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APPLICATIONS OF DECISION SUPPORT SYSTEM FOR AGROTECHNOLOGY TRANSFER IN PRESENT DAY AGRICULTURE

U. Singh, G.Y. Tsuji, and F.H. Beinroth

International Fertilizer Development Center,
Muscle Shoals, AL 35662
IBSNAT Project, University of Hawaii, Honolulu, HI 96822, and
University of Puerto Rico, Mayaguez, PR 00708

ABSTRACT

The Decision Support System for Agrotechnology Transfer (DSSAT) is an interactive, user-friendly, microcomputer-based software package designed to assist scientists, policymakers, and resource planners in rapidly accessing a natural resource data base, evaluating predicted outcomes, and prescribing solutions to site-specific problems. It is a powerful tool for enhancing the efficiency of agricultural research and assessing new agrotechnology packages in the rapidly changing and exacting environments in which farmers have to operate. The DSSAT, developed by a team of international scientists under the auspices of the IBSNAT Project, consists of a data base management system, crop simulation models for cereals and grain legumes, and application programs. Its application on agricultural, environmental, and global issues offers valuable assistance in decisionmaking and long-term strategic planning.

INTRODUCTION

Crop production is influenced by many complex, dynamic, and interdependent factors like weather, soil condition, crop, cultivar, and management. It often involves making high-risk decisions requiring considerable effort and expertise in the management of agricultural resources. Research work has generated an enormous amount of information, which means that extension agents and farm managers must process a large amount of information every time they need to make a decision. Also, in many instances such information is incomplete and/or during the decision-making process some relevant information is not utilized. A successful transfer of crop production technology from researchers to farmers, in essence, is dependent on complete understanding of the biological, economic, social, and cultural constraints faced by farmers. A common biological cause of failure is the mismatch between the environmental requirements of a technology and the environmental characteristics of the land, while the main socioeconomic fault is the mismatch between the requirement of a technology and the resource capabilities of the farmer. Current means of agrotechnology transfer are trial and error, transfer by analogy, and system simulation.

Transfer of information by analogy, based on a network of field experiments on research stations and farmers' fields, may not solve the mismatch problem because each farmer, as well as each farm, is unique, whereas results of experiments are heavily dependent on season, soil, cultivar, and management factors under the control of the researcher. The objective of crop simulation modeling is not to replace field experimentation; field experimentation is expensive but essential. Crop simulation modeling and decision-aid programs are intended to improve research and extension in terms of efficiency and cost effectiveness and also to provide the farmer with a tool that will enable him to make quick, wise decisions in the absence of experts.

In recent years mathematical modeling and simulation techniques relying on the use of powerful, versatile computers have been developed to provide a comprehensive and quantitative description of the behavior of dynamic crop growth patterns. Because computer hardware is becoming readily available and affordable, even in developing countries, and software packages are more user-friendly, computers are the tools of the day to facilitate storage of information and simulation of agricultural processes to aid decisionmaking and planning.

A major milestone in adoption of systems simulation in agricultural research was achieved when the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT)[1] Project released the Decision Support System for Agrotechnology Transfer (DSSAT) to the general public in July 1989. The DSSAT is an interactive, highly modular, user-friendly, and microcomputer-based software package that integrates data bases, crop models, and application programs. The DSSAT is designed to assist scientists, policymakers, and resource planners in rapidly accessing a natural resource data base, evaluating predicted outcomes, and prescribing solutions specific to a particular soil, climate sequence, and/or particular set of management inputs. Initially intended for agricultural research, it may be used to handle such critical issues as resource allocation, land-use planning, environment protection, and impact of global climate change. DSSAT provides data, narrative information, and simulation models in an organized manner to suggest solutions of these issues. Thus, it is a powerful tool for enhancing the efficiency of agricultural and environmental research and assessing new agrotechnology packages in the rapidly changing and exacting environments in which the farmers have to operate.

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[1] IBSNAT is a program of the U.S. Agency for International Development implemented by the University of Hawaii, under Agreement No. AID/DAN-4054-A-00-7081-00.

In this paper the structure and components of the DSSAT, validation of DSSAT crop models, and application of the DSSAT on agricultural, environmental, and global issues will be described.

]STRUCTURE OF DSSAT

The DSSAT consists of a data base, knowledge base, control program, and user-interface program (Figure 1). It derives much of its power, flexibility, and utility from its capacity to provide the user with convenient access to these components and with the opportunity to change input parameters to assess the effect of changes on interrelated processes. The data base consists of numerical data, technical information, and narrative information (IBSNAT, 1988). The knowledge base consists of crop growth simulation models, weather simulators, and an application program for strategic decision-making. The strategy evaluation program defines the exact nature of the problem presented to the system, i.e., a series of prompts and menus help the user to frame questions. The problem definition allows the DSSAT, through its control program, to identify pertinent elements in the data and knowledge bases. The user communicates with the system through a user-interface program consisting of an interactive, windowed, menu-driven environment. Operations of the DSSAT subsystems, as described above, are directed by a control program written in C language. The workings of all the subsystems (including the crop models) are fully automated, i.e., not seen by the user, who merely responds to system prompts and then evaluates the results and reports that are generated.

The DSSAT's modular structure (Figure 1) and standardized file format (IBSNAT, 1990) lend themselves to incorporation of new models that describe the effects of nutrients other than nitrogen (e.g., phosphorus, potassium, calcium, sulfur), trace elements, soil acidity, pests, pesticides, ground water quality, farming systems, socioeconomics, and intercropping as well as expert systems to cope with the ever-increasing knowledge base. The DSSAT's structure has been described in detail elsewhere (ATNews 2, 1986; IBSNAT, 1989; Singh et al., 1989a) and therefore a brief overview follows.

A. Data base management system

The data base management system (DBMS) component of the DSSAT is designed to organize and store data and narrative and technical information; integrate data from several sources; and provide user-friendly data entry and retrieval programs for crop models, weather simulators, and strategy analysis. DBMS is programmed in dBASEIII, Clipper, and C. The minimum data set (Nix, 1984) essential for describing crop growth, soil water balance, and nitrogen dynamics stored in DBMS is accessible to crop models in a standardized format (IBSNAT, 1990).

The minimum data set (MDS) needed to run and validate the crop growth simulation models includes daily weather sequences, site information, soil characteristics, management inputs, cultivar characteristics and field-measured crop information (Table 1). The latter is extremely important for crop model validation. The function of DBMS is not limited to storing and generating input and validation files for crop models. It can also be used to retrieve files for statistical analyses, graphics, and expert systems applications (Figure 1). The DBMS (data entry and retrieval programs) can also be accessed by crop models other than those integrated in the DSSAT package as long as they adhere to the standard input/output structure described elsewhere (IBSNAT, 1990).

B. Knowledge base

Crop growth simulation models, weather estimators, and strategy evaluation programs form the knowledge base of the current version of the DSSAT - DSSAT V2.1 (Figure 1). DSSAT V2.1 contains the simulation models for only the following four crops: wheat (Godwin et al., 1989), maize (Ritchie et al., 1989), soybean (Jones et al., 1989), and peanut (Boote et al., 1989). The CERES models for rice (Godwin et al., 1990) and sorghum (Singh et al., 1989b) will be available in the next update of DSSAT. Models for the other six crops are at various stages of development. All of the 12 DSSAT crop models are developed on the basis of the dynamic relationship between biophysical processes and environmental and management factors. The DSSAT crop models, however, do include some instances where deductions about mechanisms/processes are based on an empirical relationship. Thus, these models are best described as functional models, containing empiricisms only when mechanisms are not well understood.

1. Crop models

The crop models include substantial biological detail such that they simulate water balance, soil and plant nitrogen dynamics, phasic development, and crop growth on a daily time step. The models use a standardized input and output structure (IBSNAT, 1990) so that soil and weather data bases are common to all the DSSAT crop models. In addition to a user-friendly interface for simulation, the models also provide graphical display of output and sensitivity analysis of key agro-environmental factors. On the average, the DSSAT-based crop models simulate a single season's crop growth on IBM compatible microcomputers in under two minutes. These models can also be run on mini- and mainframe computers; however, the DSSAT itself, capitalizing on the portability and affordability of personal computers, is a microcomputer-based package.

The crop models predict daily changes in such crop growth variables as aboveground biomass; weight of leaves, leaf area,

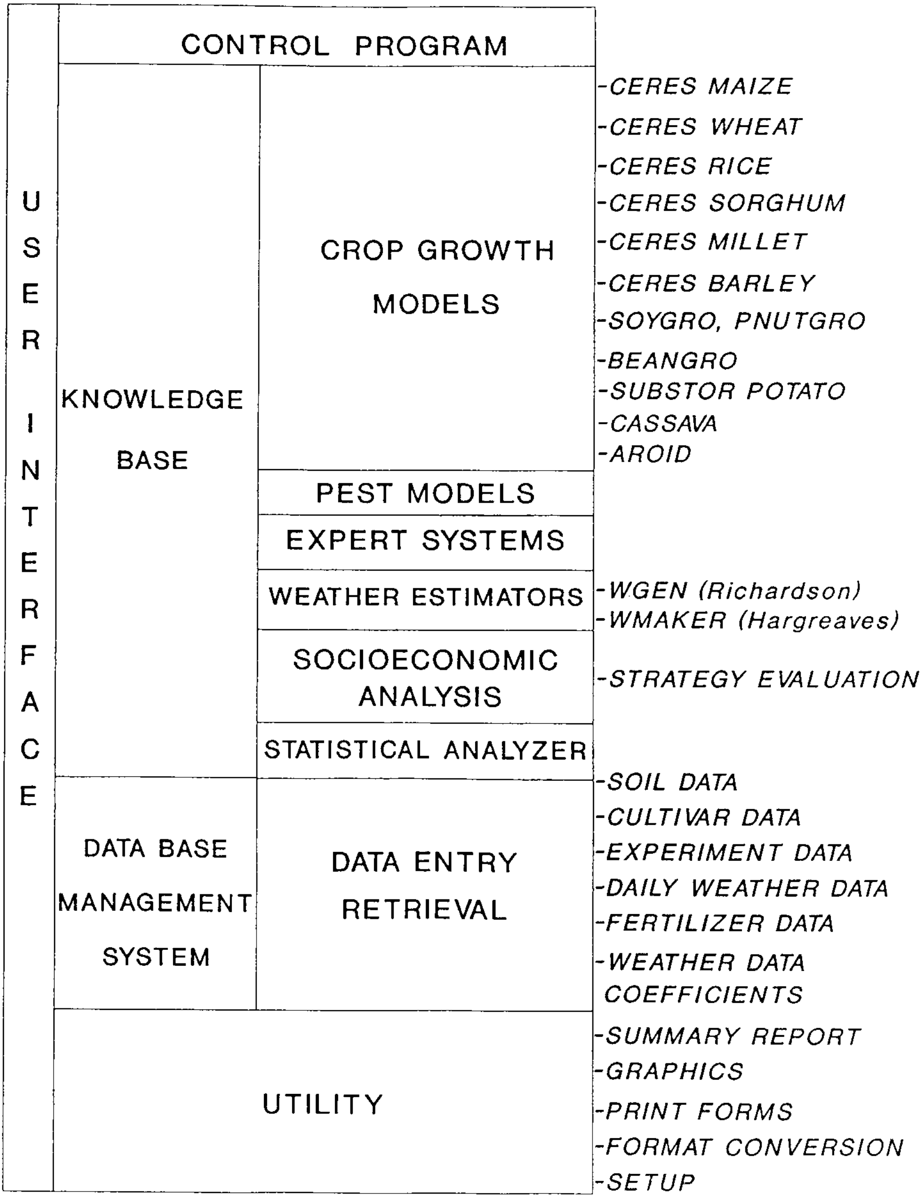

Figure 1. Structure and Components of the Decision Support System for Agrotechnology Transfer.

Table 1. Input and Validation Data Requirements for CERES models.

Input	Daily Weather	solar radiation (MJ m^{-2}) maximum and minimum air temperature (°C) rainfall (mm)
	Site	latitude (°), soil albedo, runoff curve number, drainage rate (cm day^{-1}), stage 1 soil evaporation (mm)
	Soil (by layer)	depth of each layer (cm) lower limit of plant extractable soil water drained upper limit water content saturated soil water content bulk density organic carbon content initial soil water content initial soil ammonium and nitrate content initial soil pH
	Cultivar	variety name genetic coefficients
	Management	beginning date, sowing date plant population, seeding depth irrigation amounts and schedules residue type (C:N), amount, depth of incorporation N fertilizer schedules, source, amount, depth, and method of incorporation
	Management (Rice)	date of transplanting age of seedling seedbed/nursery temperature biomass of seedling (optional) bund/levy height schedules for flooding and amounts percolation rate perched water-table depth
Validation	Development	emergence, floral initiation, anthesis, and maturity dates
	Growth	LAI, biomass, grain weight, leaf weight, stem weight, tiller number, and grain and straw N content during the growing season final grain yield, biomass, grain N uptake, and straw N uptake
	Water balance	soil water content with time
	Nitrogen	soil nitrate and ammonium content with time

leaf senescence, and leaf number; weight of roots, stems, ears, and grains; root length per unit volume of soil; and rooting depth. They also simulate the duration of growth stages and predict the following events: floral initiation, anthesis, and physiological maturity. The water (Ritchie, 1985) and nitrogen (Godwin and Vlek, 1985) balance submodels simulate availability of water and nitrogen (nitrate and ammonium) for growth and development and the dynamic fluxes of water and nitrogen in the soil.

The model inputs (Table 1) can readily be obtained from meteorological stations, soil-survey and soil-characterization data, and agricultural journals. The validation data are normally generated from field experiments conducted for at least 2 years at a particular location. The DSSAT crop models CERES Maize (Singh et al., 1989b; Singh 1985), CERES Wheat (Otter-Nacke et al., 1986), SOYGRO (Jones et al., 1989), and PNUTGRO (Boote et al., 1989) have been extensively tested in many radically diverse environments and locations worldwide. These tests indicate that the crop models in the DSSAT can be used with confidence as a research and extension tool.

2. Weather estimators

Once confidence has been established that a crop model can produce results similar to those obtained from field trials, then crop models can be used to simulate differing cropping and management strategies at various locations where real field trial data do not exist, as well as over time and season. To simulate the latter, long-term weather sequences from a given site are required. Unfortunately, long-term weather data are often not available. An alternative is to use stochastic time-series modeling procedures with short-term (5-10 years) weather data to generate a sequence of weather records with statistical parameters that are indistinguishable from the existing weather data for the site. Two weather estimator programs (Figure 1), WGEN (Richardson and Wright, 1984) and WMAKER (Keller, 1987), are included in the DSSAT. Both these programs estimate daily synthetic weather, as needed by crop models, from a set of weather coefficients. The procedures for incorporating these procedures are also included in the DSSAT.

Production stability in terms of weather can thus be investigated explicitly for a particular set of input or management specifications over many years by using generated climatic data. The DSSAT (using historical or synthetic weather) allows the exposure of weather-related risks in a way that could never realistically be accomplished through the use of field trials.

3. Strategy evaluation

Crop production strategies, using long-term weather sequences either real or synthetic, are generated by the DSSAT's strategy evaluation program with a series of menu-driven prompts that provide the user with choices of different cropping, management, and/or environmental factors. Thus, the strategies may include choice of crop (e.g., maize, wheat, peanut, or soybean in DSSAT V2.1), cultivar, planting date, planting density, soil type, soil initial moisture and nutrient status, irrigation application, residue management, and fertilizer application. Multiple-year simulations are then carried out and cumulative probability is estimated for grain yield, biomass, net return, nitrogen loss, water and nitrogen stress, and duration of the crop's life cycle over the range of seasons generated. The DSSAT's strategy evaluation program also has procedures, as described by Anderson (1974), for selecting strategies under conditions of uncertainty and providing due recognition to farmers' attitudes toward risk.

VALIDATION OF CROP MODELS

Model validation ensures that models perform correctly when tested against observed data (real world) that have never been used in model development. It is important that those assumptions inherent in the simulated results also apply to the observed data. For example, nutrients other than nitrogen are nonlimiting; pests and disease effects and catastrophic events like floods and typhoons are absent.

One of the main functions of DSSAT is to facilitate crop model validation by storing and providing user-friendly data entry and retrieval options for minimum data sets needed for validation (Table 1). IBSNAT crop models have been validated extensively in very diverse environments. The comparison of predicted results with those observed over the range of nitrogen rates (Figures 2 and 3) indicates that the models responded well to the effects of added nitrogen fertilizer. The maize model simulated a good response to applied nitrogen on maize under well-irrigated conditions on an Oxisol in Hawaii (Figure 2). For rainfed wheat at Wagga Wagga, Australia, the wheat model correctly simulated no response at all to applied nitrogen fertilizer (Figure 3). From the above examples it is evident the IBSNAT models effectively capture the water-nitrogen interactions.

Simulated days to anthesis and final grain yields are plotted against the observed values in Figures 4 and 5 for the IBSNAT/CERES Maize, Wheat, Sorghum, Pearl-millet, and Barley models. These experiments were performed in Indonesia, the Philippines, Brazil, Costa Rica, United Kingdom, the Netherlands, Australia, Fiji, Malaysia, Thailand, India, Bangladesh, Syria, and the United States including Puerto Rico.

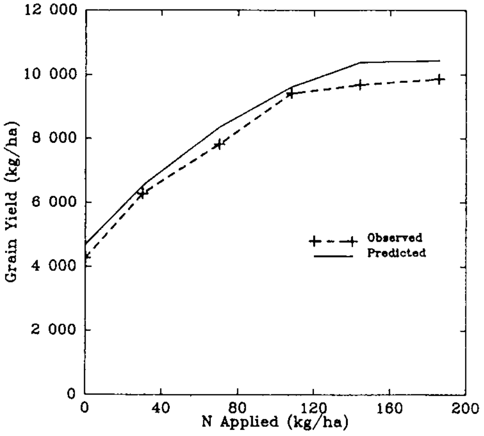

Figure 2. Performance of the CERES Maize Model Over a Range of Nitrogen Rates for Grain Yield.

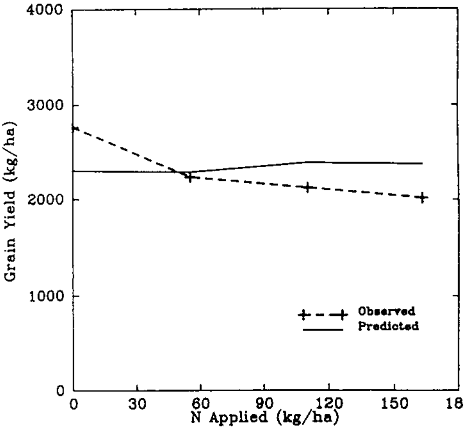

Figure 3. Performance of CERES Wheat Model Over a Range of Nitrogen Rates for Grain Yield.

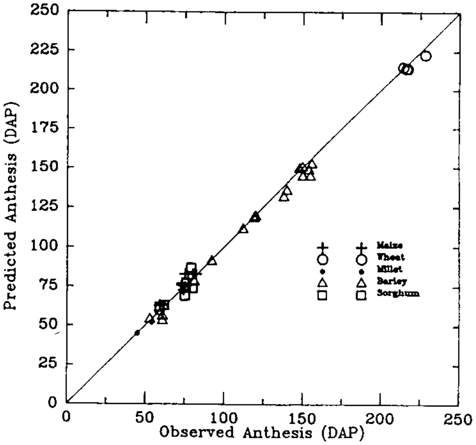

Figure 4. Observed Versus Simulated Anthesis Date as Days After Planting (DAP).

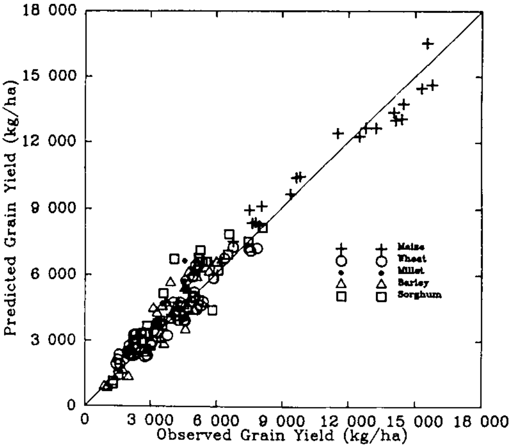

Figure 5. Observed Versus Simulated Grain Yields by the CERES Models.

A 1:1 line between observed and simulated results is also depicted on the figures. The results show that the predictions closely approach observations, and the scatter around the 1:1 line is quite small. Similar results have been obtained with the IBSNAT/CERES Rice model (Godwin et al., 1990).

APPLICATION OF DSSAT

The DSSAT can be used to "conduct" simulation experiments, once it has been shown that the crop models work adequately for the sites and regions of interest. Such experiments can be designed to aid in tactical as well as strategic decision-making. DSSAT can facilitate adoption and transfer of agrotechnology packages. For example, varieties, technologies, or management options that give poor performance or are infeasible for the location under study can be rejected without the need for costly, time-consuming field trials. Importantly, a thorough evaluation of only the promising strategies could be carried out at both research stations and farms. To adequately capture the uncertainties associated with weather, simulations must be run with long sequences of weather. Only then can promising technologies be selected over those that are less promising.

At any given location, even where real field data do not exist, the DSSAT can be used to evaluate the impact of growing a different crop, using a new variety, changing the planting date, increasing the plant stand, and modifying fertilizer and irrigation management. With recently incorporated modifications, it can also simulate the impact of long-term climatic change on yield, crop duration, and nutrient losses. The DSSAT can be used to evaluate long-term agricultural productivity and sustainability. Examples of some of the above-mentioned applications follow.

A. Strategy selection

The DSSAT was used to identify appropriate planting date for maize under Costa Rican rainfed conditions. A tropical hybrid maize (Pioneer X304C) was planted on a clayey Oxisol with extractable moisture content of 18 cm with nonlimiting nutrient status in January, April, July, and November. The simulated yields of 20 years for each of the four treatments were ranked, and the cumulative probability function was plotted as shown in Figure 6. As evident from the results, the best planting times are April to July because yields are higher (the cumulative density curves are to the right) and variances are extremely low (Figure 6). The choice of a planting date for a particular crop is dictated not only by rainfall but also by variety, occurrence of pests, soil type, costs and market prices. For instance, in the above soil it is possible to get good yields (7 Mg/ha or higher) 50% of the time, even during January planting. However, if the same trials were conducted on a sandy soil with low-moisture status, planting in January would be out of the question (Figure 6). The maize yields for July planting on sandy soil are practically unchanged from those obtained on clay soil because the rainfall is adequate and well distributed.

Users, therefore, can ask "what if" questions and conduct long-term multiple-year simulations to select appropriate varieties, fertilizer strategies, planting dates, etc. Multiple-year simulations are very important because yield responses are influenced by weather. It is vital to know how sensitive or insensitive a crop production strategy is to the prevailing climate.

B. Sequential cropping

In the multiple-year simulations previously described (Figure 6) the prime objective was to show the variability and risks in farming that were associated with climate. Thus, it was assumed that management and fertility status were constant from one year to another. The sequential cropping option, currently under development, allows the DSSAT to respond to declining fertility with continuous cropping and identify management and technologies to sustain productivity.

An irrigated maize simulation experiment was conducted on a deep clay soil with high fertility status and organic carbon content (2.5%) at Isabela, Puerto Rico. The simulation was continued for 20 years using estimated daily weather data for Isabela. The crop was planted in June of each year, with a bare-fallow period between cropping. During the entire 20-year simulation it was assumed that all nutrients other than nitrogen were nonlimiting, that there were no incidences of pests and diseases, and that the crop was free of weeds.

The continuous cropping simulation without the addition of nitrogen fertilizer, crop residue, or green-manure resulted in drastic reduction of yields (Figure 7) and organic matter content. Thus, within 20 years a highly productive soil was converted to a marginal soil with inadequate fertilizer management and improper conservation of organic matter. Without the fallow period, the decline in production would have been greater than predicted. Annual incorporation of green-manure at the rate of 1 Mg/ha one month prior to the June planting was sufficient to maintain the high level of productivity (Figure 7). With future developments, DSSAT will be able to assist farmers in selecting appropriate crops in their crop rotation system.

C. Geographic information systems

In studies being conducted in semiarid tropical India by IFDC and in Puerto Rico by the University of Puerto Rico and the University of Florida, the DSSAT has been integrated with the PC

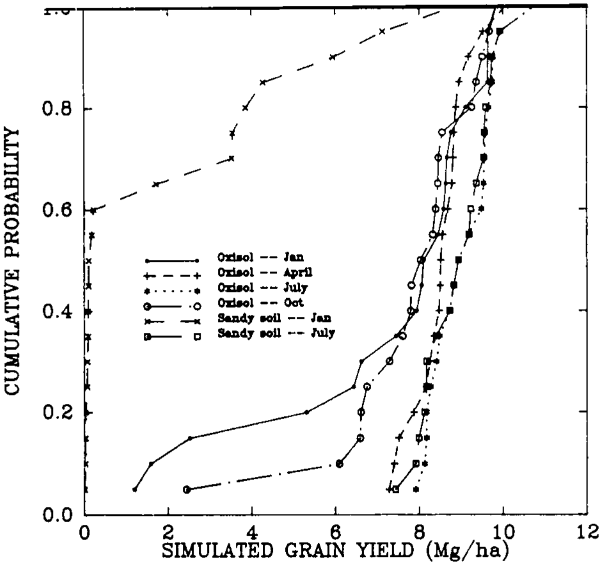

Figure 6. Simulated Maize Yield Response to Planting Dates on Two Soils.

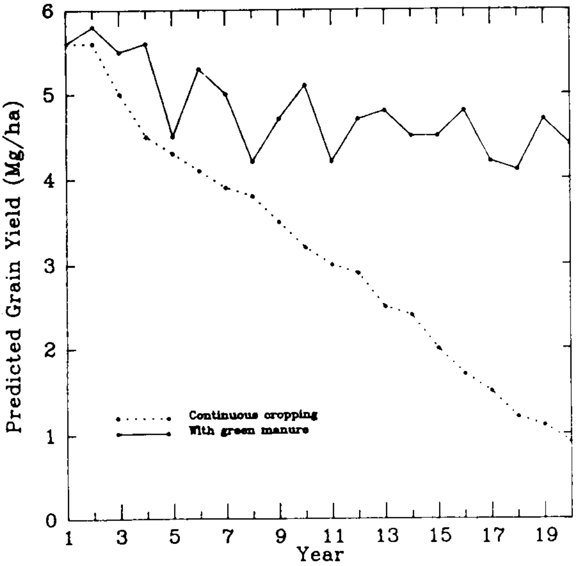

Figure 7. Simulated Maize Yield Response to Continuous Maize-Fallow Cropping Versus Maize-Fallow Cropping With Addition of Green Manure.

ARC-INFO geographic information system (GIS). The GIS provides the crop models access to spatial data on soils, climate, and topography. The models are thus run in locations/ regions with similar soils and climatic data. The simulated results from the crop models are stored in the GIS data base, which proves to be a very powerful tool for expressing data in map forms. The crop model-GIS analysis has considerable potential because complex interactive and dynamic relationships among crops, soils, and climate can be shown by simple map displays. The impact of poor management of soils on agricultural productivity and environment can be mapped and presented to policymakers and planners more effectively. There are many potential uses of crop model-GIS analysis.

The IFDC study, for example, integrates the IBSNAT/CERES Sorghum model with GIS to identify nitrogen fertilizer use efficiency in the semiarid tropical regions of India. Because India is one of the top users of nitrogen fertilizer, it is imperative for policymakers and planners to know areas of potentially poor (or high) fertilizer use efficiency and low (or high) yield responses and areas of high/low risks in relation to fertilizer use and losses.

D. DSSAT users

The DSSAT has been adopted by many international and national centers and universities around the world. These include IFDC and IBSNAT collaborative projects in India, Thailand, Malawi, Zambia, Bangladesh, the Philippines, Indonesia, and Malaysia. Another project, recently initiated by the Environment Protection Agency (EPA) and the IBSNAT Project, investigates the effects of climatic change on agriculture in developing countries. Other major users of the DSSAT are the University of Florida, Michigan State University, and the University of Edinburgh.

Inclusion of root crop models and future modifications to the crop models will make the DSSAT a very versatile and useful tool. The major improvements will be inclusion of phosphorus simulation by all the cereal and grain legume models and modeling of biological nitrogen fixation by the legume models.

Also in the future, the types of data bases in the DSSAT will increase to handle floodwater chemistry data, perennial crops, multiple and sequential cropping, intercropping, and socioeconomic factors.

CONCLUSIONS

The DSSAT is the product of an international network of scientists. One of its major but rather unnoticed achievements has been to bring together a diverse group of people to cooperate and collaborate on model development and validation.

Agriculture is facing enormous pressures and challenge to feed an ever-increasing urban population on scarce land resources, modify production systems to minimize environmental pollution, and sustain productivity on a long-term basis. The DSSAT with its data base and crop simulation models is an invaluable tool for diagnosing the above agroproduction problems and prescribing solutions to them. It can also be used to evaluate the impact of long-term changes in climate and ground water table on crop growth, water balance, and nutrient dynamics. Therefore, the DSSAT has considerable potential for providing relevant information and solutions quickly and cheaply.

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