characteristics and capabilities as those of the cereal and grain legume models.

Evapotranspiration Calculation

In the DSSAT v3 models, options exist for using either the Priestly-Taylor method (Ritchie, 1972) for computing potential evapotranspiration or for using the Penman method with the FAO definition of the wind term. The use of the Penman method requires daily humidity and wind speed data. The new DSSAT v3 weather file format includes columns for these data.

Carbon Dioxide Effects

The DSSAT v3 models have the capability to simulate the effects of CO_2 on photosynthesis and water use. Daily potential transpiration is modified by CO_2 concentration based on the effects of CO_2 on stomatal conductivity (Peart et al., 1989). A multiplicative modification is made to daily canopy photosynthesis as described by Curry et al. (1988).

[We are] storing and accessing data from field and lysimeter experiments [and]...using this database to provide information to advisors and growers on suitability of planting dates, N fertilizer practices and variability to be expected from year-to-year in crop development rates.

---W. Meyer, Australia

Climate Change Studies

The DSSAT v3 models can modify daily weather, as well as daylength, data which are read in from the weather file. Each weather variable can be modified by multiplying a constant times the input value and/or by adding a constant to it. This gives flexibility for changing one or all weather variables and includes the capability to make them constant, as in controlled environment experiments. Users can specify the date that a given modification is to begin, and can have more that one entry if the experiment includes environment switching of any type. These options are available in FILEX for any experiment and are also available interactively during any model run.

Strategy Evaluation

Strategy evaluation in DSSAT v3 is now composed of two programs. One, "Season," was in DSSAT v2.1, called "Seasonal Analysis." The new program is called "Sequence" and allows users to do sequential analyses. As was the case in DSSAT v2.1, the "Season" program allows users to setup simulation experiments, simulate them and analyze the results. It provides access to the interactive model input creation program ("XCreate") which sets up one or more strategies for one or more crops. Initial conditions are reset in this mode for each run, so that results represent the variability expected if the practices were implemented with fixed starting conditions. In addition to having the new "XCreate" program to setup runs and new crop model versions, DSSAT v3 also has a new seasonal strategy evaluation program which analyzes means variability and economic risk and provides graphical outputs (cumulative probabilities, mean-variance, and box plots).

The program "Sequence" enables users to simulate sequences of crops, or crop rotations, for studying the long-term effects of management practices on crop and soil performance, with emphasis on time trends and uncertainty. With this application program, soil water, N, and organic matter ending conditions are used as starting conditions for the next crop or fallow period. The program analyzes the time trends in crop, soil, and economic variables.

Weather Generators

The DSSAT v3 models have built-in capabilities for simulating weather using either one of two generators. As in DSSAT v2.1, one generator is WGEN

(Richardson, 1984). The second is SIMMETEO (Geng, 1988) which requires only monthly averages of solar radiation, maximum and minimum temperatures, precipitation and days with precipitation. This generator then computes coefficients and uses WGEN to simulate daily data. The models' ability to simulate weather internally, using only monthly averages of variables, will greatly expand the application of the models to areas where the monthly data are all that are available.

Pest Damage

A framework was developed for simulating the effects of pest damage on crop performance. The approach is mechanisti and allows simulation of multiple pest effects on a daily basis. Users can input time courses of pest populations or crop damage, and the model will simulate response to this information. The module can be used to introduce the effects of given infestation levels of different pests via physiological coupling points. This feature is presently available only in the three grain legume models. This approach, however, was also implemented in an earlier version of the CERES-Rice model (Pinnschmidt, 1990) and reported in the Crop Models secton of this report.

P.S. Teng explaining Pest model at the American Society of Agronomy meeting in Las Vegas, Nevada, USA.

[We are] doing strategy analysis on current cropping practices for wheat and maize using 40 years of local data.

---W. Meyer, Australia

[We use DSSAT for] demonstration of corn bind impact of climate on crops and pests, especially economical implications.

---J. Mumford, United Kingdom

Model Linkages

AEGIS (Agricultural and Environmental Geographic Systems)

Intercropping

Whole Farm Systems

AEGIS was developed by:
J.P. Calixte, UF;
F.H. Beinroth, UPR;
J.W. Jones, UF;
H. Lal, UF.

AEGIS

In IBSNAT's Decision Support System for Agrotechnology Transfer (DSSAT), the crop simulation models produce output that is specific for a point in the landscape. Since the practice of agriculture and the management of ecosystems take place in time and space, it would clearly be advantageous if the capabilities of DSSAT could be used to evaluate agricultural and environmental scenarios that consider the spatial realities of farms, watersheds or regions.

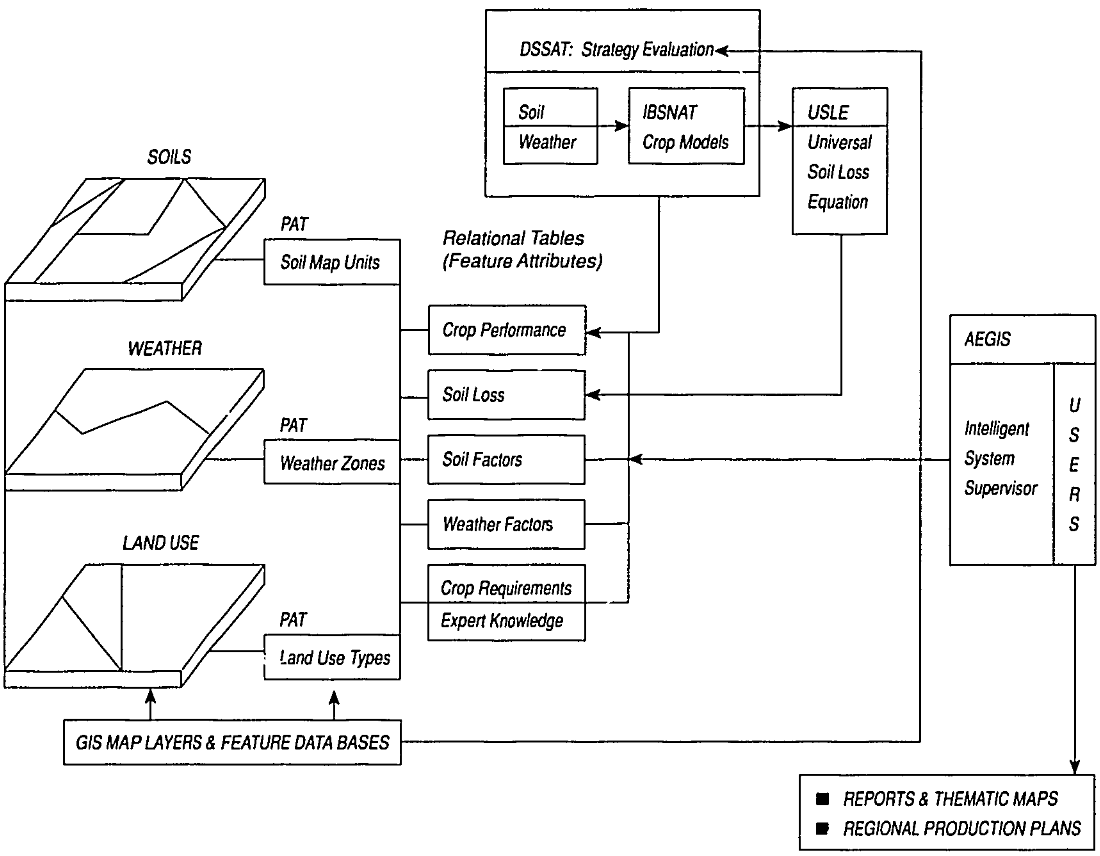
A challenge, then, exists to expand the scope of analysis of DSSAT from a point to an area for specified time horizons. While the temporal variability of weather can be assessed with generated time sequences, the spatial variability of weather and land characteristics is more difficult. However, the technology residing in geographic information systems opens up new avenues to address this issue.

To meet this challenge, the approach taken by an IBSNAT-related project of the Universities of Florida and Puerto Rico, funded by the USDA/CSRS Special Research Grants in Tropical and Subtropical Agriculture managed by the Caribbean Basin Administrative Group (CBAG), was to georeference the spatial databases to DSSAT. Crop model output could then be aggregated over areas of varying size and for different periods of time. As a result of this project, software named AEGIS, the Agricultural and Environmental Geographic Information System, was developed.

AEGIS is a prototype system that links DSSAT and its crop models with a GIS and allows decision makers to evaluate different production strategies in a regional context and interactively develop a regional plan to suit their objectives. AEGIS can perform several tasks such as: estimating production and resource requirements for different agricultural strategies (i.e., combination of crop, variety, planting date, irrigation and fertilization treatments), assessing potential environmental impact, generating tables and thematic maps (i.e., maps of simulated yield, biomass accumulation, runoff) and creating, modifying and saving a production plan for a selected region.

A production plan is defined as a set of maps and tables which indicate the crops and management practices selected for a given region. The main components of the system include:

- A set of spatial data bases of soil, weather, and land use attributes and a relational data base management system (dBase IV);
- BEANGRO v1.01 and the CERES-Rice v2.1 model;
- A simple expert system which provides optimum ranges of soil and weather requirements for bean production;
- A soil erosion model which predicts the longtime average soil loss (USLE);
- A Geographic Information System (pcARC/INFO v3.4D) which facilitates the production of thematic maps based on results obtained from the models;
- The Strategy Evaluation program of DSSAT which uses IBSNAT crop models, and soil and weather data bases to predict crop productivity (potential yield, biomass accumulation, irrigation requirements, cumulative evapotranspiration and nitrogen leaching);
- A menu interface designed to facilitate the interaction of users with the system.



AEGIS design schematic.

The system was developed using three areas of western Puerto Rico selected in consideration of their environmental diversity and representativeness of the Caribbean region. The 38 soil series occurring in the three areas belong to the orders of Alfisols, Entisols, Inceptisols, Mollisols, Oxisols, Ultisols, and Vertisols and thus exemplify seven of the eleven orders recognized in the U.S. Soil Taxonomy (1975). The soil parameters required to run the IBSNAT crop models were derived from soil survey reports and series-specific analytical data available for 28 of the 38 series. For the remaining series, surrogate data were estimated using analog procedures. Combining the field and laboratory data, soil data files were created for each of the 67 agriculturally suitable polygons. To enhance the user-friendliness of the system, these units were grouped into 12 generic groups.

The climate in the region ranges from humid to subhumid to semiarid tropical. Historical weather data (daily precipitation and maximum and minimum air temperature) recorded at four representative stations were used. Long-term solar radiation data were not available but time sequences were estimated with a stochastic default procedure developed for Puerto Rico. Landuse coverage of AEGIS was generated by processing LANDSAT imagery with the Earth Resources Data Analysis System (ERDAS).

Linking AEGIS to DSSAT provides direct access to the functions that reside in that system. More than 250,000 runs, representing various combinations of management practices and production strategies, were made with BEANGRO v1.01. In addition, soil erosion under various conservation practices was estimated for each map unit with the USLE. The results were statistically analyzed and stored in the system for instant recall. Using these data, or information generated

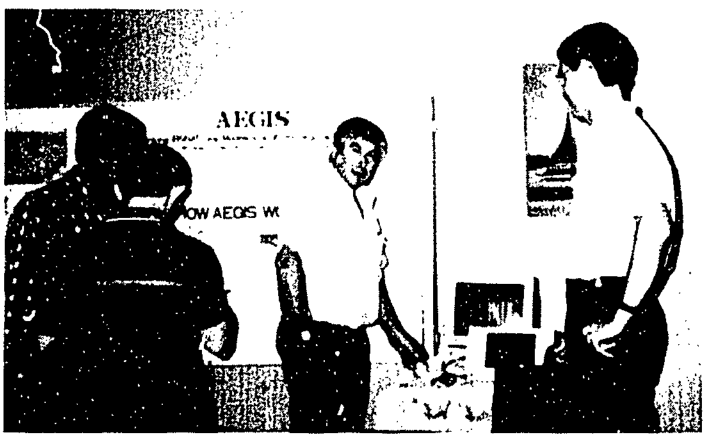
J.W. Jones demonstrating GIS software.

interactively, AEGIS can predict crop performance and soil loss, aggregate polygon attributes over space and time, estimate production and resource requirements for different agricultural strategies, assess potential environmental impact, generate tables and thematic maps, and develop a production plan for a region.

The success and relevance of the AEGIS concept is evidenced by the fact that it is being used by the University of Florida in a project sponsored by the South Florida Water Management District to determine the effects of several "best management practices" (BMPs) in reducing the import of nutrients into Lake Okachobee, the single most important water supply for southern Florida. Also, IFDC, the International Fertilizer Development Center, is planning a GIS-based information and analysis system for Albania and projects in other countries. An interactive version of AEGIS was developed at the University of Georgia (Hoogenboom and Gresham, 1993). Now Florida and Georgia are working together to apply AEGIS to study possible climate change effects on crop production in a project sponsored by the Southeast Region Climate Center.

AEGIS is a significant step forward in the development of a decision tool that incorporates contemporary geographic, environmental and agricultural systems technology. A novel attribute of AEGIS is that it expands the scope of analysis of DSSAT from a site to an area by linking it to a geographic information system (GIS).

F. Beinroth and G. Hoogenboom presenting AEGIS at the Asian Institute of Technology in Bangkok, Thailand.



[DSSAT is used for] application of crop models and GIS to evaluate area potential productivity on agricultural land in Taiwan.

---C. Chen, Taiwan

CropSys was developed by:
R.M. Caldwell, UH.

Intercropping

In many parts of the tropics, intercropping, the production of more than one species in the same field at the same time, is the dominant cropping practice. The reasons for intercropping are complex, but as a general rule, intercrops make better use of limited resources and minimize farmers' risks from very poor yields. Cereal/legume intercrops and intercrops of long and short duration crops have been particularly successful.

Because of the complexities of multiple cropping, a systems approach is required for the evaluation and improvement of the practice. While use of crop simulation models would be a natural part of a systems approach, little work has been done modeling sequences and combinations of crops. Given the value of crop simulations in support of decision making, a new model, called CropSys, was developed to simulate multiple cropping systems. CropSys v1.0 incorporates submodels from SOYGRO v5.42 and CERES-Maize v2.0, along with process-level models of competition for light and competition for soil moisture (Caldwell 1990; Caldwell and Hansen 1990).

While the general benefits of intercropping have been established by numerous field trials, agronomists face a difficult challenge helping farmers to better manage their intercrops. Part of the difficulty is due to the number of decisions a farmer must make, and the wide range of options available. The effectiveness of each option also varies from environment to environment, further complicating the task of the agronomist.

Management decisions are dependent upon each other and the success of a given decision will depend on the particular environment in which the farmer is growing his intercrop. Intercropping research performed over multiple locations has shown that management x genotype x environment interactions are significant. Based on these interactions and the perceived use of the model in decision support, sensitivity to the following factors was designed into CropSys: (i) soil chemical and physical properties, varying by layer; (ii) daily weather conditions; (iii) tillage and residue management; (iv) irrigation; (v) nitrogen fertilization; (vi) planting date, permitting relay intercrops with any degree of overlap in time, as well as permitting sequential crops; (vii) plant spacing, giving users control over population densities, row widths and row arrangement, including the variety of patterns used in strip intercrops; and (viii) cultivar differences for phenology and stature (height and compactness).

Most of the elements required from outside the project were available through IBSNAT. The data, models and software developed by IBSNAT and contained within DSSAT were selected as the starting point for CropSys. DSSAT file formats (IBSNAT 1986) were adopted so that CropSys could use input files residing in DSSAT and could create output files to be graphed and analyzed by DSSAT programs.

Of particular interest were the programs and files used for Strategy Analysis in DSSAT. A stochastic weather generator, called WGEN, allowed CropSys, to create daily weather that mimics the variety of sequences found in historical records and to output sequential files conforming to DSSAT's Strategy Evaluation program formats.

Intercropping of maize and soybean, shown here, can be simulated with CropSys.

CropSys can handle not only combinations of maize and soybean, but sequences as well. Double cropping and triple cropping can be simulated, along with different rotations and monocultures, all analyzed under DSSAT's Strategy Analysis program. Long-term simulation capabilities are facilitated by a built-in weather estimator that removes the need for storing large amounts of data on a hard disk. To enhance the crop sequence capabilities of the model, the following features were added.

- *Conditional planting.* The model can delay the planting of a crop if calendar date, soil temperature, soil moisture and crop status do not fall within acceptable boundaries.
- *Tillage and residue management.* Conditional tillage can incorporate various amounts of crop residue to different depths. Residue decomposition is coupled with DSSAT's soil nitrogen model.

A submodel for nitrogen fixation, developed by IBSNAT scientists J.W. Jones at the University of Florida and G. Hoogenboom at the University of Georgia, Griffin, and researchers at the NifTAL Project, will provide CropSys with the ability to simulate both in-season and between-season benefits of biologically fixed nitrogen. This will significantly improve evaluation of low-input intercrops and crop rotations.

Targeting of research and translation of findings into technology packages that are relevant to the needs of local farmers and which therefore will be adopted are major issues of concern in many countries. Decisions that farmers make about which crop to plant in a particular field and the practices to use depend on the availability of land, variations in soils, previous history of each field, preferences and other information on economics and resource availability. Such elements impact upon all three component types of the farm system (biological, economic and socio-cultural) creating uncertain behavior of farming families in response, for example, to exposure to new technology, the availability of new opportunities created by markets or to provision of credit and uncertain outcome of any management strategy selected by the farm household.

The study of farm systems must progress in balance; the weakest area of understanding will be the one which limits knowledge of the whole. Research programs that create this balance are desirable but unfortunately have not been the reality. Farming systems are dynamic in nature and are subject to uncertain elements that rightly may be considered exogenous to the system. Interactions are not only or even mainly of a biological type; important economic and socio-cultural links between components are also involved. Neglect of the economic and socio-cultural components in research programs has been responsible for enormous deficiency in understanding farming systems. Policy makers and planners of land use and food throughout the world are currently greatly hindered in their work because of this and consequentially farmers and the population in general are achieving less welfare than they might otherwise have had.

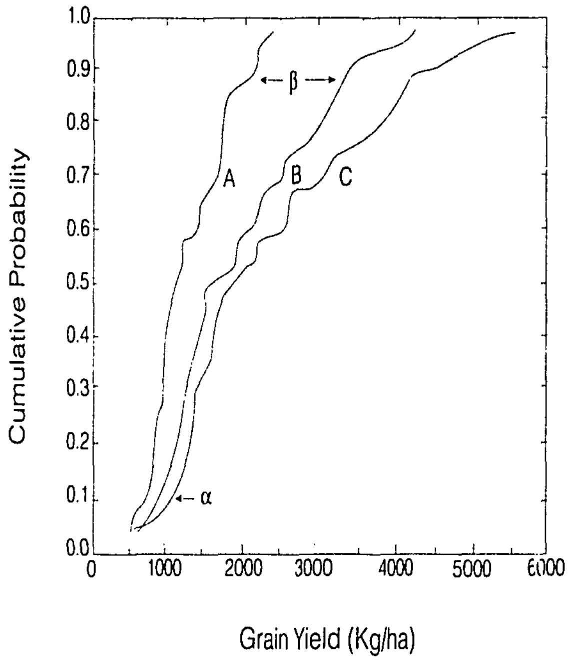
One way of attempting to deal with these factors and redress the balance is through the use of whole-farm modeling. The principal advantage of farm system modeling as a methodology is that a specific technology can be assessed *ex ante* in a whole-farm context. Interactions between the various farm activities 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 as is the limitations of these as well as managerial and social implications that influence the impact of new agrotechnology on farmers and their families.

The Whole Farms Systems approach was led by: J.B Dent, Edinburgh School of Agriculture.

Farming Systems Research and Simulation

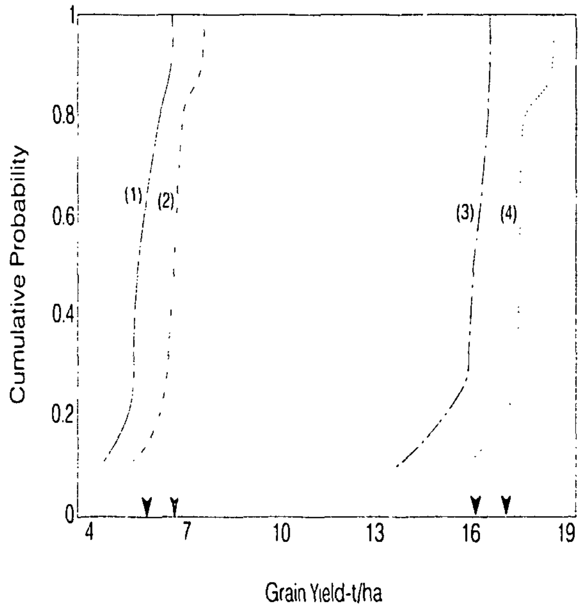
The use of mathematical modeling techniques has become integrated with the study of systems. In the context of farming systems, perhaps the most persuasive reason for this is the fact that experimentation in the real world is expensive, time consuming and there are severe problems in controlling variables exogenous to the experiment. This is particularly the case in field experimentation which is consequentially a poor framework for expanding knowledge. As a result, the concept of using locally validated detailed models of farming sub-systems as the preferred medium for applied research is a viable one. It is well appreciated that it is now possible to create, for example, a model that will simulate the growth, development and final yield of a crop in a specific locality with tolerable precision. Assuming that confidence has been established in the capability of the model to produce outcomes similar to those experienced in the real world, then the model can become the medium whereby alternative management strategies can be assessed (experimentation). Using site specific, historical or simulated weather time series, frequency distributions of the seasonal outcomes from each strategy quickly may be established.

An example of this use was testing the capabilities of the CERES-Wheat model in relation to fertilizer application in Australia (Godwin et al. 1989). Simulation of the same variety in the same location, subject to three nitrogen fertilizer levels, revealed large variation in yield from season to season according to the weather.



Cumulative probability functions for simulated grain yield response to three fertilizer strategies at Dubbo, Australia. (A=0 kg N ha-1; B=30 kg N ha-1; C=60 kg N ha-1)

Source: Godwin et al. 1989



Cumulative probability functions for four hypothetical varieties of Maize 'grown' in Gainesville, FL.

Source: Dent 1993

Simulated climate data for the locality was used over a period of 50 years. Such data could not have been provided by way of field trials which may, over a two three year trial period, only indicate the means for a small sample of climate years and some view of experimental error from the plots. What can be achieved for simple treatments like nitrogen fertilizer level can equally easily be done by way of the model for much more complex strategy-type 'combination treatments'.

This kind of research opportunity presents a flexibility not available to research restricted only to field trials.

Equally useful would be the exploration of cropping sequences: biological and economic performance of a particular sequence is dependent on a range of factors such as actual date of sowing, ability to harvest on time and hence to prepare subsequent seed beds. Cropping sequences with alternative management rules can be explored to locate stability of output and economic achievement.

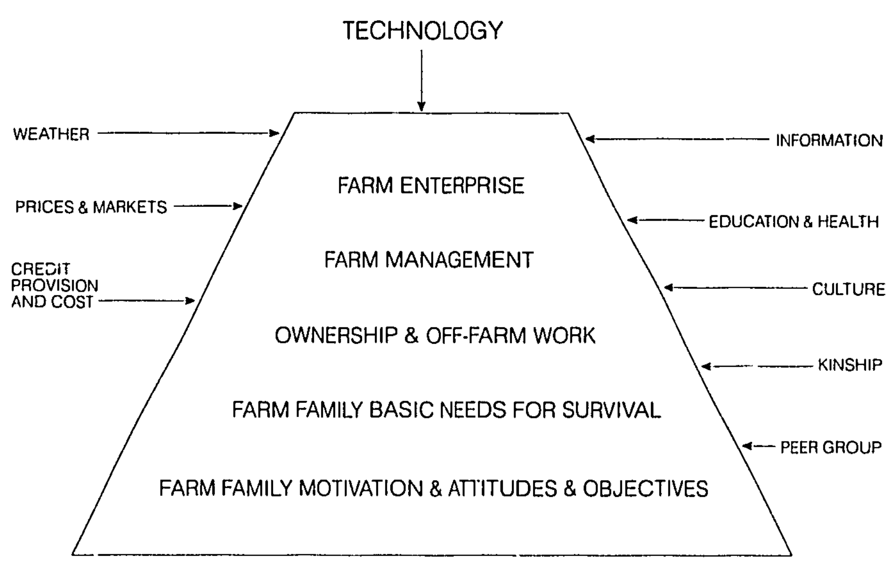
Another use would be to direct aspects of technical research: both field and laboratory based. An example is the IBSNAT crop models where cultivars are characterized by a small number of "genetic coefficients" (Hunt et al. 1989). Any particular variety is represented by a number from a range for each coefficient. For any particular location defined by soil type and climate a number of hypothetical cultivars can be defined and yield outputs for each simulated. This type of procedure provides insights into the characteristics best suited to the locality in question and potential for expressing results in terms of economic parameters clearly exists. The decision to adopt a new cultivar or management strategy is complex but at least with yield frequency distributions for a specific location generated by a crop model there is more information on which to formulate an extension program.

Modeling capabilities such as these are able to strengthen the arm of the agricultural research scientist by improving relevance of results, timelines and cost-effectiveness. But they do not, directly, address the key area integrating research and adoption.

Technology adoption for farmers represents a process of change – usually gradual. Opportunities for technology options within this process of change have to fit within economic and socio-cultural values. Even comprehensive results leading to the determination of yield dominant strategies within an enterprise is a relatively small part of the tapestry of factors influencing farm change by 'improved technology'. Mechanistic simulation modeling of the growth and development process are predictive for the precise local circumstances to which the data apply; they are in no way explanatory of the processes nor the interactions between farm decisions, farm family behavior and the socio-cultural network in which rural people live and work.

A Whole Farm Framework

A more acceptable model might be one that included the components presented in the figure below. The farm/farm-family components are presented



Components for a whole-farm model.
Source: Dent 1993

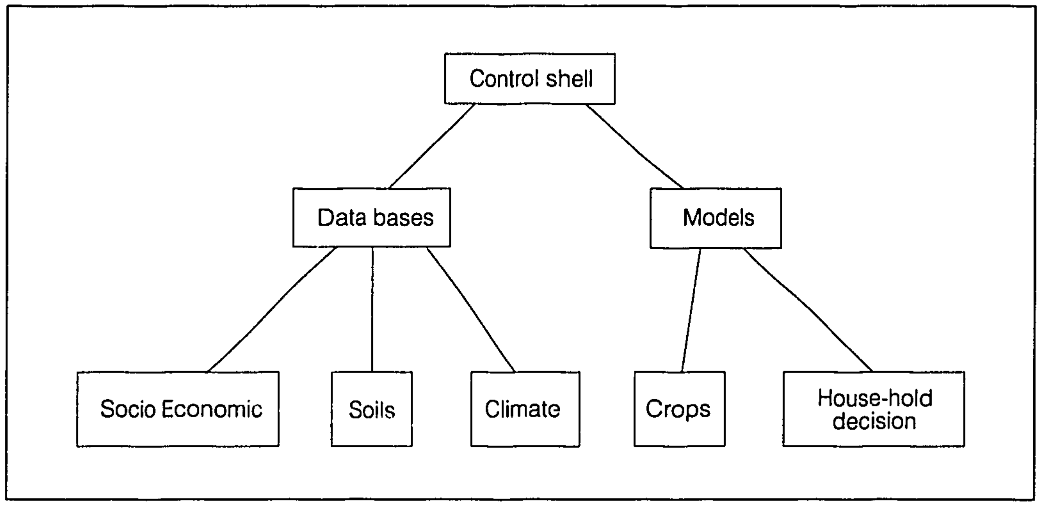
within the box. Those factors on the right hand side of the box influence behavior by acting on socio-cultural components, while on the left hand side, economic and physical forces are described which might be expected to have a more immediate impact on decision-making. With such a model, a farm family representative of a target group of farm families could be 'exposed' singly or in combination to new circumstances that might, for example, include alternative prospective new technologies in the various enterprises, alternative market scenarios and credit opportunities and alternative levels of extension support.

A computer model based on these components as well as upon the factors influencing key farm management decisions would not bear much structural resemblance to the crop simulation models discussed previously. So many of the mechanisms and relationships involved have simply not been explored, or placed in qualitative relationship.

Thus, it seems likely that any basic computer structure will involve rule-based algorithms, relying on experiential data to express many of the behavioral characteristics. A first concept might be that the overall model will take the form of a shell which will call, as appropriate, enterprise simulation models (crop models, for instance), databases and an expert system, reflecting the farm household decision process. The rule-based approach of the expert system permits a formal structure while at the same time handling both quantitative and qualitative data. In circumstances of data scarcity rules may be formulated within the expert system in a manner similar to the expert using 'rules of thumb' when data are limited.

Thus, a probable structure for the whole farm model would include a shell, socio-economic, soils and climate databases, and crop and household decision models, as illustrated in the figure on the following page. The climate and soil databases are already well known. The socio-economic database is not yet explored but will have endogenous and exogenous elements: endogenous data will include land tenure arrangements, economic status and resources, family size, age and education and a range of cultural factors including traditional values and beliefs; exogenous factors will include credit provision and cost, market prices for inputs and products, and availability of extension services. These data would be managed within the rules-based household decision model.

The implications for the satisfactory modeling of the socio-economic behavior of an individual farm in a region are profound. In addition to the use of crop



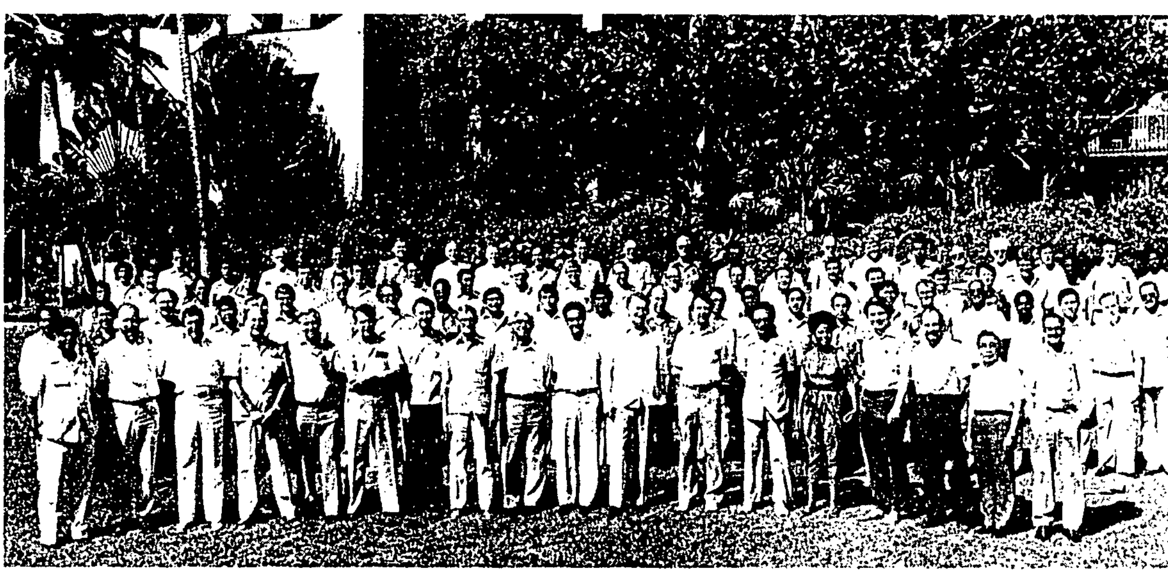
Potential structure for a whole-farm model.
Source: Dent 1993

models in a technology-design mode, there exists the possibility of aggregating responses over a wide area. Within this kind of framework, the whole concept of farming operations can be judged within stochastic environments. The prospect of a whole farm model holds out the scepter of improvement in the allocation of scarce local research resources, in the balance of regional expenditure between technical research and infrastructure improvement and in the welfare of farm families operating with limited resources in uncertain climatic, economic and political environments.

[DSSAT is used for] crop modeling studies on wheat, maize, soybean, peanut, sorghum...barley; for genetic coefficient calculations; and for economic applications.
---H.M. Eid, Egypt

use [DSSAT] in teaching simulation and farming systems research at undergraduate and masters level.
---G.Edwards-Jones, Scotland

Networks



Networks

Networking is defined in Webster's as "the exchange of information among individuals, groups, or institutions." This definition is embodied in the systems research approach undertaken by IBSNAT. Planning for IBSNAT began in 1978 and it was during this early stage of program design that project proponents made it a point to include the term "network" in any new undertaking. Additionally, the "S" in IBSNAT was designated as "Sites" instead of soils, because, even though the IBSNAT project had its "roots" in soil science, a broader network base was planned to involve a multiplicity of disciplines. A global network of benchmark sites and scientists was envisioned to implement a systems research approach to agrotechnology transfer.

IBSNAT Collaborators

The IBSNAT network of collaborators was established in 1983 to assemble and to eventually distribute a portable, user-friendly, computerized decision support system which would enable users to match the biological requirements of crops to the physical characteristics of land to attain objectives specified by the user. The network included a multi-disciplinary team of researchers and institutions involved in the development of crop simulation models, including the University of Florida and the Agricultural Research Service, USDA, Temple, Texas. Later, researchers from Michigan State University, the International Fertilizer Development Center, the University of Puerto Rico, the School of Agriculture at Edinburgh University, the University of Georgia, the University of Guelph, the University of Hawaii, and the International Rice Research Institute, among others, participated in the development of additional models and modular components of DSSAT.

The consensus in the beginning, and it is still true today, was that no single individual or institution could achieve what can be accomplished by a network of collaborators. The DSSAT software is an example. It is a product of knowledge synthesis and represents the multidisciplinary and integrated effort of many and could not have been completed in such a short period of time without the network. Successful calibration and validation of crop models in a range of global sites provided the necessary level of confidence to continue development of DSSAT.

Organization:	Development of:
Michigan State University, MI, U.S.A.	Cereal models; potato model; water balance
University of Florida, FL, U.S.A.	Grain legume models; pest models; DSSAT
Edinburgh School of Agriculture, U.K.	Whole-farm systems
IFDC, AL, U.S.A.	Cereal models; N, P modules; cassava; DSSAT
CIAT, Colombia	Bean model; cassava model
ICRISAT, India	Peanut model; sorghum model; millet model
University of Georgia, GA, U.S.A.	Bean model; DSSAT
USDA/ARS/TARS, Puerto Rico	Aroid model
USDA/ARS, TX, U.S.A.	Maize model, MDS
CSIRO, Australia	Minimum data set
Dept. of Agriculture, Bangkok, Thailand	Cassava model; rice model
Chaing Mai University, Chaing Mai, Thailand	Cassava model
University of Hawaii	Aroid model; intercrop model; DSSAT; rice model; pest model
University of Guelph, Canada	Cassava model; genetic coefficients; DSSAT
IRRI	Pest models
SMSS/SCS/USDA	Soils database
NifTAL	N-fixation

Institutions that collaborated with IBSNAT in software generation.

DSSAT Users

During the first five years of IBSNAT, its network consisted primarily of model developers and those interested in validating models, previously referred to as data generators. Those validating models collected approximately 250 minimum data sets, almost exclusively with their own funds. In the first half of the IBSNAT decade, there were approximately 50 members in the network. With the publication and release of DSSAT v2.1 in 1989, the IBSNAT network of DSSAT users grew to well over 500 in three years; this figure represents only the number of distributed copies of version 2.1.

Africa & Middle East

Algeria
Botswana
Burkina Faso
Burundi
Egypt
Ethiopia
Ghana
Guyana
Israel
Jordan
Kenya
Kuwait
Lesotho
Malawi
Mali
Mauritius
Morocco
Mozambique
Niger
Nigeria
Saudi Arabia
Sierra Leone
South Africa
Syria
Uganda
Zambia
Zimbabwe

Asia

Bangladesh
China
India
Indonesia
Japan
Malyasia
Pakistan
Philippines
South Korea
Sri Lanka
Taiwan
Thailand

Europe

Albania
Austria
Belgium
Bulgaria
Cyprus
England
Finland
France
Germany
Greece
Hungary
Ireland
Italy
Netherlands
Norway
Poland
Portugal
Russia
Scotland
Spain

The Americas

Argentina
Brazil
Canada
Columbia
Costa Rica
Guatemala
Mexico
Nicaragua
Peru
St. Lucia
Trinidad & Tobago
Uruguay
USA
Venezuela

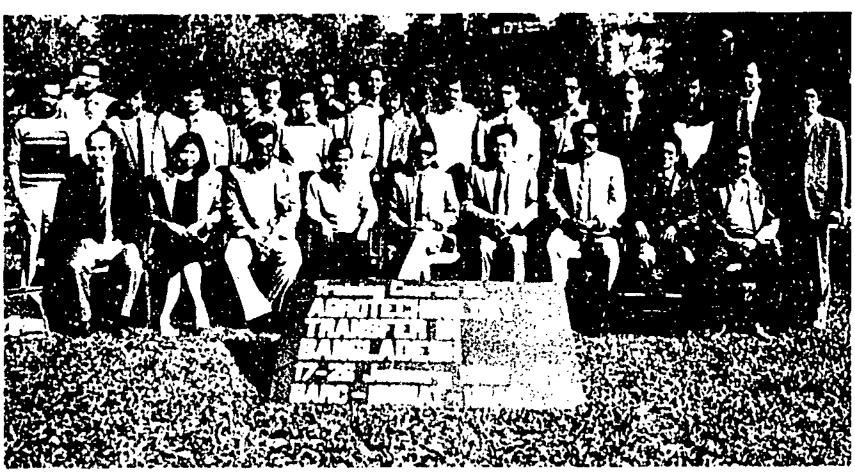
The Pacific

Australia
Fiji
French Polynesia
Guam
New Caledonia
New Zealand

Countries in IBSNAT network of DSSAT users.

The IBSNAT network is a unique participatory network where membership is open to any individual or organization willing to share data, information and models with a like-thinking group. Where necessary, memorandum of agreements have been executed to provide documentation for collaboration. Subcontracts were entered into with a number of institutions to complete or develop new models for those crops identified by participants to the first two IBSNAT meetings in India (1983) and in Hawaii (1984). These included the University of Florida; ARS/USDA, Temple, Texas; Michigan State University; the University of Puerto Rico; The school of Agriculture, Edinburgh University; the International Fertilizer Development Center; and the University of Guelph.

Although the IBSNAT network of collaborators has a distinct purpose and focus, its membership varies widely in resource capabilities, expertise, interest and priority of effort; nevertheless, the products developed during the IBSNAT decade would not have been possible without the contribution of every one of its members.



IBSNAT collaborators in the Philippines (top left), in Thailand (top right) and in Bangledesh.

[We used DSSAT for] comparison with field-measured values of maize and soybean trials in different climatic regions of Austria for: yield, dry mass contribution, phenology, course of soil water content, and leaf area index.

---E. Josef, Austria

Regional

Regional networks were proposed to serve as a permanent network of interested parties or countries in systems research for a specified area or region of the world. A critical assumption being that IBSNAT was a project with a limited life. It was envisioned that a regional network would be responsible to the needs of users and collaborators with common goals and interest. A number of regional networks would then link together to form a global network.

To initiate establishment of regional networks would have been prohibitively costly and would have required more diplomacy than science. While IBSNAT recommended and encouraged regional collaboration through such networks, establishing one required building an awareness of the technical and economical benefits derived from systems research and application. While interests were generally high among scientists, many had difficulties in conveying this interest to decision makers, even in countries where regional cooperation for economic, technical and security exists, for example, ASEAN (Association of South East Asian Nations). Regional research organizations such as AVRDC, CATIE, ACSAD and SARCCUS could eventually serve as network hubs but a global strategy would be required to have any kind of meaningful interaction among such organizations.

IBSNAT was involved in discussions with several groups interested in establishing regional networks as they were described conceptually at conferences and meetings. Country representatives from the Caribbean, in the Pacific or Oceania and Southeast Asia invited IBSNAT to participate in preliminary meetings for this purpose. The Universities of Puerto Rico and Hawaii represented IBSNAT at these meetings. CARIBSNAT, OBSNAT, and ABSNAT were proposed acronyms of these networks. Of the three, only OBSNAT evolved into a regional program. A brief description of OBSNAT and ABSNAT follows.

OBSNAT

The Oceanic Benchmark Sites Network for Agrotechnology Transfer (OBSNAT) was planned as a regional network for Oceania in 1984. Parties to this plan included IBSNAT, the South Pacific Commission (SPC) and the New Zealand Department of Scientific and Industrial Research. A second meeting was held in 1989 at the headquarters of the SPC in Noumea, New Caledonia. Both ORSTOM and CIRAD of France were in attendance. Subsequent actions after that second meeting resulted in support by member nations and donor groups of OBSNAT and its concepts. During implementation of the program in 1991, the same OBSNAT was supplanted by the Pacific Agricultural Information System (PAIS). PAIS would be a program of the SPC with an office in Fiji. Management of PAIS is currently being carried out by Philip Hart.

Participants in planning meeting organized by the South Pacific Commission in New Caledonia.

PAIS is planning and organizing a training course on systems analysis and crop models using DSSAT in 1994. System scientists from IFDC have been contacted to conduct the training course in Suva. Approximately 25 researchers and decision makers from the region are expected.

ABSNAT

The ASEAN Benchmark Sites Network for Agrotechnology Transfer or ABSNAT was proposed in a regional meeting of participants from each of the ASEAN countries in Tagaytay, Philippines in 1984. A resolution was prepared and submitted to the ASEAN Committee on Food, Agriculture and Forestry (COFAF) for action. In his communication to IBSNAT in July 1993, C.R. Escano of PCARRD informed IBSNAT that the resolution is still alive in the COFAF and awaiting action. The political reality of establishing such collaboration at the technical level was one reason several participants had indicated their preference of communicating directly with IBSNAT. They've continued to do this in the absence of a regional program.

Applications & Acceptance

Acceptance implies approval. If we measure acceptance of the concepts embodied by IBSNAT in a product such as DSSAT by how well received they are by the general public as well as by the scientific community, IBSNAT has been successful. The DSSAT software was first released in late 1989 and has gained widespread support and use since then.

Stephen Strauss, a feature writer with the *Toronto Globe and Mail* reported on IBSNAT in a two-page news article and subsequently contributed a similar article for the Trends chapter in *Technology Review*, published by the Massachusetts Institute of Technology (Vol. 93(3):24-25) in April 1990. Soon thereafter, in October 1990, an Australian science newsmagazine television program, *Beyond 2000*, produced by the Australian Television Network, contacted IBSNAT to arrange for an interview and demonstration. Associate producer, Ann Buchner, and anchor reporter, Maxine Gray, accompanied by the program's camera and sound men, produced a show entitled "Global Farming." *Beyond 2000* introduces innovative ideas and concepts to general audiences and is shown globally. "Global Farming" aired initially in Australia in 1991. Another reporter, Emily Looney of Associate Press, wrote, under her byline, an article entitled "Computer Lowers Risk to Farmers" which first appeared in the July 15, 1991 edition of the *San Diego Union*. The article was reproduced and published in USAID's *Frontlines* newsletter in its October 1991 issue.

The utility of DSSAT to the scientific community was clearly demonstrated in a joint program involving USAID and the U.S. EPA to study the impact of global climate change on food production and trade. Scientists from nearly 25 countries participated in this two-year program. Further discussions are presented in this section.

For development programs, the end user of introduced agricultural technology has been the resource-poor grower or farmer in lesser-developed countries. A direct transference from technology developer to user is not the norm. A transfer agent is generally involved and determines whether a technology is appropriate and acceptable. Who are the transfer agents of technology to the end users?

IBSNAT and USAID identified two types of agents or target groups who would eventually judge the acceptability and applicability of products developed through systems research. The first group included technicians and scientists in both industrialized and developing nations who would assess the technical merit of the product or products. To a large extent, they represented the primary target for IBSNAT model developers. The second group included government policy and decision makers responsible for planning and implementing programs on sustaining or improving agricultural productivity and development. This latter group represented the principal clients of USAID missions.

To document and demonstrate the acceptance of IBSNAT technology and DSSAT, a mid-term evaluation of IBSNAT in 1990 by an external panel for USAID recommended "socio-economic case studies in Guatemala, Venezuela and Malawi be undertaken...as resources permitted."

By leveraging available resources, collaborating scientists from a number of countries were able to accommodate local needs of their programs, as well as global needs of IBSNAT. For example, researchers were able to include monitoring and collection of the minimum data sets by enlarging plot sizes in their planned field experiments. A common outcome of the case studies reported in the following pages was improved research efficiency through application of crop models and DSSAT. Researchers were able to predict and assess the impact of different cultivars or of management. Several reported activities have elevated crop model outputs at the field level with DSSAT to a watershed or mapping unit level by aggregating model outputs with tools associated with geographic information systems.

I continue to look for opportunities to encourage use of DSSAT. Recently I had a chance to recommend it to the Sorghum and Millet Improvement Program in Zimbabwe which is working with the 10 SADC countries.

---D. Alter, Washington, DC

We are engaging in a watershed level study research project under Rockefeller Foundation support. DSSAT plays a major role... It helps us in screening the suitable rice varieties of the highland areas of Northern Thailand. The DSSAT-Rice model will be used during the early phase...to collect, analyze and interpret the...data sets needed for agricultural planning and development at the farm, community and regional levels.

---A. Jintrawet, Thailand

International Centers

The International Rice Research Institute (IRRI) in Los Baños, Philippines.

Several international agricultural research centers (IARC) supported by the CGIAR have had key roles in promoting the principles and concepts of IBSNAT. The initial international meeting of IBSNAT on the minimum data set was hosted by L. D. Swindale, Director-General, and his staff at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Hyderabad, India in 1983. ICRISAT not only provided the venue for this meeting but also the resources to have the proceedings entitled, *Minimum Data Sets for Agrotechnology Transfer*, edited, published, and made available for distribution to a global audience.

Outputs from that first meeting and a second held in Hawaii resulted in the compilation of guidelines necessary to design and collect the minimum data set for systems analysis and crop simulation. The strategy was sound but the resources necessary to achieve IBSNAT's objectives were limited. Successful achievement of the stated objectives required cooperation and collaboration among a network of scientists, not only from national programs, but also from international centers to pool existing and available resources for a common goal.

The IARCs filled this role by sharing research outputs from ongoing programs or by inviting IBSNAT's participation in these programs. Mutual benefit through such collaboration resulted in validation of model outputs over a range of environments not possible for a single program or organization to carry out.

The following is a list of major contributions derived by IBSNAT in collaboration with these IARCs.

Center	Researchers	Activity
ICRISAT	S. N. Virmani P. Singh	Validation of PNUTGRO
	G. Alagarswamy	Development/calibration of CERES-Sorghum and Millet.
	D. Faris	Application of SOYGRO in AGLN (Asian Grain Legume Network)
ICARDA	H. Harris	Validation of CERES-Wheat Development of CERES-Barley
	W. Goebel	Spatial weather generator for DSSAT
CIAT	J. White	Development/calibration/validation of BEANGRO
	M. Sharkaway	Data sets for SUBSTOR-Cassava
CIMMYT	M. Bell S. Chapman	Validation of CERES-Maize and CERES-Wheat
CIP	D. Midmore	Data sets for SUBSTOR-Potato (now at AVRDC)
IRRI	R. J. Buresh S. K. DeDatta P. S. Teng H. O. Pinnschmidt S. Calvero	Validation of CERES-Rice for lowlands; submerged N-dynamics Development of rice blast module for CERES-Rice

These collaborative activities with IARCs and their research scientists provided unexpected (or another better word) impetus in developing, calibrating, and validating crop models and DSSAT. Minimum data sets derived from IARC stations as well as from their involvement in national agricultural research stations (NARS) allowed a more accelerated time frame to validate several crop models in DSSAT. Collaboration of IARCs with IBSNAT in the above activities demonstrate leveraging of resources for mutual benefit of both as well as in promoting systems research activities and in demonstrating its application in agrotechnology transfer.

P. Teng of IRRI and IBSNAT, M. Kropf of the SARP (Simulation of Rice Production) program at IRRI, and F. Penning de Vries of CABO organized an international symposium entitled "Systems Approaches for Agricultural Development" in December 1991 at the Asian Institute of Technology in Bangkok, Thailand. The symposium was planned with Teng as the final major activity for IBSNAT as a project supported by USAID.

It is perhaps fitting that two IARCs, ICRISAT and IRRI, which served as partners from the beginning, also staged the first and the last symposium of the IBSNAT Decade.

Special Study:

Global Climate Change

Global environmental concerns, particularly global warming and its consequences, have received much more political and scientific attention than in the past, due primarily to improved communications and a burgeoning range of electronic media. With a greater awareness of world events, the impact of reports, from famine and destruction of rainforests, depletion of the ozone layer in the atmosphere to flooding, the greenhouse effects and the eruption of long dormant volcanoes, the world has grown smaller and the world's populace become a single global community. Truly, the last decade of the 20th century ushered in the information age.

In order to assess the impact of humankind's action on the environment and the consequences of natural climatic events on humankind's ability to sustain itself, information technology and tools derived from it are essential to understand systems and predict outcomes. The IBSNAT project was and continues to be involved in three activities or programs established to study the impact of a changing global climate

PAN-EARTH

Prediction of crop productivity as influenced by environmental changes was the principal aim of IBSNAT's involvement with the PAN-EARTH, the Predictive Assessment Network for Ecological and Agricultural Responses to Human activities, program directed by M. Harwell at Cornell University. PAN-EARTH's strategy involved an international network of physical and biological scientists studying the potential impact of global environmental change on the biological systems of selected case study countries and regions. The success of the network was a function of its ability to access tools to assess the effects of climate change on agricultural production systems. The

PAN-EARTH group organized their first workshop in Beijing in August 1988 to: (i) initiate case study analyses by specifying physical scenarios of climate change, identifying stresses, and agreeing on methodologies and data bases for the study; and (ii) to test the physical/biological interaction methodology for each case study site. Harwell contacted IBSNAT and organized a demonstration of the DSSAT software in China as a potential tool in their network studies. Subsequently, G. Hoogenboom of the University of Georgia, Griffin represented IBSNAT at two workshops held in 1990 at two additional case study sites in Senegal for the sub-Saharan Africa region and in Venezuela. Case studies were also under development in India, Japan, Australia/New Zealand, and Switzerland where earlier studies were conducted on the impact of climate change due to nuclear war.

The crop models in DSSAT were used by Hoogenboom in the training workshops to demonstrate its utility to assess productivity as influenced by increased temperatures by means of systems simulation and *ex ante* experimentation. Techniques and methods necessary to calibrate the models with local minimum data sets and sensitivity analyses of the model outputs were presented by Hoogenboom in both workshops. In addition to the CERES-Maize, CERES-Wheat, SOYGRO, and PNUTGRO models, Harwell reported interest in having the CERES-Rice, Sorghum and Millet models for PAN-EARTH network scientists as they became available.

EPA/AID Study: Global Climate Change

The U.S. Environmental Protection Agency (EPA) and USAID jointly supported a program entitled *Implications of Climate Change for International Agriculture: Global Food Production, Trade, and Vulnerable Regions* to study the impact of increased temperatures and greenhouse gases. This study, under the guidance of C. Rosenzweig of the Goddard Institute for Space Studies at Columbia University, J. T. Ritchie of Michigan State University, J. W. Jones of the University of Florida, and R. Benioff of EPA/Washington, invited the participation of IBSNAT network representatives from Bangladesh, India, Pakistan, Thailand, Philippines, Indonesia, Costa Rica, Egypt, Mali, Niger, Senegal and Zimbabwe. Other countries represented included Australia, Japan, China (PRC), Canada, Mexico, Argentina, Brazil, El Salvador, Uruguay, France and Russia.

A training workshop was held in January 1990 in Washington, D.C. for participants. Included in the program was training in the use and application of DSSAT in conjunction with weather outputs by G. Hoogenboom of the University of

Georgia, D. Imamura of the University of Hawaii, B. Baer of Michigan State and U. Singh of IFDC. Outputs of future weather were generated from Global Circulation Models (GCMs) and presented by Rosenzweig as the global climate scenario for all participants to use interactively with the IBSNAT crop models and DSSAT. The GCMs, which included the GISS, GFDL and UKMO, predicted temperature increases ranging from 4.0 to 5.2 ^{o}C and an increase in precipitation from 8.3 to 15 percent at two different levels of CO_2.

A special version of DSSAT version 2.1 was developed to permit the crop models in DSSAT to accommodate and simulate changes in levels of carbon dioxide in the atmosphere. The daily canopy photosynthesis and transpiration sections of the CERES and GRO crop models in DSSAT were modified to respond to changes in CO2 concentration. The management sections of the models and the strategy analysis program were expanded to include the option to modify weather data interactively.

The modified version was referred to as DSSAT version 2.5 and was used by participants in 1990. During the two-year study, crop models for wheat, maize, rice and soybeans and the strategy evaluation program in DSSAT were used extensively by participants.

Outputs were reported in the second and final meeting of the group in Washington, D.C. in March 1991. The collective outputs were to be organized by Rosenzweig for an economic assessment by G. Fishcher of IIASA (International Institute for Applied Systems Analysis). The economic modeling will allow for estimation of potential effects of climate change on the comparative advantage of the major food-producing regions, on prices and patterns of food production and trade. Outputs from this study were to be coordinated with similar type efforts by the U.S. Department of Agriculture and the Organization for Economic Cooperation and Development.

A symposium was organized during the 1992 American Society of Agronomy meetings in Minneapolis in November to have participants report their accomplishments to a larger audience and to publish their findings in a proceedings to be published at a later date.

International Geosphere-Biosphere Programme (IGBP)

The International Geosphere-Biosphere Programme: A Study of Global Change was established in 1986 by the International Council of Scientific Unions to improve our knowledge of the dynamics of the biosphere influencing, and influenced by, global environmental change (IGBP, 1992). According to the

IGBP, scientific research has identified the problems, and tasks to address them include improving confidence in the predictive capabilities of evolving computerized decision tools by reducing uncertainties.

The IGBP raised six questions to assist in project definition and design. One of them "How will global changes affect terrestrial ecosystems?" resulted in the establishment of a Core Project entitled *Global Change and Terrestrial Ecosystems* (GCTE). Each of the questions focuses on "...environmental systems and processes that are likely to have greatest worldwide significance on a timescale of decades and centuries." The GCTE core project has three foci. The first two relate to the interactions of the structure (physiological) and functions (dynamics) of ecosystems, which should lead to a better understanding of ecosystems response to global change. The third was on agriculture and forestry and is the focus under which IBSNAT would be recognized as a potential contributor.

H. A. Nix, D. C. Godwin, J. W. Jones, and S. S. Jagtap represented their respective institutions and collectively represented IBSNAT at the first meeting of the GCTE in Yaounde, Cameroon in 1989. As a result of their participation, the IGBP recognized IBSNAT's crop models for a number of species as providing "the basic format for crop plant species" to study the influence of global change under Task 1, Activity 1, Focus 3 (IGBP, 1990).

Under Activity 1, the effects of climate and atmospheric change on key agronomic species, and Task 1, develop an understanding of the effects of climate change on crop and livestock species, of Focus 3 of the GCTE, IBSNAT was invited to participate in a Temperate Zone Network by P. B. Tinker from England. Two sub-tasks were developed to design experiments on and to model growth of key crops under changed atmospheric conditions and climate. Tinker met with J. W. Jones and G. Uehara in Gainesville, Florida in February 1992 to confirm this collaboration. Jones was nominated to serve as IBSNAT's representative to the GCTE. In July 1992, the GCTE Focus 3 group organized a workshop on *The Effects of Global Change on the Wheat Ecosystem* in Saskatoon, Canada. Jones made a presentation on the IBSNAT/CERES wheat model for predicting global change effects on the wheat ecosystem after jointly presenting a general introduction to the IBSNAT family of models with L. A. Hunt.

Subsequently, a meeting/workshop was scheduled for November 1993 in the Netherlands to allow system modelers to establish guidelines for a wheat model sensitivity analysis program. Jones, Ritchie, and Hunt are expected to participate. The final outcome and the scope of continued involvement of IBSNAT with the IGBP and GCTE has yet to be determined.

Regional:

Transfer agents in the African continent have commonly been associated with aid programs. A larger percentage of third-country nationals affiliated with international centers and donor-supported development programs, rather than country scientists and national programs, have acquired and applied DSSAT and its crop models.

Copies of DSSAT have been distributed to 24 countries in Africa either through individual requests of through training programs. Reports from collaborators are collectively summarized.

Africa

Applications

Prior to the release of DSSAT v2.1 in 1989, stand-alone versions of crop models were shared with researchers invited to workshops on the minimum data sets and crop models in Venezuela in 1984 and in Jordan in 1985. O. Lungu and V. Chinene of the University of **Zambia** participated in each, respectively. Both were instrumental in being the first to collect the minimum data set from an African country for the IBSNAT version of CERES-Maize.

Validation of the CERES-Maize model was of interest to Clement Mathieu and Salvator Kabarungu of the Université du **Burundi.** With the acquisition of weather instrumentation by the USAID/Bujumbura office for the experimental site at the Kajondi Seed Farm, minimum data sets for maize and wheat were collected. The farm, supported by both the Burundi government and AID, is charged with seed multiplication for distribution to local farmers. Soils at Kajondi were characterized by A. Touchet of USDA/SCS with support from SMSS. Mathieu and A. Bruyere, from the University of Louvain, Belgium, were instrumental in this activity. Mathieu, a soil scientist, had intentions of using crop models and soils information in Burundi to assess potential productivity before his relocation. Luc d'Hase represented both Burundi and Belgium in the IBSNAT workshop held in Jordan.

Minimum data sets were reportedly collected for model validation in **Kenya** for wheat and dry beans by the Kenya Agricultural Research Institute in cooperation with CSIRO, Australia and the Mid America Universities International

Consortium in Agriculture (MUCIA); in **Niger** for sorghum and millet by ICRISAT; in **Malawi** for maize by the University of Malawi and IFDC; and in **South Africa** by the Soil and Irrigation Research Institution of the Department of Agricultural Development for soybeans and maize. Some of these data sets were sent to IBSNAT. Others were reported and retained by users.

Application of DSSAT involves acquisition of resource data sets on sites (soils), weather, management and crops. The first stage normally includes validation of selected crop models in DSSAT. Estimation of crop genetic coefficients from available information and from experiments to record the MDS requires commitment and resources normally not available in most national programs. Hence, the international research centers of the CGIAR play an important role. S.S. Jagtap of IITA and M.V.K. Sivakumar of ICRISAT/Niamey shared information and data to apply systems simulation concepts in **Niger**, **Mali** and **Nigeria.**

Sivakumar represented **Niger** in a two-year study on the impact of global climate change on food production and trade organized jointly by the U.S. Environmental Protection Agency and USAID. Representatives from **Egypt**, **Mali**, **Kenya** and **Zimbabwe** participated. Each received a copy of a modified version, version 2.5, of DSSAT and was responsible for acquisition of local soils, weather and crop data sets. In combination with DSSAT, probable outcomes of increased temperatures and doubling of CO_2, based on outputs from three global circulation models, were reported for each respective country at the end of the study in 1991. A report of the outcome of this study will be published as the proceedings of a symposium held in Minneapolis in 1992.

Technical Assistance

At the request and support of local USAID missions in Kampala, **Uganda** and Gaborone, **Botswana,** scientists affiliated with IBSNAT have provided technical assistance to local programs associated with MUCIA and INTSORMIL/ATIP, respectively. F.H. Beinroth, of the University of Puerto Rico, represented IBSNAT in developing plans to implement systems application programs with DSSAT in Kampala. One outcome of that visit resulted in an Ugandan scientist, studying at Ohio State University, being sent to Honolulu to gain experience in data input and handling of the minimum data set from IBSNAT staff at the University of Hawaii. U. Singh met with N. Persaud of INTSORMIL/ATIP and D. Gollifer of SACCAR in Botswana to demonstrate DSSAT and its applicability to their tillage studies for sorghum and millet in mid-1990. A copy of DSSAT was ordered by the USAID mission for the national program in Botswana in 1992.

Training Courses and Workshops

Training courses have been held in **Malawi** in 1992 and in **Mauritius** in 1991. The former was organized by IBSNAT cooperators from IFDC (P.K. Thornton and U. Singh) and Edinburgh (G. Edward-Jones) at the University of Malawi for scientists and planners from Malawi, as part of a program supported by the Rockefeller Foundation. Twenty copies of DSSAT were provided by IBSNAT. The course held in Mauritius was organized by IBSNAT cooperators from Australia (H.A. Nix and D.C. Godwin) for scientists from Commonwealth African countries. A total of 25 participants attended. The Australian government, through ADIAP, provided funds for the training course which included acquisition of 25 copies of DSSAT from IBSNAT. **Cameroon** hosted the second IGBP (International Geosphere-Biosphere Program) in which IBSNAT was invited to participate to present and describe DSSAT and the minimum data set as systems for adoption by the IGBP. The Malawi training course is described in detail in the following section as an example of IBSNAT-organized training

Malawi

The project "Agrotechnology Transfer Using Biological Modeling in Malawi" was initiated in late 1989 with support from the Rockefeller Foundation as a collaborative effort between the Department of Agricultural Research, Ministry of Agriculture, Malawi; the Edinburgh School of Agriculture, UK; and the

International Fertilizer Development Center (IFDC), USA. The work was carried out locally by A. Saha of the Department of Agricultural Research, Malawi.

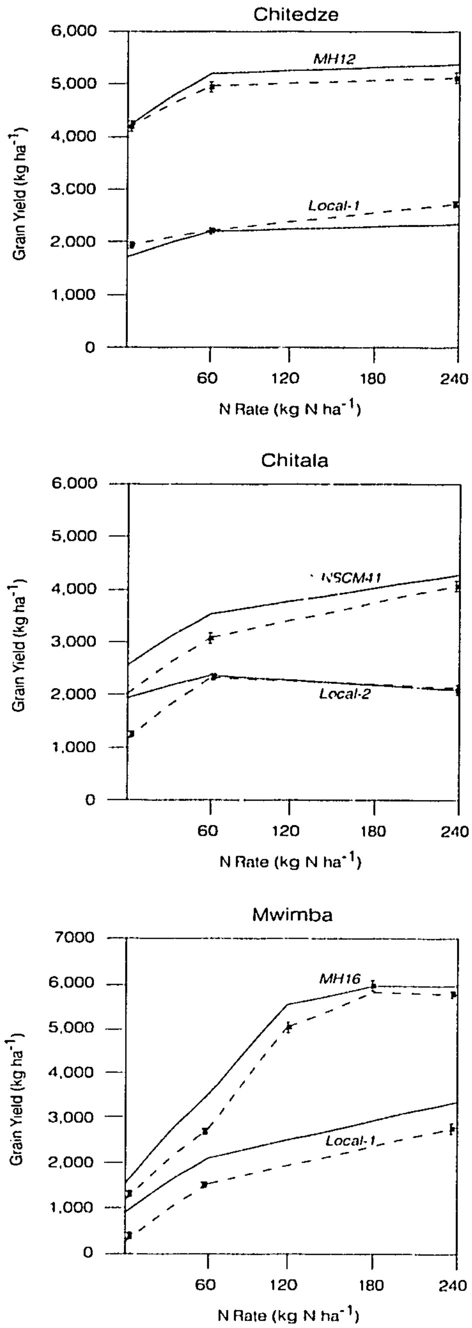
The major objectives was to validate a crop simulation model of growth, development and yield of maize, through a series of field trials carried out over three seasons at a number of locations in the mid-altitude maize ecologies of Malawi. The rationale was to see if simulation techniques had potential in enhancing the efficiency of the research and development process by helping to relieve the pressure on scarce research resources by screening large numbers of production alternatives using a computer model. Promising alternatives identified in this way could then enter field testing for eventual transference to the farmer, in the search for increased smallholder maize production to enhance food security for a rapidly growing population. The program was developed with the following objectives in mind:

U. Singh with Malawian researchers visiting a farmer's field during training course in Malawi.

1. Build a data base for soil and weather variables for Malawi's major maize-producing areas.

[used DSSAT] in simulating field experiments, multi-year strategy analysis and regional yield prediction.

---S. Jaglap, Nigeria



Comparison of observed and simulated grain yield for local and hybrid maize.

2. Validate and calibrate CERES-Maize for representative cultivars in three study areas.
3. Predict maize production and its variability between sites and between years in the study locations, and extrapolate results to other regions of the country.
4. Illustrate how the maize model can be used to short-circuit the traditional approach to agricultural research based on field experimentation.

Field trials were conducted at three research stations and in several farmers' fields. Results were analyzed and used to calibrate and validate the CERES-Maize model with respect to the local and hybrid maize varieties used in the field trials, and climate and soils information was collated. The CERES-Maize model appeared to work reasonably well by simulating a range of yields from 0.5 to 6.5 t/ha over the three seasons. Some adjustment may be required to other areas of the model apart from final yield prediction, such as biomass accretion over time and leaf area index as observed in the field.

A large amount of model experimentation was carried out to investigate such things as planting windows and fertilizer response as affected by weather, soil type and planting date. An effort was made to link the model to the spatial climate and soils databases of a Geographic Information System for a small area in Kasungu Agricultural Development Division, primarily to illustrate the potential for regional analysis using these tools.

Training activities included a one-week training course held at Chitedze Research Station and several informal visits during the project for helping with data collection and analysis and training in modeling techniques. Informal collaboration has continued, as there are more field trials to be analyzed and further weather and soils data to be collated. When these are completed, CERES-Maize will be recalibrated for Malawian conditions.

Practical alternatives for particular soil conditions were identified in terms of yield and enterprise gross margins and a small number of the most promising alternatives entered field testing. The modeling work also has a larger role to play, within the framework of the Soil Fertility Research Program in Malawi.

The following are some general observations concerning the project:

- Data collection procedures form no inherent barriers to the use of what are often perceived as relatively sophisticated computing tools to attack research problems in Malawi.
- For such technology to make a difference, it has to be integrated in some way into the research and development decision-making process.

Globally, the considerable potential of modeling can only be realized through the demonstration of real and tangible benefits to its use. The technical problems of agriculture in much of sub-Saharan Africa with respect to population growth, resource base depletion and weather risk, are such that all available tools should be brought to bear in the attempt to find solutions. The start made in modeling activities in Malawi should provide a base on which to build for the future.

[used DSSAT for] teaching demonstrations to both undergraduate and postgraduate students [and for] compilation of weather data and input into growth models.

---J.J. Owonubi, Nigeria

Thailand

Scientists affiliated with two departments in the Ministry of Agriculture of the Royal Thailand Government, Land Development Department and Department of Agriculture, have played important roles in development and application of crop simulation models and the concept of the minimum data set. M. L. C. Tongyai of the Soil Science Division, Department of Agriculture, and S.Panichapong and T. Vearasilp of the Land Development Department, were instrumental in providing the technical backstopping to acceptance of systems research in Thailand. Memorandum of agreements between IBSNAT and both departments were executed in 1984.

Tongyai and Vearasilp participated in IBSNAT training programs in Venezuela (Tongyai) in 1984 and in Hawaii (Vearasilp) in 1986. Both later provided technical assistance in the conduct of an IBSNAT workshop in Malaysia in 1987 at the Malaysian Agricultural Research and Development Institute (MARDI).

In 1991, both agencies and the Multiple Cropping Center at Chiang Mai University hosted the final meeting of the IBSNAT Technical Advisory Committee. During the same period, the Asian Institute of Technology in Bangkok hosted an international symposium on "Systems Approaches to Agricultural Development" organized in part by IRRI, CABO, and IBSNAT. The meeting permitted a sharing of information and commitments between IBSNAT, its co-organizers and Thai scientists.

Training and Education

The Multiple Cropping Center at Chiang Mai University now offers graduate level courses on systems research in which concepts of IBSNAT are taught. Case studies are carried out in the application of these concepts with DSSAT v2.1. These courses are taught by A..Jintrawet and S. Jongkaewwatana. Students enrolled in the Center's program include those from Thailand and its neighboring countries.

Two training courses were organized and conducted in Thailand in 1988 in Bangkok by the Department of Agriculture and the Land Development Department and in 1993 in Chiang Mai by the Multiple Cropping Center. Both courses were conducted in Thai and included researchers and planners from Royal Thai government agencies and universities.

Research

Under the leadership of M. Ekasingh, the Multiple Cropping Center has embarked on an innovative program to address issues and problems in the conservation and reforestation of watershed areas in the Northwest area of Thailand. Using satellite imagery and geographic information system, they are making an assessment of the existing situation. Erosion models developed by the Agricultural Research Service of USDA are being reviewed for their applicability. And coupling of DSSAT to GIS in a manner similar to AEGIS is planned.

MDS experiment with rice in Surin, Thailand.

Minimum data sets on rice, cassava and peanut have been used in the development, calibration and validation of IBSNAT crop models for both crops. Rice data sets from seven locations were provided by C. Nammuang of the Department of Agriculture. Cassava data sets collected from research sites located in the southeast, south, and central Thailand were being assembled by Tongyai for model validation of the SUBSTOR-Cassava model in DSSAT v.3 at the close of IBSNAT. Jintrawet and Jongkaewwatana are communicating with Thailand Sugar Planters Association for possible support in their participation in the validation and application of a decision support system which includes sugar-cane.

Biomass sampling of peanut in Lampung, Thailand.

IBSNAT training course, organized by PCARRD, in Los Banos, Philippines.

Philippines

The Republic of the Philippines has been an active collaborator from the earliest days of IBSNAT. Through the Philippine Council on Agriculture and Resource Development (PCARRD), it has been a strong supporter of and major contributor to IBSNAT activities.

A brief listing of IBSNAT–related activities in which the Philippines participated follows.

- PCARRD conducted experiments to collect the IBSNAT minimum data sets.
- PCARRD hosted a workshop to develop IBSNAT's proposal for the ASEAN Benchmark Sites for Agrotechnology Transfer (ABSNAT).
- In 1990, PCARRD organized and conducted an international training workshop on DSSAT in the Philippines.
- PCARRD participated in the USAID-EPA collaborative project on Global Climate Change and Crop Modeling and presented the results in the USA and in Japan.
- PCARRD funded a two-year project on Applications of the DSSAT soybean Model in the Philippines.
- PCARRD is currently conducting experiments to validate the PNUTGRO model and plans to do the same for CERES-Maize and SUBSTOR-Potato.
- PCARRD scientists presented technical papers at seven professional meetings in the Philippines.

Clearly, the Philippines not only contributed positively to IBSNAT but also adopted its concepts and products in their research and development efforts. PCARRD also made a conscientious effort to disseminate systems approach principles and methodologies throughout the Philippines.

[We use DSSAT for] identification of suitable areas for pilot testing and the eventual expansion/commercialization of specific crops including appropriate varieties/cultivars.

---C.R. Escano, Philippines

Taiwan

National ChungHsing University and the Food and Fertilizer Technology Center for Asia and the Pacific are collaborative agencies of the IBSNAT Project in Taiwan. During the spring and fall seasons of 1987, six agricultural experimental stations located in Taiwan, carried out experiments for the calibration and validation of the CERES-Maize model under the direction of Chenfang Lin. The purpose of the work was to find a set of acceptable parameters for the models so that management options for local corn production and integration of the natural resources of Taiwan could be probed.

Soybean plot in Taichung, Taiwan.

The experiment was designed to evaluate the major factors affecting the growth of corn. For example, it is known that water and fertilizer are two factors responsible for observed differences in crop yield at different locations and seasons in Taiwan. Therefore, the treatments in the experiments attempted to accommodate variation of these conditions in order that the calibrated parameters for these experiments would represent variable situations in the field.

The experiments were conducted on different planting days and seasons for the purpose of calibrating the model in response to the different types of climatic and seasonal (spring vs. fall) conditions in Taiwan. Because the project focused on an island-wide basis, the six experimental stations around the island recorded the effects of different soil types, climatic zones and management methods. A natively-bred variety of corn, Tainan 351, was chosen for the study and grown in experiments designed in triplicate, with six treatments of two factors.

The results of the experiments proved highly significant in the model's ability to predict the major phenological stages of corn production, and this capability will be useful in determining the timing of cultivation and harvesting and in marketing programs. Moreover, the CERES-Maize model's ability to simulate grain yield and biomass will allow exploration of possible outcomes under different strategies of irrigation, fertilizer application, planting day and other cultivation techniques.

[Will use the DSSAT] simulation crop growth model for rice and compare to actual rice production at the MUDA project over a period of 17 years (1968-1985). [Will] also run the crop growth model under climate change scenario using GIS.

---S. B. Said, Malaysia

India

In India, sorghum (Sorghum bicolor L.) is grown on 16 million ha (total cropped area 140 m ha) predominantly under dryland conditions in regions where seasonal rainfall varies between 500-900 mm. Because of the inherent variability of the Indian monsoon, sorghum yields vary significantly (cv>25%) from year to year. Farms in India are small, and the farmers are resource poor. Because of this, the resource base is constantly diminished by ever increasing population. Farmers growing sorghum do not use fertilizer on a large scale because the fixed fertilizer schedules advocated in irrigated agriculture do not apply in the drylands. Moreover, fertilizer dosage has to be carefully adjusted keeping in view the variation in soil quality and moisture availability.

To help solve the complex problem of scheduling nitrogen (N) application for dryland sorghum for some locations in peninsular India, S.M. Virmani and G. Alagarswamy of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) used IBSNAT's DSSAT v2.1. D. Godwin and U. Singh of the International Fertilizer Development Center (IFDC) collaborated in this research. Long term weather records provided by the India Meteorological Department were used, and data on soil parameters were obtained from the National Bureau of Soil Survey and Land Use Planning, Nagpur, India. The CERES-Sorghum model for simulating growth and development was employed, and the risk to sorghum production evaluated by using DSSAT's strategy evaluation program. One typical set of results for estimating N-fertilizer needs of two soils and its application for improving sorghum production in India's dryland is presented.

Hyderabad represents a typical dryland region located in the heartland of India's sorghum producing area. Here, two distinctly different soils: Vertisols (Typica Pellusterts) and Alfisols (Typic Rhodustalf), dominate. The Vertisols are clay soil (fine clay content>50%), deep (generally >.80 m), and can potentially hold more than 150 mm of available water in the root profile. The Alfisols are shallow (generally <.50 m), sandy loam (clay content <15%), and have a low water holding capacity, generally about 100 mm in the root profile.

Sorghum yields simulated for the two soils at various levels of N application show that in fertile Vertisols (initial mineral N content 36 Kg ha-1, available water storage capacity 172 mm), a basal application of 30 kg ha-1 could boost yields to over 4.5 t ha-1, indicating a response of 53 kg yield per kg of fertilizer N applied. The results also show that split application is not advantageous and that economic response (1 kg N for at least 5 kg sorghum grain) is obtained up to 90 kg ha-1.

In the Alfisols, a much higher level of N fertilization is required to obtain comparable high yields, and split application is superior to a single basal application. The efficiency of fertilizer N utilization (ratio of kg N to kg additional grain produced) is much lower than it is in Vertisols. The practice of applying at least 30 kg N per hectare at the time of sowing can be safely extended to sorghum growing areas in the Vertisols where the annual rainfall exceeds 750 mm.

$kg\ N\ ha^{-1}$	Fertilizer N applied	Soil: Vertisol	Soil: Alfisol
		$t\ ha^{-1}$	
Control	—	2.95	0.85
30	At sowing	4.54	2.53
	Split	4.56	2.65
60	At sowing	4.84	3.57
	Split	4.86	3.74
90	At sowing	5.10	3.84
	Split	5.12	4.07
120	At sowing	5.24	4.24
	Split	5.24	4.24

Split = Half at sowing and the other half 20 days after emergence.

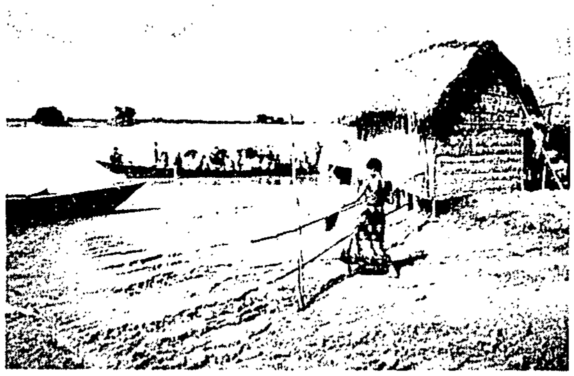
Simulated yield of sorghum in two soils as influenced by five levels of fertilizer N and two methods of application.

These simulated results correspond with the experimental evidence reported for the ICRISAT Center in its 1984 Annual Report. Extension of these analyses to other sorghum growing areas in India is under way.

I plan to use DSSAT in developing crop-weather relationships in mustard crops under Hisar (India) conditions, which is part of a project being undertaken by me and colleagues...under the All India Coordinated Research Project on Agrometerology.

---D. Singh, India

Bangladesh



Bangladesh provides a useful example of how IBSNAT responded to requests for technical assistance on behalf of USAID. IBSNAT's activities were supported locally by non-IBSNAT funds and were considered an informal rather than a formal buyin from the local AID mission. At the request of the Bangladesh Agricultural Research Council (BARC) through USAID/Dhaka, M. M. Rahman and Z. Karim of BARC, A. R. Hurdus and K. Rushing of USAID/Dhaka and G. Uehara and G. Y. Tsuji of IBSNAT met in Dhaka in 1988 to share common concerns and demonstrate the applicability of systems research at the national level. Highlights of activities since that initial meeting in 1988 are listed below.

- Training course on crop simulation models and DSSAT held at BARC headquarters in Dhaka in 1989. Twenty-three participants from universities and government agencies in Bangladesh attended.
- BARC participated in a study on the impact of global climate change to food production and trade organized by the U.S. EPA and USAID in 1990. Z. Karim and A. Mahbub represented Bangladesh in the two year study using rice and DSSAT.
- Sk. Ghulam Hussain of BARC admitted to the University of Hawaii graduate division in 1991 and enrolled in a Ph.D. program under G. Uehara, IBSNAT's principal investigator.
- Z. Karim of BARC organized a national risk management workshop involving policy makers in government in 1991. DSSAT and systems research presented and demonstrated by IBSNAT. At the conclusion of the workshop, one action recommended was a risk assessment strategy for Bangladesh.
- Minimum data set collection for model validation planned for CERES-rice in DSSAT by BRRI for 1992 season in Joydepur.
- IBSNAT provided technical assistance in BARC draft of a proposal to utilize systems tools to provide a means to assess risk to agriculture production and

alternative action plans with probable outcomes to government ministries in times of natural emergencies. Some of these include natural events such as flooding and cyclones. The proposal was being readied for submission to donor agencies in 1992. The outcome is not known as this report was prepared.

Other Asian Countries

Other countries in Asia have reported activities related to the application and acceptance of DSSAT.

Scientists in **Malaysia**, **Pakistan**, and **Indonesia** have also actively participated in the collection of MDS and application of crop models and DSSAT. All three countries sent participants to the initial IBSNAT meeting at ICRISAT in 1983 and to the initial IBSNAT training workshop on the minimum data set and crop models in Venezuela in 1984. Both Malaysia and Indonesia have served as hosts to training courses or workshops. The training course held in Serdang, Malaysia at the MARDI headquarters included participants from the Philippines, Indonesia, Thailand, and Malaysia in 1987. The one in Indonesia was held in Bogor at the headquarters of the Center for Soils Research in 198x and included participants from several Indonesian government agencies and institutions. Key local organizers were A. Yusoff of MARDI and I P. G. Widjaja-Adhi of CSR. Both were at the Venezuela workshop and continue to serve as country contacts for IBSNAT.

More importantly, each of the three countries also supported the travel and accommodation costs for participants from each respective country to attend a month's training course at the University of Hawaii in 1987. The course focused on the principles and methods to collect the minimum data sets and to test and validate crop models with the MDS. The mutual commitment by collaborators represented a milestone in IBSNAT training program.

Though Pakistan was an active participant and collaborator for IBSNAT during its first half decade, during the second 5 years, activities slowed considerably. A memorandum of agreement was signed in 1988 between IBSNAT and PARC or NARC. At about the same time, political changes in Pakistan may have had some impact on continued collaboration. Some highlights of IBSNAT's acceptance in Pakistan follows.

A. Muhammad, Director of the Pakistan Agricultural Research Council (PARC), served as a member of the IBSNAT Collaborators Advisory Panel from 1984 to 1987. Under his leadership, the National Agricultural Research Council (NARC) began a program to collect the minimum data set for wheat.

- A. Khan of NARC participated in the initial IBSNAT meetings at ICRISAT in 1983 and at Maui in 1984.
- Md. M. I. Nizami of NARC attended the first IBSNAT training workshop in Venezuela in 1984 and A. Majid attended the second in Jordan in 1985.
- Minimum data set for wheat collected by NARC in Islamabad.
- Md. Aslam received full support from PARC to attend one month's course on principles and methods to collect the IBSNAT minimum data set at the University of Hawaii in 1987.
- Memorandum of agreement signed between PARC and IBSNAT in 1988.

Regional:

Europe

Albania

Albania is a small mountainous country covering 28,000 square kilometers with about 720,000 hectares of arable land. In the past, about 200,000 hectares were planted each year to winter wheat which provided 600,000 metric tons of grain, an amount historically sufficient for Albania's 3.4 million inhabitants. However, the rapid deterioration of the centrally planned economy and breakup of agricultural cooperatives resulted in less area being planted to wheat and also brought the fertilizer supply and distribution system to a near halt. Facing an imminent shortage of wheat, Albania had to receive food imports from other countries.

In its efforts to assist Albania with an expected shortfall in the size of the 1991-92 winter wheat harvest, the U.S. Agency for International Development's Bureau for Europe and the Near East (ENE) wanted to determine to what extent wheat imports might be offset with emergency nitrogen fertilizer imports. The timely importation and distribution of nitrogen fertilizer could improve grain yield forecasts and substantially decrease the amount of demand for emergency wheat imports. Officials from the ENE bureau turned to AID's Bureau for Resource and Development (R&D) for assistance to provide a rapid appraisal of the benefits that could be derived from nitrogen fertilizer imports. AID's Resource and Development officials in turn consulted with IBSNAT in October, 1991. In order to utilize DSSAT and its crop models or any other available decision tools, reliable crop, soil, and weather data were required to provide a relatively accurate assessment of winter wheat performance. Natural resource data from Albania were sparse, and previously unavailable to the west.

In late November 1991 a two-week visit was made by IBSNAT collaborators, W. Bowen and P. Papajorgji of the University of Florida, to Albania to demonstrate the DSSAT software and explain crop model data requirements to Ministry of Agriculture officials and research scientists. During the visit, Albanian scientists provided soil and weather data to use in the wheat model for a site in Lushnja, an important winter wheat growing area in the alluvial plains of western Albania. Afterwards, these data were used to run computer-based experiments designed to test the effect of a single nitrogen topdressing applied at different times during the spring. USAID was then able to utilize the model-predicted yields to evaluate the potential benefit of imported nitrogen and the importance of timing applications.

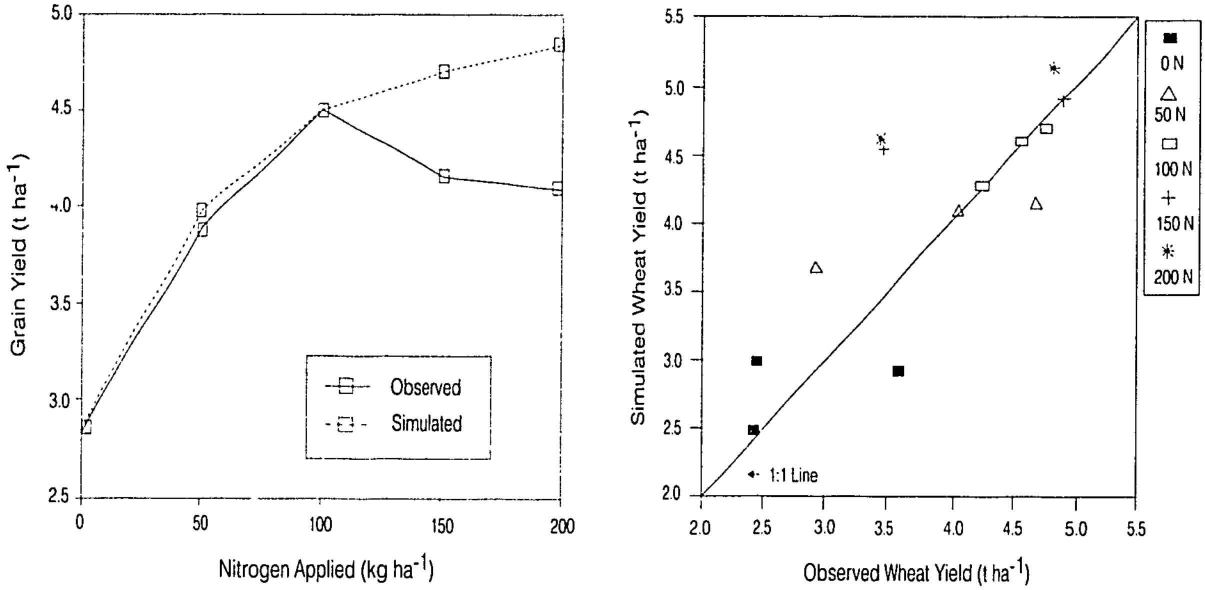
Model Calibration

The wheat model was first calibrated against experimental data to determine if it could realistically simulate the effect of nitrogen management on wheat yields in Albania. This was accomplished by comparing simulated yields with observed yields from a three-year field experiment designed to measure winter wheat response to increasing rates of nitrogen fertilizer. The experiment was conducted in Lushnja by the Institute for Soil Studies. In the first year there were three rates of nitrogen applied: 0, 50, and 100 kg N ha-1. In each of the next two years five rates were applied: 0, 50, 100, 150, and 200 kg N ha-1. As usually recommended in Albania, the nitrogen was topdressed at four different times corresponding to the three-leaf, tillering, stem elongation, and heading stages of growth with no nitrogen applied at planting. The nitrogen fertilizer utilized was ammonium nitrate. For each year of the experiment, a different variety of winter wheat was planted.

Model Inputs

The weather data required by the IBSNAT crop models includes daily values for solar radiation, precipitation, and maximum and minimum air temperatures. The type of soil information needed includes upper and lower limits of volumetric soil water content, bulk density, and organic carbon content in consecutive layers down to at least the depth of rooting. To account for the genetic potential of different wheat varieties, the model also requires a set of six coefficients particular to each variety.

Although measured values for many of these data inputs were unavailable for the Lushnja experiment, sufficient information was obtained to estimate the required inputs not directly measured. Solar radiation was estimated from sunshine hours recorded daily, along with precipitation and maximum and minimum temperatures from a nearby weather station. A soil representative profile of the experimental site was defined within DSSAT with available data for soil texture, soil color, and organic carbon content determined at the site. The genetic coefficients were estimated for each variety by calibrating the model using only the 100 kg N ha-1 treatment results; that is, the coefficients were adjusted until there was good agreement between simulated and observed harvest date and final grain yield when the model was used to simulate this treatment. The coefficients were then left unchanged when simulating the other nitrogen treatments.



Observed and simulated effect of N fertilizer on winter wheat yields averaged over the 3-year study.

A comparison of simulated and observed grain yields for all years and nitrogen rates showed a decrease in observed grain yield above 100 kg N ha-1. Although there is no explanation for this, lodging of plants or insect infestation might have been responsible for the decreased yield. Even with the limited information available about the soil and wheat varieties, the nitrogen response curve averaged over the three years for both simulated and observed grain yield show the model performed well in simulating grain yield response to increasing rates of nitrogen fertilizer.

Late-Season Nitrogen Application

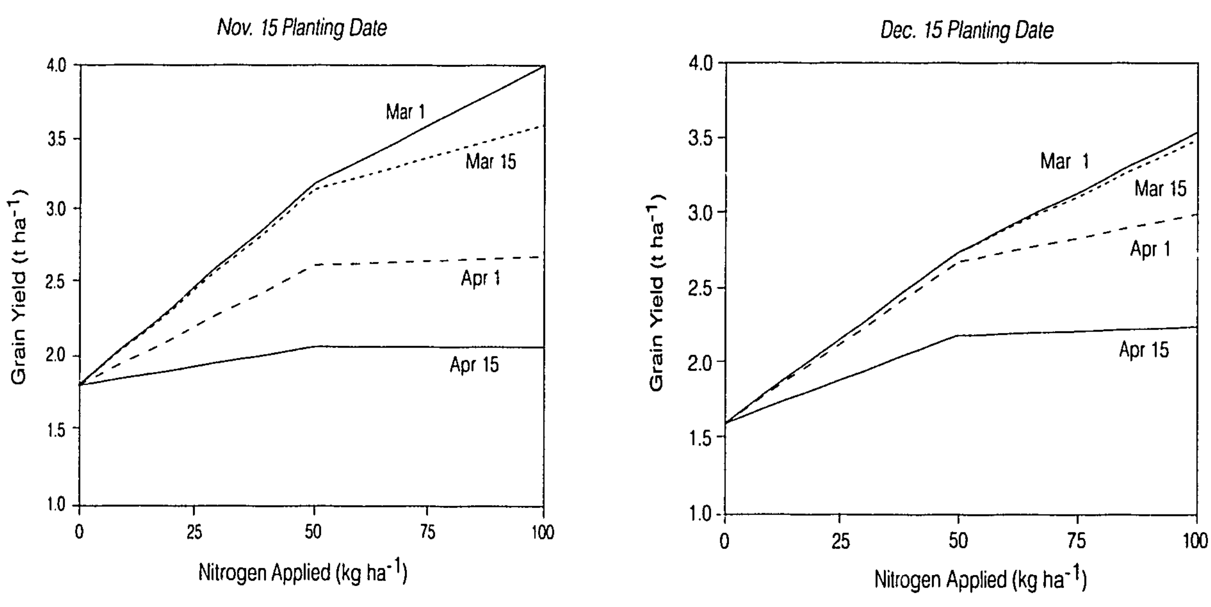
Soil and weather data from Lushnja were used to simulate the yield response of winter wheat to nitrogen fertilizer applied late in the season. The results presented here assume that wheat was planted on November 15 or December 15, and a single topdressing of 0, 50, or 100 kg N ha-1 was applied on 1 January , 15 January, 1 February, 15 February, 1 March, 15 March, 1 April, 15 April, 1 May, or 15 May. Each combination of planting date, nitrogen rate, and application time was run for 24 different years using historical daily weather data from Lushnja (1961-84). The resulting grain yields were then ranked from lowest to highest to determine the cumulative probability of expected yields.

The simulation results indicate a topdressing of nitrogen would be of greatest benefit if applied as late as mid-March for the November planting date, or early

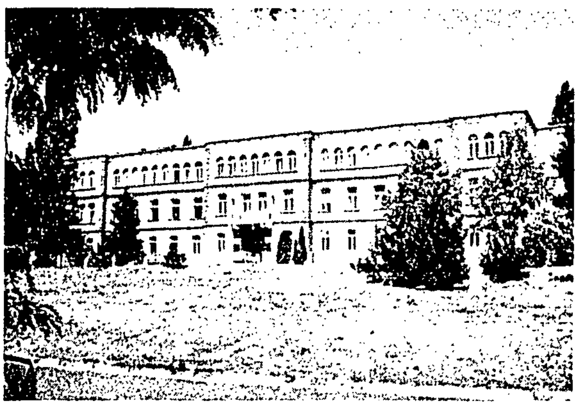
April for the December planting date. If applied by mid-March, a topdressing of 100 kg N ha-1 could be expected to increase grain yield to about 3.5 t ha-1 regardless of the planting date. Nitrogen applied beyond mid-March would still result in increased yields relative to applying no nitrogen, but the expected yield would decrease and there would be less difference between the two nitrogen rates as the application date is delayed. Thus if nitrogen could only be applied after March, a rate no greater than 50 kg N ha-1 should be adequate. Nitrogen application after late April would not be expected to provide any benefit.

Implications and Suggestions for the Future

This project demonstrates how DSSAT and its crop models can improve the response capability of agencies or individuals, and provide relevant data on which to base a decision within a time constraint. Although the simulation results obtained from this one site do not necessarily represent what would be expected in other regions or on other soil types in Albania, a limited study such at this one shows the potential models possess as decision support tools. Similar simulation studies could be conducted for other regions, but considerable effort must first go into identifying the appropriate soil, weather, and crop data bases. Such data bases could then also be accessed by a GIS-based agricultural decision support system and become a valuable tool for conducting an analysis of the type presented here at the regional or national level.



Simulated winter wheat response to applied N as affected by date of application.



RISSAC in Budapest, Hungary.

Hungary

In Hungary, the "Systems Approach to Assess the Impact of Agricultural Decisions on Natural Resource Management" project is designed to facilitate establishing a new generation of computer tools to assess environmentally sound strategies for sustainable agricultural development in Hungary. The Research Institute for Soil Science and Agricultural Chemistry (RISSAC) of the Hungarian Academy of Sciences (HAS) and the Research Centre for Water Resources Development (VITUKI) in Budapest are two organizations that have used currently available versions of such tools for environmental and agricultural decision support.

These tools will be used to address the substantial problems of environmental pollution associated with unsound agricultural management practices. For example, state-run farms have a history of heavy nitrogen fertilizer use which has led to unacceptable levels of nitrates in ground and surface water resources.

Both organizations recognize that concerns for the environment are directly related to constraints of inputs to sustain agricultural productivity. These tools and a systems approach to problem solving will be used to provide insights into appropriate cropping strategies which optimize use of inputs to stabilize production and at the same time minimize environmental damage.

It was proposed to establish a computer training capability for both agricultural development and environmental preservation sectors and to adapt the DSSAT for research prioritization, agricultural resource data base management, training and technology transfer.

To facilitate implementation of a systems approach to sustainable agricultural development, a trained cadre of technicians and scientists would be necessary. Both RISSAC and VITUKI proposed establishing a training program to improve the capability of these individuals to adapt DSSAT for research prioritization, agricultural resource data base management, training and technology transfer.

IBSNAT personnel (D. C. Godwin, G. Hoogenboom, and G. Y. Tsuji) were invited to Budapest by G. Kovacs of RISSAC in June 1991 to participate in the first workshop involving both IBSNAT and Hungarian scientists. The latter included T. Nemeth of RISSAC and J. Feher of VITUKI. Plans were then developed to schedule a second workshop involving a wider spectrum of local participants.

From May 8 to 15, 1992, the second workshop was divided into two sessions and conducted at two locations to accommodate two audiences. The first session was held at Godolla University for 30 researchers and educators from five universities and the second was held in Budapest for government decision makers. Kovacs reported 16 individuals from the first session have since visited with RISSAC with their own datasets for review and input into DSSAT. Teams or groups of scientists from the five universities were formed locally to work jointly with both RISSAC and IBSNAT.

One group worked with IBSNAT in outlining the development of a crop model for peas, an important agronomic and economic crop in Hungary. G. Hoogenboom and J. T. Ritchie represented IBSNAT in the second workshop.

A third workshop was planned for 1993 and would have been more regional in emphasis. However, both fiscal and political realities in the region prevented any followup to date.

IBSNAT and RISSAC scientists plan to collaborate on a Pea model based on data collected at the Keszthely research station, shown here.

[used] millet crop model for test of early drought impact on millet growth in Niger-West Africa [and] maize crop model for teaching undergraduate students in crop modeling and calibration for conditions in Southern Benin, West Africa.

---P.L.G. Vlek, Germany

Regional:

Individuals and organizations from both American continents have collaborated with IBSNAT in a number of activities, ranging from model development to collecting minimum data sets for model validation to application of DSSAT and the crop models to address real issues and problems. The following paragraphs illustrate activities undertaken by a number of collaborators from developing, graduated and developed countries in both hemispheres.

South America

Argentina

Argentina's interest and involvement with IBSNAT started with the participation of A. J. Hall of the University of Buenos Aires in the second IBSNAT workshop on crop modeling at the University of Jordan in 1985. Because of Argentina's status as a graduated country by USAID, his participation in the network required utilization of their own human and fiscal resources. The following activities reflect, in part, the acceptance through application of DSSAT and the crop models.

- A. J. Hall has subsequently become involved in the development of a sunflower model with F. Villalobos of the University of Cordoba, Spain and J. T. Ritchie. The model is compatible with input/output formats specified for DSSAT and is being made available to IBSNAT in 1993.
- C. O. Scoppa, Director of INT. (Instituto Nacional Technologia Agropecuaria), signed a memorandum of agreement with IBSNAT in 1990.
- S. Meira of INTA participated in the third annual IBSNAT training course on computer simulation for crop growth and nutrient management in 1991 at IFDC, Muscle Shoals.
- An in-country training program entitled "Uso de Modelos en Agricultura: Sistemas de Apoyo Para la Planificacion y la Toma de Decisiones" was held in Buenos Aires in August 1992. The program was conducted by INTA scientists, G. O. Magrin and R. A. Diaz, and Hall. Magrin and Diaz are affiliated with the Instituto de Clima y Agua of INTA in Buenos Aires. Emphasis was on the minimum data set and the CERES-wheat model in DSSAT.
- INTA's interest in collaborating with IBSNAT and its network resulted in implementation of a national program to assess grain production in the Pampas

region of Argentina. The program described by Scoppa was directed towards testing a combination of remote sensing data, soils maps and the IBSNAT crop models in DSSAT as tools to predict total grain yield for the Pampas.

Two principal activities of the program are (1) an assessment of land area planted to each of the major crops (wheat, maize, sorghum, soybean, and sunflower) based on analysis of LANDSAT and SPOT satellite images, and (2) application of simulation models to estimate crop yields in these areas.

INTA and JNG (Junta Nacional de Granos) led the program which involved the collaboration of other Argentinian agencies and institutions, including the Meteorological Service and the Universities of Buenos Aires and Mar del Plata. The initial effort was carried with spring wheat, sown to nearly 6 million hectares annually. Scientists from these organizations worked collaboratively to establish field experiments at six locations ranging from 33 to 39°S latitude to 58 to 63°W longitude across the Pampas region of Argentina with wheat. Six planting dates spaced at 25 days intervals were used to obtain estimates for genetic coefficients for local wheat varieties with DSSAT and to calibrate and validate the CERES-wheat model in DSSAT for the Pampas region.

The successful outcome with wheat resulted in continuing efforts with maize, sorghum, soybeans, and sunflower.

Brazil

- A memorandum of agreement between a Brazilian state agency, IAPAR, Instituto Agronomico do Parana, and IBSNAT was signed in 1993. By means of the agreement, L. C. de Assumpcao of IAPAR proposed to invite IBSNAT scientists to Londrina in Parana for training and orientation on applications of DSSAT and crop models for their ongoing programs in crops and farm systems and in organizing their existing soils and weather resource data base.
- L. C. G. Barros of EPEAL (Empresa de Pesquisa Agropecuaria do Estado de Alagoas) participated in the 4th IBSNAT training course held at the University of Hawaii in June 1992. Upon his return to Brazil, he contacted EMBRAPA's (Empresa Brasileira de Pesquisa Agropecuaria) headquarters with a report of his participation in the workshop and a recommendation to utilize IBSNAT's concepts to characterize Brazilian cultivars and validate IBSNAT's crop models for application in Brazil. In 1993, Barros prepared a proposal to calibrate and validate crop models for rice and maize in DSSAT and couple it to AEGIS for the Northeast region of Brazil.

Central America

Scientists from several organizations in Costa Rica, Guatemala, Panama and Honduras, as well as Colombia and Mexico, which borders the Central American land mass, have participated in IBSNAT training and model validation/application activities in the past decade. The latter two countries are also hosts to two IARCs, CIMMYT and CIAT. A regional center, CATIE, is located in Turrialba, Costa Rica.

The following illustrate some types of activities in which researchers from Costa Rica and Guatemala have interacted with IBSNAT. Guatemala is featured in an extended write up as a report of a joint research effort between IBSNAT and Guatemalan scientists with support provided through a research grant from USAID.

Costa Rica

- J. Arze of CATIE participated in the first IBSNAT training course in Venezuela in 1984 and subsequently provided technical and language assistance to IBSNAT in conducting local and regional training activities to collect minimum data sets for model validation in Honduras and Costa Rica. Arze was also instrumental in calibrating and validating the CERES-maize model in DSSAT for cultivars and conditions in Nicaragua and the Dominican Republic in 1988.
- R. Tarte, Director General of CATIE, agreed to serve as chairman of the IBSNAT Collaborators Advisory Panel. Originally from Panama's IDIAP, he supported IBSNAT activities in both Panama and in the region. CATIE hosted and conducted local training on the application of crop models and DSSAT.
- The Universidad Estatal a Distancia (UNED) received one of the first copies of DSSAT for possible implementation into their "Sistema de Educacion Computarizada" or computerized education systems. G. Hidlago of UNED requested the copy and explained their use of DSSAT as part of their agriculture courses for the Agriculture Administration Academic Program for students at the national level. UNED was established in 1976 and was described as an institution of higher learning in Costa Rica using long distance teaching methods.

Guatemala

Cropping systems researchers in Jutiapa, Guatemala.

One important goal of the IBSNAT project was to encourage the use of systems analysis and simulation techniques in agricultural research and decision making, especially in developing countries. In a project in Guatemala, partially funded by USAID's Program in Science and Technology Cooperation (PSTC), which seeks to stimulate new and innovative scientific research on developing-country problems, DSSAT and the incorporated IBSNAT crop simulation models were used to identify and assess the changing circumstances of smallholder farmers; changes which may result from technology development, government policy, or long-term agroclimatologic phenomena.

The project, which ran from 1989 to 1992 and involved IBSNAT collaborators, G. Hoogenboom of the University of Georgia, C.E. Heer of the Instituto de Ciencia y Tecnología Agrícolas (ICTA), Guatemala and P.K. Thornton of IFDC, was designed to study the bean-maize-sorghum cropping system in Jutiapa, a region in southeastern Guatemala.

The Guatemalan Setting

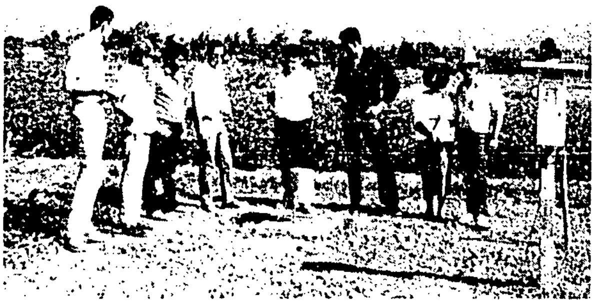
In Guatemala, a republic in Central America, with a land area of 108,780 km2 (42,000 square miles) and a population that is now at 8.8 million population and growing by over 2 percent per year, there was and is substantial interest in the prospect of expanding national bean production for the export market and for domestic consumption. Significant improvement in the nutrition of rural and urban Guatemalans could come about through an increase in the proportion of beans in the standard maize-bean diet, which is typically about 90 percent maize and 10 percent beans. An amendment of this ratio to 70 percent maize and 30 percent beans would lead to a significant improvement in many people's diet. However, such increases can only be achieved through increased bean production and/or lower prices.

Ideally, new technology options would increase the productivity of Guatemala's family farms, which produce 12 percent maize 37 percent sorghum and 39 percent beans, accounting for most of the rural family income and food source, and thereby improve the dependability of the food source and providing surplus production for sale.

One of the most important characteristics of agriculture in Central America is the extreme variability of soil and climate, especially rainfall, over short distances. The project's target area was the Departamento (county) of Jutiapa, one of the most important bean producing areas in the country. Levels of agricultural input in this region remain low and crop yields are highly dependent upon weather and have only slowly increased in the last few years.

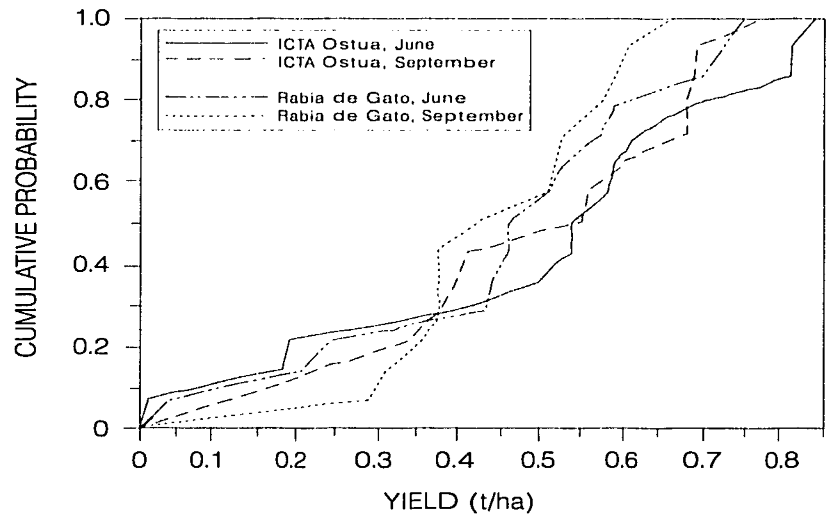
In response to the need of increased production, the Guatemalan national agricultural research organization, ICTA, has been active in developing and transferring new varieties to smallholder farmers. The development of new disease-resistant and high-yielding varieties has been followed by active technology promotion. ICTA has a long tradition in farming systems research and is seeking to gain a better understanding of the reasons behind farmers' adoption or rejection of agricultural production alternatives. Because problems often arise when attempts are made to transfer research results directly from the experimental station to the smallholder's farm, most of ICTA's field work is carried out in farmers' fields. The research programs thus have access to a large number of cooperating farmers which have provided a considerable information base of prevalent agricultural production systems in Guatemala.

These conditions provided an excellent opportunity for studying farmers' production practices in contrasting site conditions with different technologies. Thus, the project's first stage involved the collation of soil and weather data for the target area which were subsequently stored in DSSAT's Data Base Management System (DBMS). Next, the crop models for phaseolus bean, maize, and sorghum were validated, using the collected data.



IBSNAT and Guatamalan researchers installing weather station to obtain MDS for beans in Jutiapa, Guatamala.

Three crop simulation models were used in this study: CERES-Maize and Sorghum and BEANGRO. The bean model was run using 14 years of weather data from Asunción Mita to investigate the effect of climatic variation on yield. A comparison was made between the performance of two bean cultivars, ICTA Ostua and Rabia de Gato, for two different planting dates, 1 June and 1 September. Both planting dates are commonly used as they coincide with the rainy seasons during which beans are normally grown. By displaying the results of the long-term simulations as cumulative probability as a function of yield, it was found that there was no clear separation of the cumulative probabilities between the respective strategies. The simulation also showed that ICTA Ostua has the best performance under good environmental conditions, but does not perform as well under poor conditions. On the other hand, Rabia de Gato performs best under unfavorable environmental conditions. Therefore, on the basis of this initial simulation experiment, no recommendation could be made to define the optimum management practice with respect to planting date and cultivar selection.



Yield distribution for ICTA Ostua and Rabia de Gato, planted in May and September for 1973-1985 and 1988.

The effect of spatial soil variability on agricultural production remains a key issue. The soil physical characteristics available from the SCS International Benchmark Soils data base were used to study potential bean production on these soils. The same 14 years of historical weather data from Asunción Mita were used to define the climatic conditions and variation. Beans were planted on 1 June, with a row spacing of 0.4 m and a planting density of 23 plants per square meter. Potential yield of both ICTA Ostua and Rabia de Gato showed a strong variation as a function of the various soil characteristics, demonstrating that the total amount of extractable soil water is crucial for bean production. However, other soil factors, such as soil composition, can limit bean production as well. For the highest yielding conditions, Rabia de Gato generally outperformed ICTA Ostua; for lower yielding conditions, however, ICTA Ostua was better.

Future Plans

Experimental data collection is in its third season in Jutiapa, generating data sets which will be used for further calibration and validation of the models. System characterization of the major farm types is under way, and the diagnostic surveys of sample farms will be carried out. The various crop and farm level models will attempt to achieve the following.

- Identify the most promising genetic lines that will produce a high and stable yield under the region's environmental conditions, thereby reducing the burden of field experimentation and decreasing the time required between first selection by the plant breeder and release to the farmer.
- Investigate the biological and socio-economic consequences of growing early maturing bean varieties in a typical smallholder production system.
- Identify ways to increase household income by screening agricultural production alternatives that fit with the objectives and attitudes of the region's resource-poor farmers.

Considerable potential exists for speeding up the agrotechnology transfer process by using biological models to enhance the efficiency of field trials. It is hoped that the models can provide objective information for researchers, extensionists, and policy makers, with reference to a farmer's agroecological and socio-economic conditions. Much remains to be done before this potential is realized, but this project in Guatemalan is an important contribution to the development of the necessary methodology.

Venezuela

Various methods of agrotechnology have been practiced over the years but systems simulation is the most recent and innovative technique. This approach was pioneered by IBSNAT in an international network of collaborators.

Two of the crop simulation models developed by the project, maize and soybean, were evaluated with data generated at six locations in Venezuela. The studies showed that the models produced excellent predictions of the soil water balance. Crop phenology biomass and yield were predicted adequately in most cases, but model performance regarding nitrogen dynamics is not yet satisfactory. For application of the models in countries like Venezuela it is proposed to combine the IBSNAT methodology with the concept of analogous areas.

Participation in the IBSNAT project of other latin-american countries is strongly encouraged.

- Juan A. Comerma of FONAIAP, Maracay and of PALMAVEN, Caracas, has served as a member of the IBSNAT Technical Advisory Committee.
- The Instituto Internacional de Estudios Avanzados (IDEA) in Caracas hosted the first IBSNAT workshop in December 1984. Participants from sixteen countries attended the 10 day course entitled "Systems Analysis and Simulation of Crop Growth for Agrotechnology Transfer".

The outcome from this initial training course had a significant impact on the development of a common crop model I/O and DSSAT. Another significant aspect was the impact the workshop had on participating scientists from Venezuela and 15 other countries. This group formed the nucleus of the IBSNAT network of collaborators with their continued interest and participation in either model development, model validation, DSSAT utilization, and training.

- Minimum data sets for maize and soybeans were collected from six locations with mean annual rainfall ranging from 950 mm to 1600 mm to validate both CERES-maize and SOYGRO crop models.
- Venezuelan scientists have enrolled and received degrees in graduate programs at IBSNAT associated institutions—University of Florida, Michigan State University, and the Australian National University. They form a nucleus that enhances Venezuelan capabilities in systems research.

USA - Private Sector

Academic and Scientific Community

In 1987, the Technical Advisory Committee of IBSNAT recommended that IBSNAT plan on organizing a series of symposiums or workshops to expose DSSAT and its crop models to scientific peers, especially in the United States.

[DSSAT] was used as a teaching tool of crop/environment interactions. It was part of a crop modeling workshop for Indian scientists. It was also used to evaluate risks for different cultural practices.

--W. Rosenthal, Texas

Basically, the goal of these presentations was to seek the acceptance of systems analysis and crop simulation models as having scientific merit by our peers.

In 1989, the American Society of Agronomy accepted IBSNAT's proposal to conduct a symposium on DSSAT as part of its national annual meetings. The two-part symposium included oral presentations (IBSNAT, 1990a) and a poster session (IBSNAT, 1990b). Subsequently, symposiums were conducted during the Software Scene presentations at the ASA meetings in San Antonio (1990), in Denver (1991), and in Minneapolis (1992).

If acceptance is measured by participation, then IBSNAT's systems approach is a success. Presentations for the Software Scene and for the traditional oral and poster technical sessions included many on the application of DSSAT and its crop models. The Agronomy Journal of the American Society of Agronomy now accepts technical journal series articles for separate sections on "Agronomic Modeling" and "Software."

Agribusiness

Agribusiness is a large industry in the United States and other G-7 counties. It is an enterprise that provides a range of products and services to agricultural concerns globally. In order to do so, agribusiness must also make decisions based on client needs. Would DSSAT serve the needs of agribusiness? Would agribusiness be in position to acquire services from IBSNAT for training and for customized decision tools to meet their needs?

At the recommendation of USAID, IBSNAT and the Industry Council for Development (ICD) jointly agreed to carry out a series of presentations and demonstrations to a number of different private and public enterprises involved in agriculture in the U.S. and in Europe. A listing of these is shown in the table on the next page.

ICD received a contract from USAID to evaluate the portfolio of programs with potential "marketable" products. The IBSNAT project was selected for its decision support system software, DSSAT. Over a six-week period, starting in April 1992, A. Grobman, a consultant to ICD, and IBSNAT personnel, including B. Dent, J. Ritchie, W. Bowen, T. Hunt, J. Jones and G. Uehara, made presentations and conducted demonstrations using DSSAT.

In addition to contracts through ICD, IBSNAT was contacted by several private sector enterprises. Two have implemented activities consistent with IBSNAT goals and objectives.

Company/Organization	Contact	Place
Europe		
Nestle	Patrick Leheup	Zurich, Switerland
IBM	Fouad Elamrami	Paris, France
CDC	Michael D. Taylor	London, England
Shell Chemicals	Luiz E. Fortes	London, England
PBI Cambridge Limited (Unilever)	Julian Stanning	Cambridge, England
ICI Seeds	Derek J. Pike	Berkshire, England
U.S.A		
International Minerals & Chemical Corp. (IMC)	Peter Heffernan	Mundelein, Illinois
Chicago Board of Trade	Eugene Kunda	Chicago, Illinois
Quaker Oats	Phil Sisson	Chicago, Illinois
Ralston Purina	James Allwooc	St. Louis, Missouri
National Corn Growers Association	Larry Rus	St. Louis, Missouri
American Soybean Association	Keith Smith	St. Louis, Missouri
Pioneer Hi-Bred International Inc.	Don Sapienza	Johnson City, Iowa
ICI Seeds Inc.	Aileen Jensen	Slater, Iowa
Cenex-Land O'Lakes	John Ahlrichs	Minneapolis, Minnesota
Cargill, Inc.	William Pearce	Minneapolis, Minnesota
Northrup King	Robert Romig	Minneapolis, Minnesota
Merril Lynch and Co.	Tony Wolfskill	New York, New York
Delta and Pine Land Co.	Roger Malkin	New York, New York
United Nations Development Programme (UNDP)	F.M. von Mallinckrodt	New York, New York
U.S. Department of Agriculture, Economic Research Service	Aqapi Somwaru/John Lee	Washington, D.C.
The World Bank	Susan Gnaegy	Washington, D.C.
NOAA/USDA Joint Agricultural Weather Facility	Douglas Le Comte	Washington, D.C.
Earth Satellite Corp.	Kevin Marcus	Rockville, Maryland
American Socity of Agricultural of Agricultural Consultants	Kelly M. Harrison	Tyson Corner, Virgina

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EarthInfo, Inc.

Weather data, especially historic ones, have been difficult to acquire. In most instances, the best source of such data is the either the national weather service or meteorological service. Acquisition of these data is only the first step, however. Evaluation for completeness, assessment of accuracy and data organization are also needed and are time consuming tasks, but ones necessary to make ready the data sets for retrieval and computer application. To fill this void, several companies have been established that sell data in electronic form.

One such company is EarthInfo, Inc. of Boulder, Colorado. J. Edwards, president of EarthInfo, agreed to make available weather data sets in the format compatible with DSSAT in exchange for our DSSAT mailing list.

AgriGraphics Software, Inc.

AgriGraphics Software of Hiawatha, Kansas plans on using DSSAT as part of an open platform system which integrates use of different tools for a hierarchy of applications. Satellite imagery from SPOT, for example, would be used at a global scale to identify and delineate areas of interest and the crop models in DSSAT would be applicable at the field level. D. Miller, CEO of AgriGraphics Software, Inc., has included IBSNAT as a partner in a initial effort to assess seed production of plant breeding plots of Pioneer Hi-Bred International in Decatur County, Indiana.

American Soybean Association

The American Soybean Association (ASA) has shown strong interest in adapting the DSSAT soybean model for use by farmers and farmer organizations in the midwest USA. The ASA has supported the crop modeling effort at the University of Florida in the past and was interested in how such models could be used to help soybean farmers. W. Bowen and A. Grobman of the University of Florida and ICD, respectively, presented DSSAT to ASA representatives in 1992.

These representatives were favorably impressed with the capabilities of using DSSAT for analyzing various production alternatives. Subsequently, they assembled a group of scientists to discuss the possibility of applying the models to determine best management practices (BMPs), taking into account the productivity and profitability of the practices as well as their environmental effects. After additional discussion, the ASA requested that a proposal be submitted to implement a BMP planning and decision support system for soybean farmers in the USA. Thus, a proposal has been submitted, led by J.W. Jones at the University of Florida, to do this work. The purposed work will extend and modify the soybean crop model and DSSAT components into a system tailored for soybean farmers and their advisors. It will include a water quality model so that productivity, profitability and environmental quality can be considered in such plans.

The reason we request the DSSAT is to provide additional tools for the MSc Dissertation on Water Resources which is being prepared by our student, Silvan Medeiros de Rosa. The purpose of her work is to assess changes in water demand for maize, considering the greenhouse effect, in the Ijui river basin, a sub-basin of the Rio de La Platam, and also to evaluate possible modifications in phenology and crop yield.

---R. Dorfman, Brazil

Regional:

Australia

Scientists associated with the Commonwealth of Scientific and Industrial Research Organization (CSIRO) and the Australian University in Canberra have participated in the continued improvement in DSSAT and its application. As stated earlier, the concept of the minimum data set was initially set forth by H.A. Nix, formerly of CSIRO and presently at the Australian National University. W. Meyer and his colleagues at CSIRO in Griffith have cooperatively interacted with J.T. Ritchie to improve the quantitative determination of soil water content in the water balance subroutine of the CERES crop models. This type of collaboration serves to reaffirm 'BSNAT's systems approach to problem solving.

An example of acceptance of this concept is the use of the "DSSAT template" in the development of a decision support system program referred to as ASPIM (Agricultural Productivity Simulator) by a team of CSIRO scientists in Towoomba led by R. Muchow and B. Keating. ASPIM supports both biological (crop) and environmental modules with a single data base system or data exchanger. The system is being customize for a specific user group, the sugar industry of Australia.

The Australian government provided funding to AIDAB (Australian International Development Assistance Bureau) to implement a global training program, Climate Impact Assessment and Management Program for Commonwealth Countries (COMCIAM), on systems approaches to agricultural development for lesser developed Commonwealth countries in 1991. Total funding for the program was A$2 million per year. Professor Nix, Director of the Resource Center at the Australian National University in Canberra, was instrumental in the establishment and implementation of this program. Crop simulation models and DSSAT were key features of the training program carried out in Mauritius in 1991 for participants from Africa and in India in 1992 for participants from the Indian sub-continent. A third is planned for the Caribbean area in 1993 or 1994.

D. Godwin, formerly of IFDC and currently at CSIRO, conducted the workshop in Port Louis, Mauritius with Nix. Participants from Nigeria, Malawi, Kenya, Uganda, Tanzania, Zambia, Zimbabwe, Botswana, Lesotho, Sudan, and Mauritius attended the two week course. Godwin and U. Singh of IFDC conducted a similar COMCIAM workshop in Secunderabad, India at ICRISAT for representatives from the Indian sub-continent. The program provided each participant with a microcomputer and software, including DSSAT v.2.1. A total of 25 copies were purchased from IBSNAT and shipped to Mauritius. Seven copies were acquired and shipped for the program in India.

Fiji

The University of the South Pacific (USP) serves eleven countries in the Pacific, and each of these countries has a separate USP campus. By collaborating with IBSNAT, through the PAIS, the USP staff hoped to assist these governments in utilizing IBSNAT outputs.

The purpose of collaboration with IBSNAT was to provide crop performance information from a number of agroenvironments in the South Pacific and to benefit from the IBSNAT–related crop research done around the world. Collaboration with IBSNAT would enable USP crop scientists to access the crop data base which is of interest to the Pacific region, assisting USP staff in their role of developing agricultural practices suitable to the needs of the region by providing information on the potential production of major crops on regional soils.

The USP collected minimum data sets for maize, rice, and taro. Maize was selected as a reference crop and has commercial possibilities in several countries. Rice is the major agricultural import of th South Pacific region, although substantial amounts are produced in Fiji and the Solomon Islands. Taro is a major stable food crop throughout the Pacific Islands, however it has not received the level of research input as that given to cassava or potato. Collaborators at USP, by providing data on taro production, wanted to contribute to the development of the taro model to be used by South Pacific regional governments for planning future development strategies.

In 1988, U. Singh and H. Prasad of USP conducted a workshop to train local staff in the collecting of the minimum data sets for model validation.

Guam

Guam wanted to adopt IBSNAT's research strategy in order to achieve the following: 1) maximize crop production on Guam;(2) transfer agrotechnology into Guam with minimum trial and error; 3) better understand technology transfer from research stations to farmers' fields; 4) assist other Micronesian islands with agrotechnology transfer; and 5) actively participate in crop production research.

The first IBSNAT corn experiment was planted at the Guam Agricultural Experiment Station (AES) Inarajan Farm. Comparison of predicted vs. measured yields with an incomplete set of crop and soil data indicated the corn model consistently estimated a value higher than the actual yield of corn hybrid, Pioneer 'X304C.'

Under farm AES Associate Director R. Muniaapan more complete data were collected to validate the IBSNAT maize model in order to more realistically predict crop yield for environments on Guam and Micronesian Islands. In addition, M. Marutani collected phenological information to assist in developing the potato model.

Chu-Tak Tseng of the Physics Department , University of Guam, participated in the first IBSNAT training course in Venezuela in 1984. He used CERES model and pointed out the need for a common input/output format. J. McConnell of the Horticulture Department participated in the 1987 short course on the management of experiments to collect the minimum data set. The course was held at the University of Hawaii.

New Zealand and the South Pacific Commission

D. M. Leslie and B. B. Trangmar, both of the former DSIR, now referred to as Landcare Research New Zealand Ltd., participated in the first two meetings of IBSNAT in 1983 at ICRISAT and in 1984 in Maui. As a result of their participation, Leslie, who had spent most of his career in the South Pacific, envisioned the establishment of a "branch" of IBSNAT referred to as OBSNAT for Oceanic Benchmark Sites Network for Agrotechnology Transfer. OBSNAT would serve as a regional information and data base center to assist the resource-poor island nations of the South Pacific move into the information and technology era.

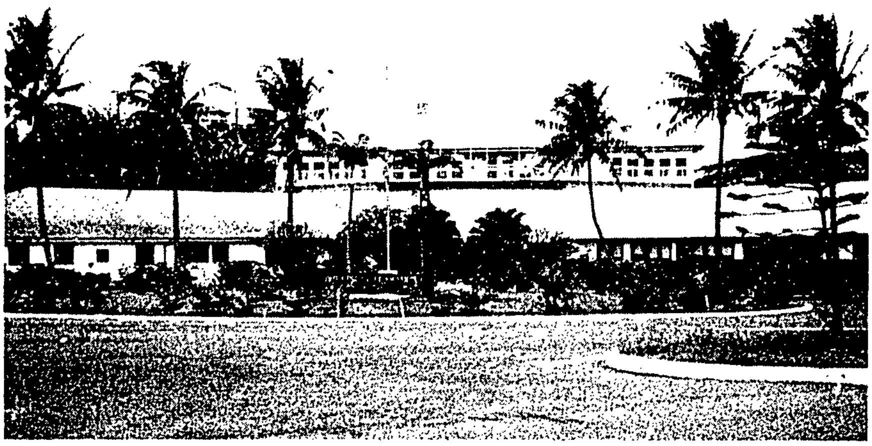
Both Leslie and Trangmar were instrumental in organizing several rounds of meetings on OBSNAT with K. Tama of the South Pacific Commission(SPC) in Noumea, New Caledonia and the directors of agricultural research of member nations of the SPC. The end result was approval of OBSNAT by the SPC Heads of Government in May 1990. OBSNAT was then renamed and implemented as the PAIS (Pacific Agricultural Information System). Funding to support PAIS was sought from the CIRAD and ORSTOM of France, AIDAB of Australia, the New Zealand Foreign Affairs and USAID. The PAIS is currently managed by P. S. Hart of Australia in Suva, Fiji.

Hart has asked IBSNAT scientists at IFDC, Thornton and Singh, to organize a training course on crop models and DSSAT in 1994.

P. Sivan, formerly of SPC, and currently residing in Queensland, participated in an IBSNAT workshop on modeling taro and tanier. His experience with taro in the South Pacific was valuable to IBSNAT in developing the SUBSTOR-Aroid model.

J. B. Dent, formerly of Lincoln College, served as a member of the IBSNAT Technical Advisory Panel and provided guidance in IBSNAT's systems approach in designing a whole farm systems program described elsewhere in this report. Dent is now with the School of Agriculture, Edinburgh University in Scotland.

B. A. McKenzie of Lincoln College reported having graduate students validate the CERES-Wheat model in DSSAT for crops grown in Canterbury. In addition, he indicated using DSSAT to study early leaf and tiller growth as affected by soil fertility for a range of cereals. McKenzie had a beta or test version of a lentil crop model that he shared with IBSNAT in 1991. IBSNAT was not aware of a final version as this report went to press.



South Pacific Commission at Noumea, New Caledonia.

I use DSSAT to help teach capabilities of crop models to answer advanced plant science questions.

---B.A. McKenzie, New Zealand

Selected Publications

Agrotechnology Transfer

The newsletter of the IBSNAT project was a joint undertaking with the Soil Management Support Services (AID Contract No. BST-1229-P-AG-2178) project and entitled, *Agrotechnology Transfer,* and referred to as *ATNEWS.* Each issue consisted of 16 pages and was mailed out to nearly 3500 individuals, libraries, missions, and many agencies and organizations globally. The 16 *ATNEWS* issues published were:

No. 1	September 1985	No. 9	November 1989
No. 2	February 1986	No. 10	January 1990
No. 3	June 1986	No. 11	May 1990
No. 4	October 1986	No. 12	November 1990
No. 5	April 1987	No. 13	April 1991
No. 6	September 1987	No. 14	August 1991
No. 7	March 1988	No. 15	January 1992
No. 8	October 1988	No. 16	October 1992

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Network Report, 1987-1990

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Dissemination

Workshops/Training Courses

Meetings/Symposiums

Workshops/ Training Courses

Since 1984, over 14 training workshops on IBSNAT crop models have been offered. Many other courses have been conducted at in-country level by former participants of these workshops. The workshops have evolved with time, providing better balance between concepts of systems research, crop growth modeling, data base management and data requirements, and applications of decision support systems in agriculture.

The IBSNAT training workshops are structured so that mornings are devoted to lectures, covering principles and concepts of IBSNAT's DSSAT and its crop models, the components of these models and the applications of the models. The afternoon sessions are hands-on exercises to reinforce the lectures. A final case study exercise is used to test the application of DSSAT and its crop growth models to any location in the world.

Training Goals

One of the underlying goals of the IBSNAT training workshops is to provide sufficient expertise in terms of software packages, lecture notes, exercises and group discussions so that all participants can be trainers for colleagues in their own country. Thus participants benefit from these training courses in the use of crop growth models and decision support systems for research, teaching, extension and policy making.

With the interaction and collaboration of participants, the predictability and user ability of the decision aides improves, and participants become active members of the IBSNAT network.

Training Objectives

The objectives of the training courses are that by the end of the course participants are able to:

1. Understand systems simulation and analysis approach to agricultural research;

2. Understand how the IBSNAT crop models are constructed so that they know: the components of the models and the processes that are simulated; the limitations of the models; and how they differ from statistical models;
3. Understand the minimum data set (MDS) concept so they know: the need for MDS and good quality data; how to collect MDS from field experiments; and the use of "expanded" MDS for model validation;
4. Learn to apply DSSAT and its crop growth models for real world problems.

The following list of workshops and training courses are designated by: (A) annual training courses organized by IBSNAT scientists and IFDC in the U.S; (B) training workshops hosted by in-country counterparts with IBSNAT scientists or trainers; (C) training courses organized and conducted by former trainees; and (D) workshops organized on specific topics.

A:

Training Program on Computer Simulation for Crop Growth and Nutrient Management
10 - 21 May 1993
Muscle Shoals, Alabama, USA

Training Program on Computer Simulation for Crop Growth and Nutrient Management
16 - 29 June 1992
Honolulu, Hawaii, USA

Training Program on Computer Simulation for Crop Growth and Nutrient Management
06 - 17 May 1991
Muscle Shoals, Alabama, USA

Training Program on Computer Simulation for Crop Growth and Nutrient Management
13 - 24 August 1990
Gainesville, Florida, USA

Computer Simulation for Crop Growth and Fertilizer Responses
15 - 26 May 1989
Muscle Shoals, Alabama, USA

Collection and Management of the IBSNAT MDS for Crop Modeling
20 January - 13 February 1987
Honolulu, Hawaii, USA

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Participants from Bangladesh, Fiji, Pakistan, Malaysia and Indonesia on the IBSNAT Training Course held in Honolulu, Hawaii, USA, in 1987.

B:

U.S./Hungarian IBSNAT Workshop
8 - 10 April 1992
Budapest and Godolla, Hungary

Agrotechnology Transfer Using Biological Modeling in Malawi
24 - 28 February 1992
Lilongwe, Malawi

Ist IBSNAT Hungarian Workshop
18 June 1991
Budapest, Hungary

International Training Workshop on Crop Models and DSSAT
30 November - 13 December 1990
Los Baños, Philippines

Sustainability/Modeling Workshop for Maize and Wheat
06 - 07 March 1990
Mexico City, Mexico

Training Course on Agrotechnology Transfer in Bangladesh
17 - 26 January 1989
Dhaka, Bangladesh

System Analysis and
Crop-Rice Simulation Models
17 - 27 June 1986
Sudang, Malaysia

Crop Soybean
Simulation and
Data Base
Management
Systems
01 - 11 June 1986
Taichung, Taiwan

System Analysis
and Crop-Maize
and Wheat Simulation Models
04 - 13 November 1985
Amman, Jordan

D. Imamura of IBSNAT discussing DSSAT at PCCARD Headquarters, Los Baños, Philippines.

System Analysis and Simulation of Crop Growth for Agrotechnology Transfer
03 - 14 December 1984
Caracus, Venezuela

C:

Modeling and Decision Support System Workshop
24 - 28 May 1993
Chiang Mai, Thailand

CONCIAM Crop Medeling Workshop
7 - 18 October 1991
Grand Bay, Mauritius

PAN-EARTH Venezuela Case Study: PAN-EARTH/FONAIAP Workshop on Crop Model Training and Calibration
13 - 16 November 1989
Maracay, Venezuela

PAN-EARTH Sub-Saharan Africa Workshop
11 - 15 September 1989
Saly, Senegal

South Pacific Commission Workshop/OBSNAT
03 - 08 June 1989
Noumea, New Caledonia

Biological N-Fixation Technology Workshop
24 October - 03 November 1988
Maui, Hawaii, USA

Fifth International Soil Management Workshop
11 - 23 December 1988
Taiwan, China

Workshop on Agroclimatology for Asian Grain Legumes Growing Areas and Regional Legumes Networks
05 - 17 December 1988
Patancheru, India

Training Workshop on Sorghum and Pearl Millet Modeling
12 - 19 October 1988
Patancheru, India

Collection of Minimum Data Set for IBSNAT Project
27 April - 5 May 1987
Nausori, Fiji Islands

D:

Workshop on Taro and Tanier Modeling
08 - 14 August 1991
Honolulu, Hawaii, USA

International Climate Change and Crop Modeling Workshop
17 January - 02 February 1990
Washington, D.C., USA

Workshop on Modeling Pest-Crop Interactions
07 - 10 January 1990
Washington, D.C., USA


Participants at Taro and Tanier Modeling Workshop in Honolulu, Hawaii, USA.

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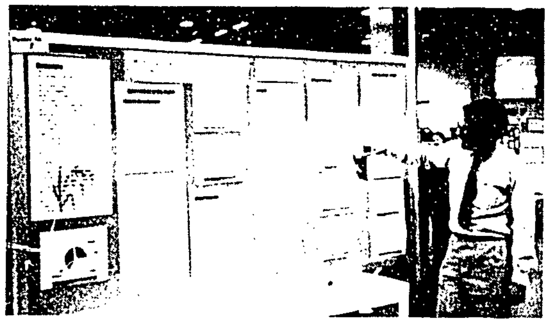
Meetings/Symposiums



U. Singh presenting DSSAT Rice model in San Antonio, Texas, USA.

IBSNAT Symposium: The Decision Support System for Agrotechnology Transfer Software Scene, American Soc. of Agronomy
1 - 6 November 1992
Minneapolis, MN, USA

International Workshop on Integration, Dissemination and Use of Environmental Data for Research on Crop Modeling
02 - 05 March 1992
Chambery, France

International Symposium Systems Approaches to Agricultural Development
02 - 06 December 1991
Bangkok, Thailand

IBSNAT Symposium: The Decision Support System for Agrotechnology Transfer Software Scene, American Society of Agronomy
27 October - 1 November 1991
Denver, Colorado, USA

South Pacific Commission Workshop/OBSNAT
03 - 18 June 1989
Noumea, New Caledonia

Western Regional Soil Survey Working Planning Conference
13 - 17 June 1989
Maui, Hawaii, USA

R. Ogoshi demonstrating DSSAT at Las Vegas, Nevada, USA.

International Symposium on Rice Production on Acid Soils of the Tropics
26 - 30 March 1989
Kandy, Sri Lanka

REDCA-CATIE Meeting
30 August - 01 September 1989
Teguicigalpa, Honduras

IBSNAT Symposium: The Decision Support System for Agrotechnology Transfer, American Society of Agronomy
16 - 18 October 1989
Las Vegas, Nevada, USA

Soil Fertility and Fertilizer Management in Semi-Arid Tropical India
10 - 11 October 1988
Patancheru, India

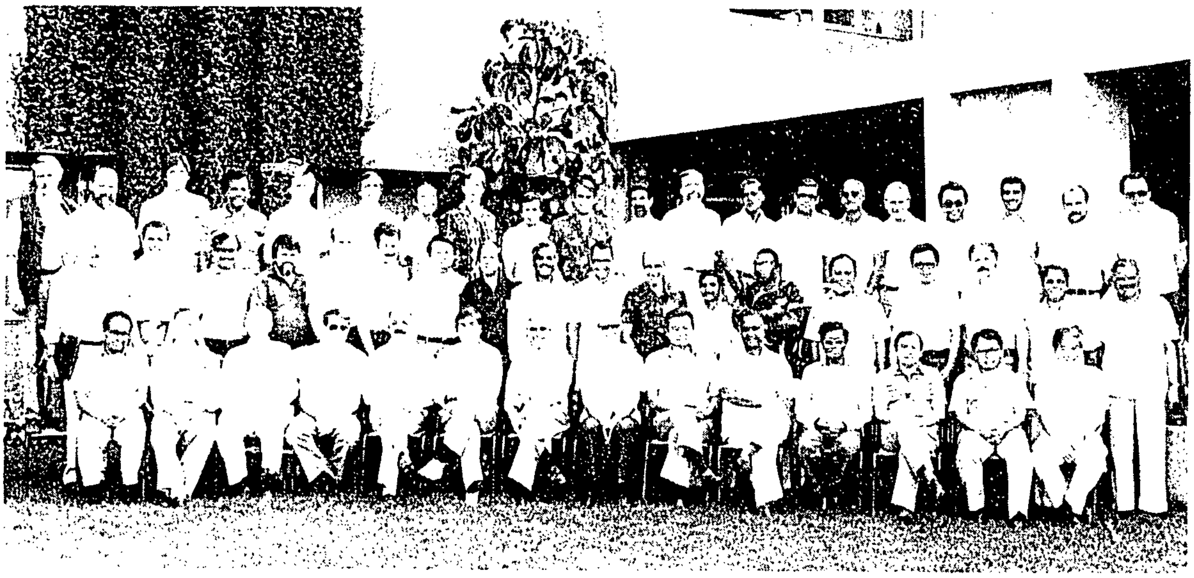
Biological N Fixation Technology Workshop
24 October - 03 November 1988
Maui, Hawaii, USA

IBSNAT "Think Tank"
28 - 29 July 1986
Honolulu, Hawaii, USA

Pest Modeling
13 - 15 November 1986
Washington, D.C., USA

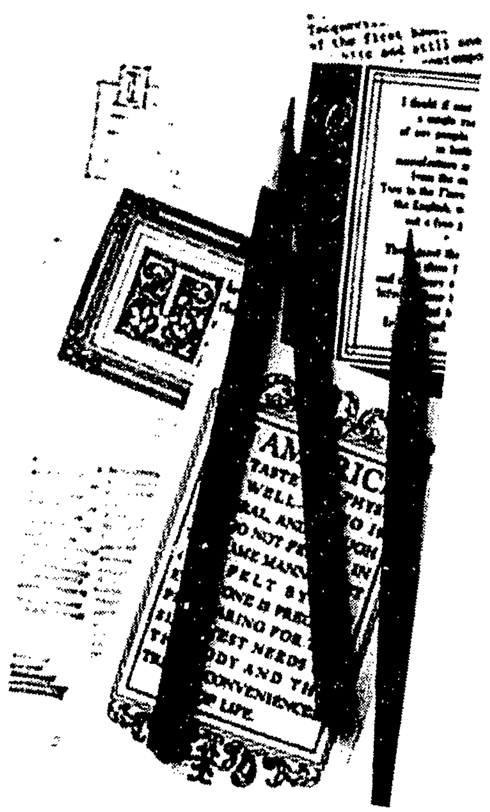
Collaborative Research Networking for Agrotechnology Transfer: Experimental Designs and Collection of Minimum Data Sets
13 - 17 August 1984
Maui, Hawaii, USA

International Symposium on Minimum Data Sets for Agrotechnology Transfer
20 - 26 March 1983
ICRISAT, Patancheru, India



The very first - the one that started it all - IBSNAT Symposium on MDS for Agrotechnology Transfer held at ICRISAT in Patancheru, Andha Pradesh, India, March 1983.

Citations



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Appendix A

Budget

Nearly $10 million were invested in IBSNAT by the U.S. Agency for International Development over the past 11 years. These funds supported activities that resulted in the development, dissemination, and utilization of decision support systems tools, including DSSAT, by an international network of cooperating scientists.

During the initial five years from 1982 to 1987, the IBSNAT project was a program of USAID implemented by the University of Hawaii through a cost-reimbursement contract. Expenditures under this contract from September 1, 1982 to August 31, 1987 amounted to $4.3 million, $800,000 less than the projected obligation.

From September 1, 1987 to August 31, 1993, including a no-cost extension sixth year, funds provided by USAID amounted to $5.4 million. For the second five years, IBSNAT became a cooperative agreement between USAID and the University of Hawaii and its network of global collaborators. The switch from a contract to an agreement was a programmatic one. USAID wanted a more vested commitment from the contractor in carrying out activities of IBSNAT as partners. The cooperative agreement required the University of Hawaii to demonstrate this commitment through cost-sharing of USAID's expenditure by 25 percent.

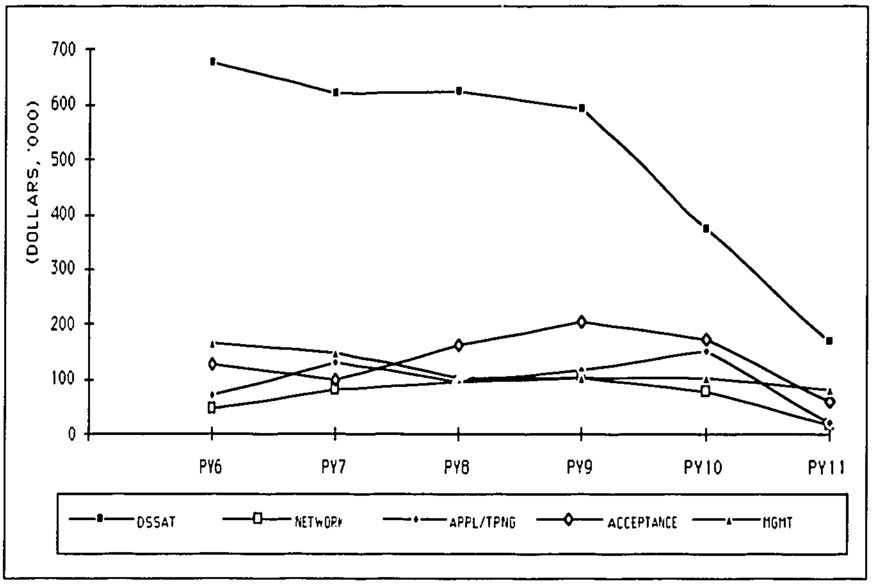
None of the USAID funds were used to compensate faculty associated with the University of Hawaii, its subcontractors, and the network of collaborating institutions. None of the members of the Technical Advisory Committee received any stipend or consulting fees from IBSNAT.

The University of Hawaii's cost-sharing total amounted to more than $1.35 million from 1987 to 1993. In addition, an estimated $4 million were cost-shared by collaborating institutions involved in model development, calibration and validation. Another $4 to 5 million were estimated for collaborating scientists in both developing and developed countries to generate minimum data sets and conduct training during this period. Hence, by leveraging the funds provided by USAID, IBSNAT was able to accelerate the development of crop models for installation and application in DSSAT and to extend its support for training.

Expenditure Plan

A projected expenditure rate of $90,000 per month was used as the basic figure for budgeting available resources in accordance with the annual work plans. The line graph shows the annual expenditures by outputs from 1987 to 1993. More than 50 percent of the budget were designated for the first three outputs.

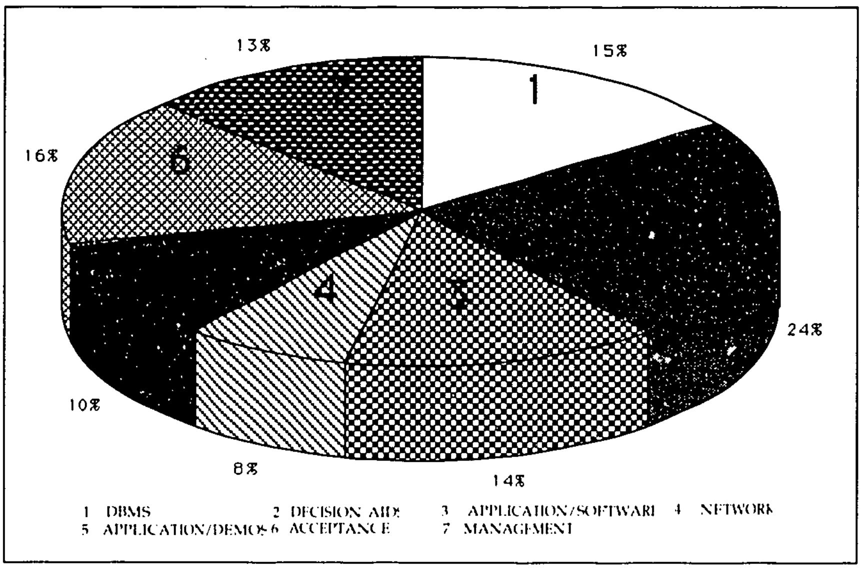
Collectively, the three outputs constitute DSSAT. Specifically, they are related to (1) acquisition of minimum data sets, (2) crop model development, calibration and validation, and (3) development and testing of application or technology transfer programs for DSSAT. By PY9 (1990-1991), resources were gradually shifted to outputs related to applications and acceptance.



Line graph depicting annual expenditures by outputs, 1987 to 1993.

The piechart shows the percentage allocation of resources by output over the last six years. More than 50 percent of funds received were assigned to the three outputs related to DSSAT. Expenditures for the network were associated with output 4 and amounted to only 8% of the total. Costs of collaboration, i.e. leveraged costs, were borne principally by cooperating institutions.

Outputs 5 and 6 on applications and acceptance do not reflect the costs involved in the conduct of training courses and workshops carried out in host-countries and the United States. Annual training courses carried out in the U.S. were self-sustaining through charges of tuition fees to participants. Similar courses held outside the U.S. were sponsored by host country agencies in cooperation with several donor agencies, including USAID,



Piechart depicting the percentage allocation of resources by output, 1987 to 1993.

FAO, and the Rockefeller Foundation. Of special note is the training program on the application of crop simulation models and DSSAT for climate impact assessment by the Australian International Development Assistance Bureau (AIDAB) for Commonwealth countries under the COMCIAM program. A brief description is presented in the Acceptance section. Nearly A$2.3 million per year were provided under this program for three years. The Centre for Pacific Development and Training of AIDAB manages the program, which has acquired 32 copies of DSSAT to date.

Management costs amounted to 13 percent of the total and were used to support the core staff at the University of Hawaii. Expenditures also included travel costs associated with the annual meeting of the Technical Advisory Committee and with meetings of those involved in the development and programming of DSSAT.

Resource Allocation

Line item expenditures for the period of the cooperative agreement are shown in the table below. Expenditures reflected the major cost items for the project. Salaries and fringe benefits of the core staff, subcontracts, and travel.

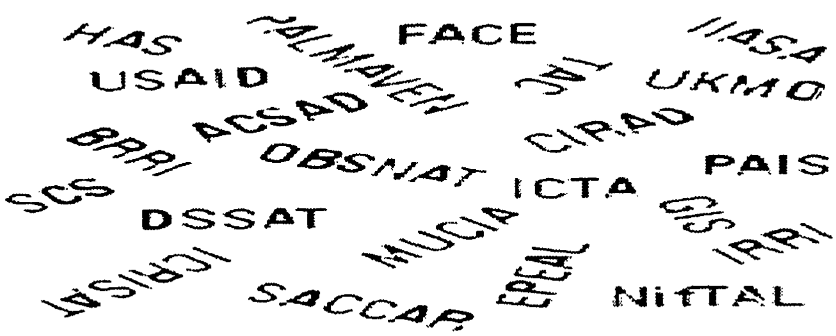
Subcontracts were entered into with eight institutions and organizations: the Universities of Edinburgh, Florida, Guelph, and Puerto Rico, Michigan State University, the USDA/ARS, Temple, Texas, the International Fertilizer Development Center, and the International Rice Research Institute. These subcontracts are described under Networks in this report.

Line Item	**1982 - 1987**	**1987 - 1993**
Direct Costs:		
Salaries/Wages	1,057,524	1,655.874
Fringe Benefits	172,315	289,424
Consultants	95,241	15,500
Supplies,services,other	337,070	200,200
Travel/per diem	716,950	552.714
Equipment	84,643	26,169
Publications	68,681	124,385
Subcontracts	951,413	1,612,291
Total Direct Costs		4,476,557
Indirect Costs[a]	814,088	924,296
Total Costs	4,297,925	5,400,853

Expenditures by line items—(a) Cost-reimbursement contract, 1982 to 1987 and (b) Cooperative Agreement, 1987 to 1993.

[a] *Negotiated indirect or overhead rates used during the period of the agreement ranged from 32.— to 45% for on-campus research activities, 13 — to 25% for off-campus research and training, and 25% of the first $25,000 expended for each subcontract*

Appendix B


HAS
PALMAVEN
FACE
IIASA
USAID
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UKMO
ACSAD
CIRAD
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OBSNAT
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ICTA
DSSAT
GIS
MUCIA
IRRI
ICRISAT
EPEAL
SACCAR
NifTAL

Acronyms

ABSNAT	ASEAN Benchmark Sites Network for Agrotechnology Transfer
ACSAD	Arab Center for Studies of Arid Zones and Dry Lands (Damascus, Syria)
AEGIS	Agricultural and Environmental Geographic Systems
AGLN	Asian Grain Legume Network
AIDAB	Australian International Development Assistance Bureau
APSIM	Agricultural Productivity Simulator
ARS	Agricultural Research Services
ASA	American Soybean Association
ASEAN	Association of South East Asian Nations
AVRDC	Asian Vegetable Research and Development Center (Taiwan)
BRRI	Bangladesh Rice Research Institute
CABO	Centre for Agrobiological Research
CARIBSNAT	Caribbean Benchmark Sites Network for Agrotechnology Transfer
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza (Turrialba, Costa Rica)
CBAG	Caribbean Basin Administrative Group
CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical (Cali, Colombia)
CIMMYT	Centro de Investigacion y Mejoramiento de Maiz y Trigo
CIP	Centro Internacional de la Papa (Lima, Peru)
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Development
COFAF	Committee on Food, Agriculture and Forestry (ASEAN)
CPF	cumulative probability functions
COMCIAM	Climate Impact Assessment and Management Program for Commonwealth Counties
CSIRO	Commonwealth Scientific and Industrial Research Organization (Australia)
CSAR	Center for Soil Research (formerly); now, Center for Soil and Agroclimate Research (Indonesia)
DBMS	database management system
DSSAT	Decision Support System for Agrotechnology Transfer
EMBRAPA	Empresa Brasilerira de Pesquisa Agropecuaria (Brazil)
EPA	Environmental Protection Agency (USA)
EPEAL	Empresa de Pesquisa Agropecuaria do Estado de Alagoeas

ERDAS	Earth Resources Data Analysis System
FAO	Food and Agriculture Organization (United Nations, Italy)
FACE	Free-Air CO2 Enrichment
FONAIAP–CENIAP	Fondo Nacional de Investigaciones Agropecuáries–Centro Nacional de Investigaciones Agropecuáries (Venezuela)
GIS	geographic information systems
GISS	Goddard Institute for Space Studies
GFDL	Geophysical Fluid Dynamics Laboratory
HAS	Hungarian Academy of Sciences
IARC	international agricultural research centers
IBSNAT	International Benchmark Sites Network for Agrotechnology Transfer
ICARDA	International Center for Agricultural Research in the Dry Areas (Aleppo, Syria)
ICD	Industry Council for Development
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICTA	Instituto de Ciencia y Tecnologia Agricolas
IDEA	Instituto Internacional de Estudios Avanzados
IDIAP	Instituto de Investigación Agropecuária de Panamá
IFDC	International Fertilizer Development Center (Muscle Shoals, Alabama, USA)
IGBP	International Geosphere/Biosphere Programme
IIASA	International Institute for Applied Systems Analysis (Austria)
INTA	Instituto Nacional Technologia Agropecuaria (Argentina)
INTSORMIL	International Sorghum /Millet, Collaborative Research Support Program (USA)
IRRI	International Rice Research Institute (Manila, Philippines
IITA	International Institute for Tropical Agriculture (Ibadan, Nigeria)
JNG	Junta Nacional de Granos (Argentina)
MARDI	Malaysian Agricultural Research and Development Institute
MDS	minimum data set
MUCIA	Midwestern Universities Consortium for International Agriculture (USA)
NARC	national agricultural research centers
NARS	national agricultural research stations
NifTAL	Nitrogen Fixing Tropical Agricultural Legumes (Hawaii, USA)

OBSNAT	Oceanic Benchmark Sites Network for Agrotechnology Transfer
ORSTOM	Office de la Recherche Scientifique et Technique Outre-Mer (France)
PAIS	Pacific Agricultural Information System (Fiji)
PALMAVEN	Filial de Petróles de Venezuela
PARC	Pakistan Agricultural Research Council
PCARRD	Philippine Council on Agriculture Forestry and Resources Research and Development
PSTC	Program in Science and Technology Cooperation
RCUH	Research Corporation of the University of Hawaii
RISSAC	Research Institute of Soil Science and Agricultural Chemistry (Hungary)
SACCAR	Southern African Centre for Cooperation in Agricultural Research (Botswana)
SARCCUS	Southern African Regional Commission for the Conservation and Utilization of the Soil
SCS	Soil Conservation Service
SMSS	Soil Management Support Services
SPC	South Pacific Commission
SPRAD	South Pacific Regional Agricultural Development project
TAC	Technical Advisory Committee
TARS	Tropical Agricultural Research Station
UKMO	United Kingdom British Meteorological Office
UNED	The Universidad Estatal a Distancia (Costa Rica)
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
USLE	universal soil loss equation
USP	University of South Pacific (Fiji)
VITUKI	Research Centre for Water Resources Development (Hungary)

The future is built by IBSNAT & its like...

...is that a wrap then, Gordon?

The International Benchmark Sites Network for Agrotechnology Transfer Project: A Review

Frank Z. Alejandro, Ph.D
Bureau for Global Programs
Field Support and Research / Program Office
U.S. Agency for International Development

This is a brief overview of some salient features and highlights of the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) Project. Although my observations are presented as the bureau evaluation officer serving ex-officio on the comprehensive external evaluation conducted in the summer of 1990, it is also based on my review of published documents, reports and on a hands-on demonstration of the Decision Support System for Agrotechnology Transfer (DSSAT).

Travel to the project site, communications with IBSNAT project staff at the University of Hawaii, and regular discussions with the project manager in USAID/W provided consistent regular updates on the project's progress, achievements, problems, and work plans. The primary objective of the project was the development and support of a prototype decision support system for agrotechnology transfer (DSSAT) and that included a natural resource data base management system, crop simulation models, expert systems and application programs to enable decision-makers to recommend reliable alternatives for solving LDC country problems. While the project may appear complex as to the useability of inputs, refinement of these inputs into the DSSAT system, and transferability, replication and use at the different levels of organizational decision making, hands on manipulation of synthetic data used as inputs to test hypothetical situations proved simple and effective. In this regard, IBSNAT has documented considerable progress towards achieving its stated objectives as specified in the original authorization of the project. In fact, from my data, I found it to be a useful tool that may have far-reaching applications not only for the developing countries where USAID works, but in developed countries as well.

During the life of the project a number of experiments and simulations were conducted under controlled situations. During my participation in the 1990 evaluation, I was able to observe DSSAT crop model and simulation experiments first hand. While the individual crop, pest, and farm systems models visited at that time were noteworthy, the Genetic Coefficients experiment was perhaps the more interesting.

These experiments were established to develop field methods that could be commonly used and applied at any global location to determine genetic coefficients for specific varieties of crops such as maize, wheat, soybeans, and others. Previously, determination of these coefficients had to be carried out in growth chambers at great cost. At scheduled intervals, observations of growth characteristics such as dates of leaf appearance, leaf number, leaf area, seed or kernel numbers and so on were documented and recorded for entry into the DSSAT database. In essence, the experiments in Hawaii were focused on the genetic coefficients affected by photoperiod and temperature. Experiments were established at two different (elevation and temperature differences) locations and consisted of one control and four photoperiod treatments at each site. The extended daylight periods simulated conditions common to areas in the higher latitudes. Results from these experiments were used to calibrate and validate crop models in DSSAT. In effect, outputs of simulations from DSSAT can be used by research scientists, policy makers, extension agents and farmers for making crop model refinements and applications and for deciding whether and under what conditions crop yields can be sustained successfully.

The network of expert scientists IBSNAT has been able to attract is quite extensive. These individuals have worked and continue to work together to solve agriculture technology transfer problems by developing crops, soils, and whole farm systems models and related interventions addressing sustainable agricultural development, the environment and natural resources with the hopes of also contributing to limiting increased global warming trends through their application.

In short, IBSNAT's success can be attributed to the effective implementation of three objectives and focusing its resources accordingly. These are:

- The Decision Support System for Agrotechnology Transfer package. This package is basically a program shell linking three elements that can be used for decision making purposes. It includes crop simulation models, a data base management system, and a management and risk assessment program. Fully integrated into appropriate Versions 2.1 and 3.0 were developed over time. It was first used in 1989 with crop models for wheat, maize, soybean, and peanut. Additional crop variety models were added subsequently to include rice, millet, sorghum, barley, dry bean, potato, cassava, and aroids.

- An international network of highly capable research scientists and systems developers including members from a number of U.S. universities and institutions from other developed countries; the U.S. Department of Agriculture; some of the International Agricultural Research Centers; and several developing countries' institutions were pulled together for their expertise and working knowledge of crop modeling and related simulation techniques.

- Dissemination and use of the DSSAT package acquired wide acceptance throughout the LDC particularly by scientist at field and farm levels in a number of countries in Europe, Africa, Asia, Latin America, and the Pacific for use on sustaining crop productivity. The package was also used extensively by others interested in studies related to global climate change on food production and trade, and a myriad of other applications.

Clearly, the IBSNAT project provides a means whereby decision makers at different levels are able to accumulate, collapse and synthesize existing knowledge into a compact and portable decision support program that can be used to identify and diagnose problems, evaluate and test options or alternatives in efforts to obtain desired results. The decision support system and the techniques and methodologies used to implement it have proven beyond a doubt that existing knowledge can be effectively used to produce useful new knowledge regarding crop varieties and related technologies.

Given the rapid pace of technology change and potential of DSSAT in generating options towards formulation and implementation of best suited policies and practices, USAID and other donors should invest in the IBSNAT network to promote and update DSSAT. It would be to USAID's advantage to build on a product that it successfully created, to achieve food security and environmental protection especially for countries that are unable to keep-up with the dynamic and holistic issues that they must face and address. Ad-hoc, piece meal approaches will not produce time -- and cost-effective beneficial results.

(fza: January, 1994)

Agency For International Development Develops Software:

A Major Innovative Approach Toward Sustainable Development

PROBLEM:

As the worldwide pressure to produce more food and protect natural resources and the environment rapidly increases, there is a clear need to promote timely and effective policies and practices that enable sustainable agricultural development. The challenge is to find an innovative process that generates the examination of options and evaluates trade-offs among complex interactive biophysical, socio-economic, and ecological issues.

A.I.D. RESPONSE:

To help address the problem, the Agency for International Development awarded a Cooperative Agreement to the University of Hawaii in 1982. A number of other institutions collaborate in this effort, including the universities of Florida, Georgia, and Puerto Rico, Michigan State University, University of Guelph, the Edinburgh School of Agriculture, the International Fertilizer Development Center, and the Soil Conservation Service of U.S. Department of Agriculture.

RESULT:

This support has led to the development of a systems simulation software that predicts and assesses various policy and production options. These options include assessment of environmental and other risks, including their costs and benefits if avoided. The software—based on technical and biophysical interactions which integrates accessible and available natural resources data—allows decision makers to simulate responses to alternative decisions involving hundreds of variables such as land and soil characteristics; climate and other agro-ecological factors; production choices regarding pest and weed control, chemical use, and different input packages; and cost and price data.

POTENTIAL IMPACT:

The computer software, called "Decision Support System-DSS", benefits both developing and developed countries as it demonstrates how complex biophysical, socio-economic and ecological factors interact simultaneously. This technology provides a scientific short-cut, a time and cost-effective process, that will provide quantitative analyses of these complex issues.

WORLDWIDE APPLICATIONS:

DSS is currently being "ground truthed" at over 500 locations, worldwide and in the United States. Last year, the Australian government allocated $2.3 million to train Commonwealth countries in Africa, Asia and the Caribbean regions in using DSS. Similar activities are being promoted in Malawi, Thailand, Taiwan, Argentina, Venezuela, Kenya, India and China. The Bangladesh Agricultural Research Council is developing a national proposal to use DSS for risk analysis on the susceptibility of food supply to weather. A.I.D. used the system to estimate the Albanian wheat crop and then determine the need for imports.

U.S. APPLICATIONS:

The DSS is being used widely in the U.S. in crop management decision making:

• The Environmental Protection Agency is using DSS to assess the impact of climate change on world food production and international trade.

• DSS is being used to determine alternative ways to increase protein content of soybean to make U.S. soybean growers more competitive in world markets.

• Significant reduction in nitrate contamination of ground water has been achieved with no loss in profit by reducing fertilizer application rates.

• DSS enables producers to assess yield loss from pest and prescribes minimum pesticide use for optimum yields and environmental safety.

RESEARCH EFFICIENCY INCREASED:

Six of the international agricultural research centers are testing the software to increase efficiency and prioritize their research. Experts conservatively estimate that, worldwide, over 20 percent could be saved from the $5-6 billion spent annually on redundant agricultural research. Future research will improve and expand DSS capabilities leading to products that meet changing needs of clients.

PRIVATE SECTOR POTENTIAL:

The major potential application of DSS is in agri-business. To facilitate the diffusion of the technology in the United States private sector, A.I.D. has given a small grant to the Industry Council for Development (ICD), a private non-profit organization, to demonstrate and promote the technology by giving numerous demonstrations in the U.S. and Europe. The following companies received these demonstrations: The Quaker Oats Co., IMC Fertilizer, Archer Daniels Midland Co., Monsanto Co., Chicago Mercantile Exchange, Chicago Board of Trade, Ralston Purina, American Soybean Association, National Corn Growers Association, Pioneer Hi-Bred International, Land O' Lakes, Inc., Northrup King Co., General Mills, Cargill, Inc., Nestle S.A., ICI Seeds, Unilever Plant Breeders Institute, Shell Petroleum, and IBM/Europe.

—USAID: LEG/PD, R&D/AGR - April 1992