CARIBBEAN

FOOD

CROPS SOCIETY

27

Twenty Seventh

Annual Meeting 1991

DOMINICA

Vol. XXVII

A MODEL-BASED DECISION SUPPORT SYSTEM FOR REGIONAL AGRICULTURAL PLANNING[1]

J. P. Calixte, H. Lal, W. J. Jones,
F. H. Beinroth, and L. R. Pérez-Alegría

Graduate Research Assistant, Post Doctoral Associate,
Professor of the Department of Agricultural Engineering
University of Florida, Gainesville, FL
Professor, Assistant Professor
Department of Agronomy and Soils and
Department of Agricultural Engineering
University of Puerto Rico, Mayaguez, PR

ABSTRACT

Agricultural decision making at the production and policy levels involves processes which can be enhanced by modern computer technologies. Crop and soil models can be used to estimate the impact of different production strategies at a regional level, and thus provide supplemental information to help decision makers select management practices in accordance with their planning objectives. This paper describes the structure and implementation of an agricultural decision support system named AEGIS - Agricultural and Environmental Geographic Information System - designed to evaluate production strategies and to facilitate the creation of a regional agricultural plan. AEGIS links simulation results from two IBSNAT crop growth models (BEANGRO and CERES-RICE) and a soil erosion model (USLE) to a geographic information system (pcARC/INFO) and an expert system. A menu-driven interface is developed to help users with limited expertise in computers interact with AEGIS. Three areas in Puerto Rico were used to develop a prototype of this system. An example is presented to demonstrate the potential use of this system as a planning tool for regional policy makers. The role of the models, the organization of the databases, the design of the user interface and the expert system are discussed. This model-based system demonstrates the effectiveness of modern computer technologies in the processes of agricultural planning, information management, and agrotechnology transfer in Caribbean countries.

INTRODUCTION

Agricultural planning at the regional level presents unique challenges due to numerous biological, socioeconomic, and political factors which must be considered by decision makers. For example, as the need for greater agricultural production becomes more evident in order to accommodate increasing population pressure or to achieve regional food self-sufficiency, planners and policy makers will have to develop new guidelines to ensure

---

[1]This work is supported by the USDA Caribbean Basin Advisory Group (CBAG) Grant. No. 89-34135-4577: "Computer Systems for Enhancing Agricultural Decision Making in the Caribbean".

that agricultural practices used toward these goals, such as conversion of marginal land to agricultural production, intensified cropping systems, introduction of new cultivars, etc., produce the desired results with minimal adverse consequences to the environment. This example already suggests that the process of formulating these agricultural and environmental guidelines can be quite complex because decision makers must find methods of evaluating various agricultural practices and strategies, and then decide whether the estimated impact of these strategies satisfies existing socioeconomic constraints and political goals. That kind of analysis requires a substantial amount of data on crops, soils, land use, weather, and most importantly an understanding of the interaction among these factors. Failure to perform such analysis in a timely manner, however, will eventually result in decisions that lead to surface and ground water contamination, soil erosion and loss of productivity, and probably expensive remedies to these and similar undesirable consequences of agricultural activities.

Recent technological breakthroughs, such as computer-based decision support systems, offer innovative ways to analyze, organize, and manipulate spatial and non-spatial data. The development of these tools, in most cases, is a corollary to advances in crop and soil modeling, reinforced by the emergence of artificial intelligence and the revolutionary vector- and raster-based geographic information system (GIS). Decision Support Systems (DSS) have a lot of potential as modern tools to facilitate decision making at the production and policy levels due to their analytical as well as predictive capabilities.

Several applications of DSS are reported in the literature, and they cover a variety of topics such as simulation of commercial greenhouse internal transport systems (Fang et al., 1988), optimization of greenhouse environmental control (Jones et al, 1988), irrigation scheduling (Thompson et al., 1989), multiresource management of pine forests (Wood et al., 1989), assessment of groundwater pollution potential from chemicals (Halliday and Wolfe, 1990; Zhang et al., 1990), and socio-economic impact of new agricultural technologies on resource-poor farmers in developing countries (Hoogenboom and Thornton, 1990). These are just a few examples which illustrate the scope and content diversity of DSS recently developed.

Nevertheless, these systems share common characteristics and a common purpose which is to enable agricultural producers and policy makers to optimize the use of natural resources by a) reducing the time and human resources required to perform complex alternative analyses, b) providing a holistic approach to solving multifarious agricultural problems, and c) increasing the overall quality of the decisions to be implemented.

This paper describes a prototype of a regional Decision Support System which links simulation results from BEANGRO, the drybean model (Hoogenboom et al., 1990), CERES-RICE, the rice model (Singh et al., 1990) and the Universal Soil Loss Equation (USLE), a soil erosion model (Wischmeier and Smith, 1978) to a Geographic Information System (pc/ARC/INFO) and an expert system. The goal of this prototype is to demonstrate the use and value of an integrated computer system which allows its users to evaluate different production strategies at the regional level, examine statistical results obtained from the models in tables and maps, and interactively build a regional agricultural plan which reflects the objectives of the user.

AEGIS: AN OVERVIEW

A prototype of AEGIS is being developed for three areas in Puerto Rico located near Isabela, Mayaguez and the Lajas Valley. These areas were selected in consideration of their environmental diversity which also represents the state of natural resources elsewhere in the Caribbean Basin. The bean and rice models are used in this project because of the importance of these crops in the Caribbean diet. Users of AEGIS will be able to 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, etc.), and finally 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.

Figure 1 shows the layout of the main components of the system. These include: 1) crop models (BEANGRO and CERES-RICE) and a soil erosion model, the USLE, which predict crop productivity (potential yield, biomass accumulation, irrigation requirements, and cumulative evapotranspiration) and environmental degradation (soil loss nitrogen leaching); 2) a set of databases of spatial and non-spatial attributes and a relational database management system (DBASE IV); 3) an expert system which provides optimum ranges of soil and weather requirements for crop production; 4) a Geographic Information System (pcARC/INFO) which facilitates the production of thematic maps based on results obtained from the models; and 5) a menu interface designed to facilitate the interaction of users with the system.

CROP AND SOIL MODELS

Crop models are developed by interdisciplinary research teams to predict crop growth, yield, and resource use based on an understanding of the interactions of soil, plant, and weather (Jones and Ritchie, 1990). Using long term weather and soils data, crop models can simulate year to year variations in the performance of a crop under diverse management practices (Ritchie, 1987), and generate estimates of production and environmental degradation based on which agricultural strategies can be compared. The International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) recently created a site-oriented Decision Support System for Agrotechnology Transfer (DSSAT) which defined a standard format for input and output files used by several crop models (IBSNAT Project, 1989). Using soil and weather databases from the three regions of Puerto Rico and the Strategy Evaluation Module of DSSAT, several management alternatives for dry bean and rice are evaluated.

The soil database contains the profile description of 67 soil types which have been previously classified as suitable for agriculture. For

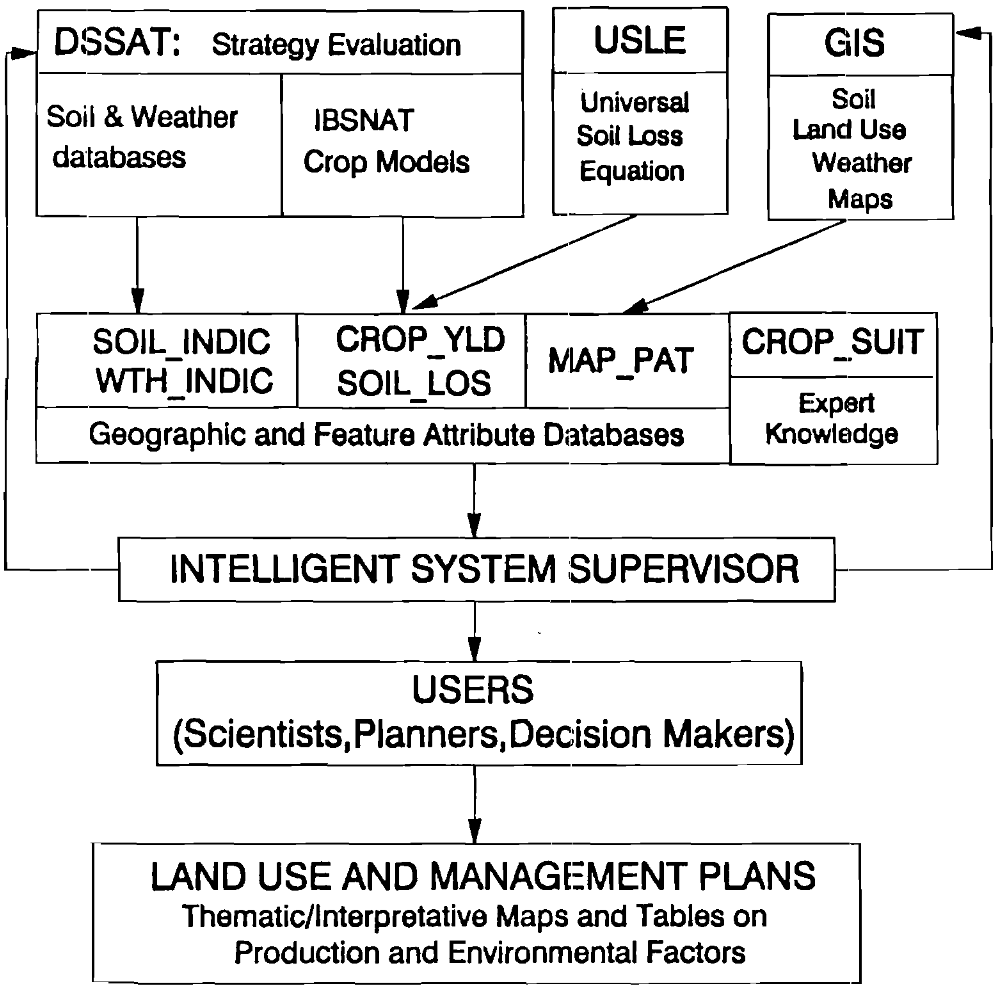

Figure 1. AEGIS Design Schematic
(Adapted from Lal et al.,1990)

each soil type, the models simulate the growth of each crop variety, under rainfed and irrigated conditions, for different levels of fertilization in the case of rice, using 12 different planting dates and 20 years of regional weather data (Fig. 2). The results from these runs are statistically analyzed and for each management alternative (i.e., combination of soil type, plant variety, planting date, irrigation treatment...), the 20^{th} percentile, average, and 80^{th} percentile values are computed for all production and environmental degradation factors, with the exception of soil loss. These percentiles represent different levels of probability of obtaining a certain value or less for a given factor. For example, a 20^{th} yield percentile indicates that 1 out of 5 years one can expect a yield lower than or equal to the quoted yield value under the selected management practices.

The crop models have certain limitations, however, since they do not account for the effects of pests, diseases, and nutrient deficiencies other than nitrogen. Furthermore, the models do not account for losses due to lodging or natural disasters (Ritchie, 1987; Godwin et al., 1989). Nevertheless, in the absence of reliable long term records of experimental results from different agricultural practices, crop models provide a cost-effective alternative for evaluating these practices and making informed decisions in agricultural planning.

The amount of soil loss during a cropping season is calculated by the USLE. The USLE is an erosion model designed to predict the longtime soil losses in runoff from specific field areas in specified cropping and management systems (Wischmeier and Smith, 1978). The USLE is expressed as:

$$A = R * K * LS * C * P$$

where A is the computed soil loss, R is the rainfall erosivity factor, K is the soil erodibility factor, LS is the topographic factor representing the slope length and gradient, C is the cover and management factor, and P is the support practice factor.

The rainfall (R) and soil erodibility factors (K) were obtained from the Technical Notes for the Caribbean Area published by the Soil Conservation Service (USDA-SCS, 1980). The LS factor is usually obtained from field measurements for each mapping unit, but the time and financial commitment that would be required to reach that level of accuracy could not be justified for the purpose of this project. Instead, a representative LS value, computed as a weighted average for each soil type, is derived from the National Resource Inventory database of the Soil Conservation Service. The C factor is computed by cropstage periods which are defined according to the percentage of canopy cover to reflect the gradual change in effectiveness of plant cover during the cropping season. A detailed description of this procedure is provided by Wischmeier and Smith (1978). The percentage of ground cover is predicted by the crop models for each strategy. A constant value of 1.0 is assumed for the P factor to simplify the model and also to reflect soil loss occurring when no special erosion control practices are applied.

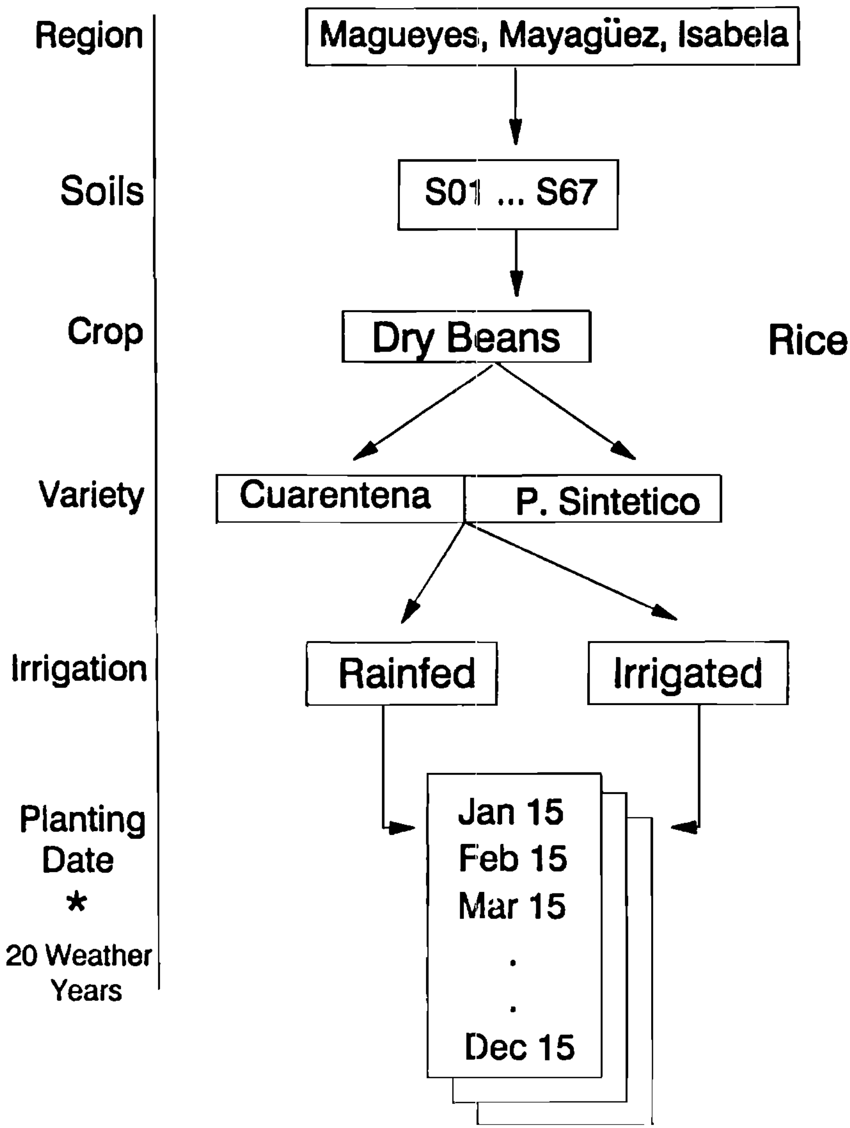

Figure 2. BEANGRO simulation for AEGIS

Computing soil loss during each cropping season will indicate the probable distribution of soil erosion and thus the portions of a rotation when improved management practices will be most beneficial (Wischmeier and Smith, 1978). In spite of its limitations, the USLE is used in this project, not necessarily to obtain accurate and absolute erosion figures, but as an index to compare relative rates of soil loss resulting from different management practices on different soils in each region (Ventura et al., 1988).

DESIGN OF DATABASE AND EXPERT SYSTEM

The databases of AEGIS store information about soils, weather, land suitability, crop requirements, and crop performance factors derived from the USDA-SCS soil surveys, historical weather records, expert knowledge, crop and soil models. Figure 1 presents an overview of the function of these databases.

First, special dabases of soil and weather data formatted to IBSNAT standards were created for the three regions. These files were used to run the crop models for evaluating crop performance under different management practices. The results of the crop models are stored in the **CROP_YLD** datafiles which are accessed by AEGIS during the evaluation of agricultural strategies. These datafiles list the results of the models for each combination of region, crop variety, soil type, planting date, irrigation and fertilization treatments. The **SOIL_LOS** file stores the values of predicted annual soil loss for each cropping season. These datafiles are used to produce tables and maps of strategy results.

Information about the spatial distribution of soils in each region is contained in the Polygon Attribute Tables (**MAP_PAT**). These tables were automatically created by pcARC/INFO (ESRI, 1989) when regional USDA-SCS soil maps were digitized. These databases list each polygon (soil mapping unit) number, perimeter and area. Other attributes, such as soil type, group, and map symbol for each polygon are then added to the records. These databases are used primarily for map production.

Other important databases include the soil indicator (**SOIL_INDIC**), the weather indicator (**WTH_INDIC**), and the crop sutiability (**CROP_SUIT**) files. The **SOIL_INDIC** files contain specific soil parameters such as slope, depth to water table, pH, and aluminum saturation whereas the **WTH_INDIC** files contain monthly weather indicators (mean precipitation and temperature) and daily cumulative percentages of the USLE's rainfall factor (R). The data from these files are used primarily to target soils that can be considered for crop production based on user-defined restrictions, or on specific crop requirements stored in the crop suitability (**CROP_SUIT**) file. Further information about the development of those files is provided by Lal et al. (1990).

The **CROP_SUIT** file contains optimal ranges of aluminum saturation, potassium, and pH recommended for different crops, assuming that no corrective measures will be implemented for soils with values outside of these ranges. These ranges are being defined by regional experts and through literature reviews. This information will be used to create the rules of the expert system which is designed for selecting soils in a region that are best suited for the production of the crop(s) considered. This is an option offered in the user interface.

LINKAGE WITH GIS

A Geographic Information System may be defined as a computer-based system which links or references digital map features (wells, roads, soil mapping units, for example) to a database of attributes describing these features. A GIS provides four basic functions: automation, manipulation, analysis, and display of geographic data in digital form (ESRI, 1989). These functions make GIS a powerful tool, well suited to spatial studies.

GIS has been used in several agricultural and environmental studies. Zhang et al. (1990) combined a solute transport model, Chemical Movement in Layered Soils (CMLS), with a GIS, pcARC/INFO, to evaluate the impact of four pesticides, Chlorsulfuron, Aldicarb, Atrazine, and Ethoprophos, on groundwater quality under different sets of environmental conditions in Oklahoma. Garland et al. (1990) integrated land use/land cover data into a GIS to identify and prioritize non-point source pollution potential of agricultural lands in Chesapeake Bay, Virginia. Using a combination of a GIS, the Geographical Resource Analysis Support System (GRASS), and DRASTIC, a systematic methodology developed by the EPA to assess pollution susceptibility, Halliday and Wolfe (1990) conducted a study to identify potential groundwater pollution from the use of nitrogen fertilizer on cropland in Texas.

AEGIS uses pcARC/INFO to organize spatial data and produce thematic maps based on results of agricultural strategies. First, soil maps (scale = 1:20000) of the three regions were converted into digital layers using pcARC/INFO. These layers are used as base maps to represent graphically different attributes of soils in each region. For example, the GIS can create maps showing the distribution of soil by series, slope, land use, or any other characteristic that is included in a database called the Polygon Attribute Table which is referenced to the digital layer. When a user selects a strategy to be evaluated by AEGIS, the results are stored first in temporary files listing the production and environmental degradation factors predicted for each soil type in the region considered. Then, these temporary files are joined to the Polygon Attribute Table (MAP_PAT), and thus the simulation results become an additional set of soil attributes which can be manipulated and presented in digital maps. Consequently, AEGIS is able to create maps of simulated yield, biomass accumulation, runoff, etc., at all three probability levels for the strategy evaluated.

More complex data manipulation and analysis can be executed with AEGIS since other map types such as regional weather distribution and land use are integrated into AEGIS (Fig. 3). These additional coverages provide the flexibility of presenting the same strategy results aggregated over different boundaries (land use, weather zone, etc.).

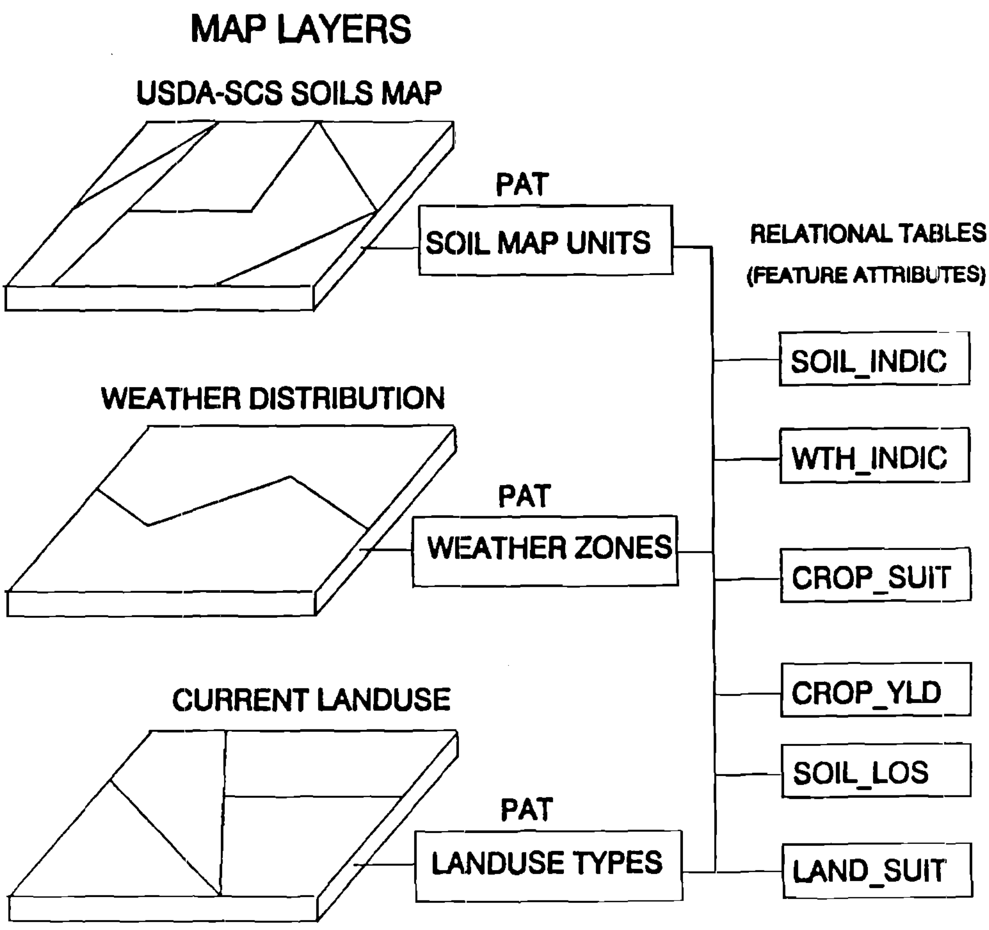

Figure 3. Coverages in AEGIS
(Reproduced from Lal et al., 1990)

THE USER INTERFACE

We have discussed so far the role and structure of several components of AEGIS. However, the integration of all these components into a coherent and useful decision making tool is done by the intelligent system supervisor.

Figure 4 presents the main functions of the interface: First, the user may select one of the three regions for which a production strategy will be evaluated. A default region (Mayaguez) is provided. Then, the user may define a strategy to be analyzed (crop, variety, planting/harvest dates, irrigation and fertilizer treatment...) and obtain the simulation results for all soils in the region. The user may also specify certain regional characteristics (soil group, land use...) to restrict the scope of the analysis to a smaller portion of the region. This option may be used, for example, to evaluate the potential of soils which are not in agricultural or urban use for producing the long-season variety of dry bean. The next step is to examine the results in tables and maps. If the crop performance predicted for all soils considered in the analysis satisfies the user's goals, then those tables and maps may be saved as a regional production plan. Otherwise, the user may designate the soil types which did not perform according to his/her objectives (if predicted yield is too low, or runoff is too high, for example) and save the remaining set as the production plan. The plan is thus an expression of the agricultural strategy(ies) that the user perceives as the most appropriate for the region considered. The user can change one or more of the strategy parameters and estimate the effect of these changes on production and environmental degradation predicted.

The user interface is composed of a bar-menu with four main options to which other pull-down menus are connected (Fig. 5). Under the "Select Parameters" option, users of AEGIS can select a region and specify the parameters of a strategy to be evaluated. For example, let's consider the case of a planner who needs to estimate the potential of soils for rainfed and irrigated long-season (LS) bean production in Mayaguez. The planner would use that option to select the appropriate region, crop variety, planting date and irrigation treatment. Then, with the "Analysis/Plans" option, the results of each strategy (crop productivity and environmental degradation by soil type) can be viewed as tables (Fig. 6) or maps (Figs. 7a and 7b). The same analysis could be carried out for short-season dry bean, and the planner would then have a larger set of options to compare. Hard copies of the maps and tables created during the exercise can be produced, thus allowing the planner to compare the results predicted by the models. Additionally, these results can be saved as a regional production plan, which can be modified at a later time. The "New Databases" option allows the user to create new sets of databases for new environments and management conditions using DSSAT.

The interface is designed using dBASE IV programming language, and pcARC/INFO small macro language (SML) for map production. AEGIS is designed as an interactive and flexible system which accommodates 'what if' queries from scientists, planners, and policy makers. However, a

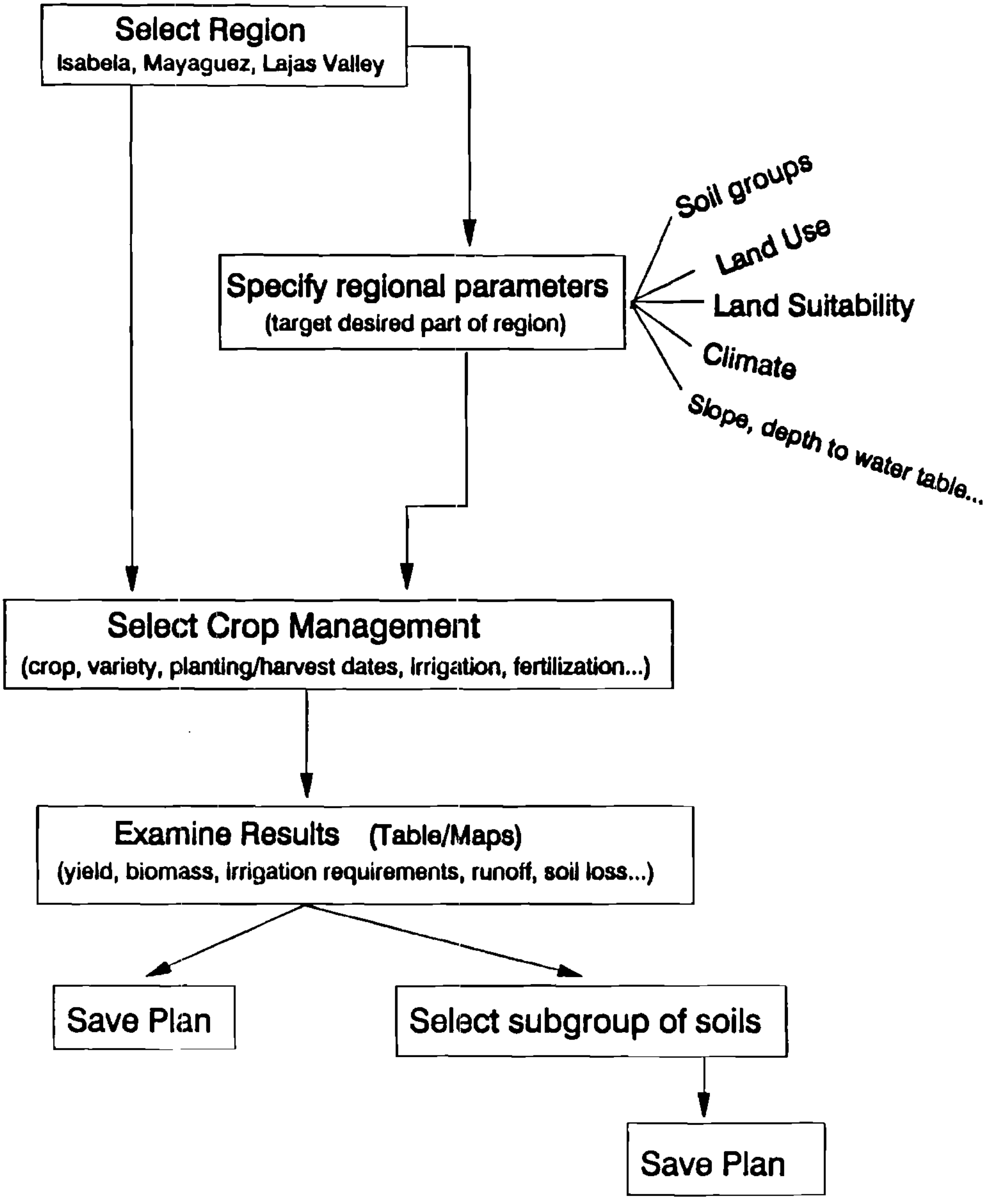

Figure 4. Flowchart for creating a Plan using AEGIS

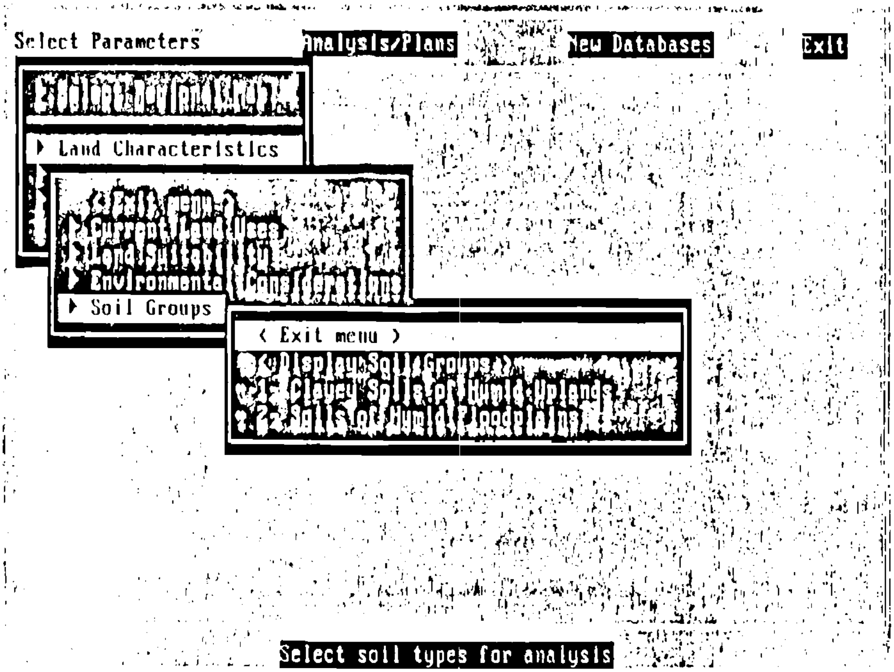

Figure 5. User Interface of AEGIS

STRATEGY RESULTS TABLE - Mayaguez

Crop 1 of 1: Beans (LS) Irrigated: No
Plant/Harv. dates: Apr 15 Jul 14 Fertilized: [illegible]

MAPSYM	GROUP	AREA	SAVE	YLD50	BIO50	IRR50	ET50	RUNOFF50
CuE	1	131.20	T	2.800	5.06	0	256	166.000
CoF2	1	5.69	T	2.870	5.16	0	258	125.000
HmD2	1	33.81	T	3.090	5.50	0	214	60.000
HmE2	1	9.24	T	3.090	5.50	0	214	60.000
LaB2	1	34.87	T	2.730	4.81	0	277	66.000
LaD2	1	62.92	T	2.700	4.79	0	276	124.000
MvC	1	0.77	T	2.500	4.50	0	271	93.000
MwE2	1	134.42	T	2.550	4.75	0	272	131.000
MwF2	1	0.89	T	2.550	4.75	0	272	131.000
MxC	1	2.75	T	2.990	5.32	0	277	90.000
MxF2	1	3.33	T	2.990	5.32	0	276	129.000
MxD2	1	3.00	T	2.990	5.32	0	276	129.000
MxE2	1	255.00	T	2.990	5.32	0	276	129.000
NcD2	1	10.02	T	2.860	5.00	0	275	56.000

F1 = Help F3 = Previous Crop F5 = Add/Remove Percentiles
F2 = Summary Table F4 = Next Crop ESC = Exit

Figure 6. Table of simulation results for long-season dry bean in Mayaguez. The columns represent the soil mapping unit symbols, their group number, area, plan status[4], and average values predicted for yield, biomass accumulation, irrigation requirement, evapotranspiration, and runoff.

[4] The plan status is a logical field which determines whether a soil type is saved in a plan. This is the only field in this table which can be edited by users of AEGIS.

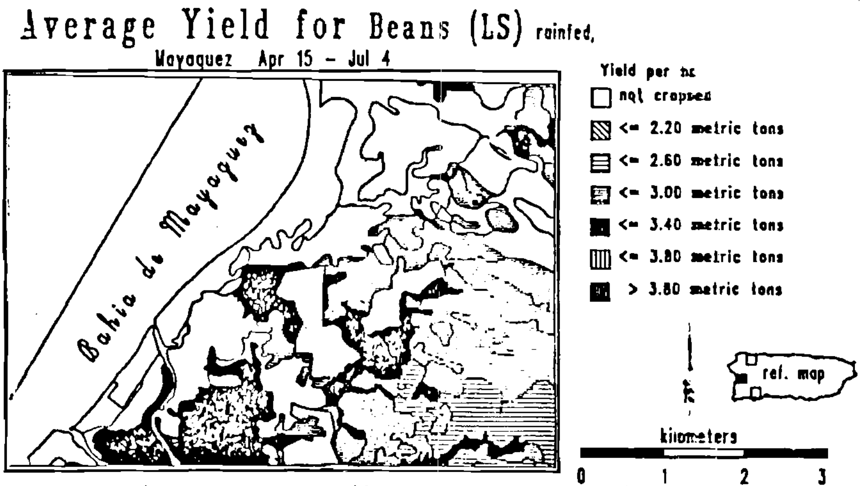

Figure 7a. Simulated average yield for dry bean under rainfed conditions.

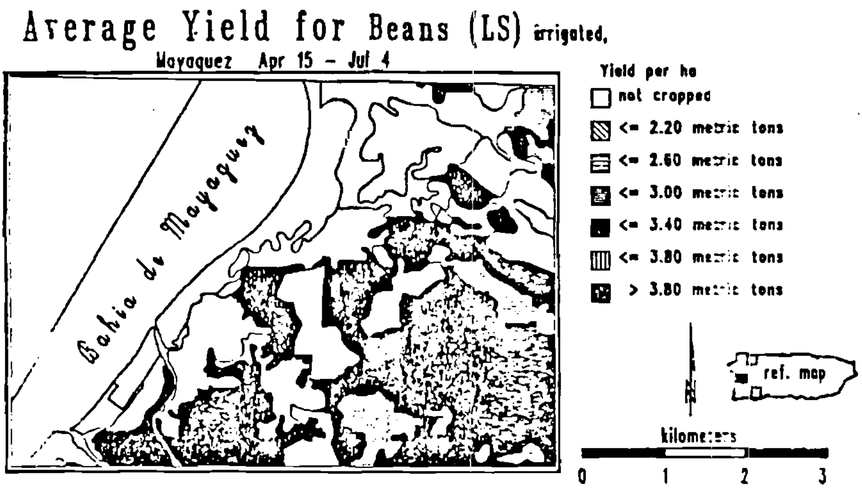

Figure 7b. Simulated average yield for dry bean under irrigated conditions.

complete description of its functions is beyond the scope and intent of this paper.

CONCLUDING REMARKS

AEGIS is a model-based Decision Support System designed to facilitate agricultural planning at the regional level. It integrates the capabilities of crop and soil models, a geographic information system, a database manager, and an expert system for evaluating different production alternatives and their impact on the environment. This prototype is under development for three areas of the island of Puerto Rico where sugarcane production is becoming non-profitable. The Land Authority of Puerto Rico is interested in alternative crops to replace sugarcane areas. Although only two crops are incorporated into AEGIS at this time, this system demonstrates the potential contribution of modern computer technologies to the solution of agricultural problems such as production planning, land use management, and agrotechnology transfer. As the crop and soil models which support AEGIS become more sophisticated, AEGIS will have greater potential as a tool for agricultural planning.

REFERENCES

ESRI. 1988. PC ARC/INFO Starter Kit. Environmental Systems Research Institute, Inc. Redlands, CA.

Fang, W., Ting, K.C., and Giacomelli, G.A. 1988. Animated Simulation Greenhouse Internal Transport Using SIMAN/CINEMA. Paper No. 88-7514. American Society of Agricultural Engineers, St. Joseph, MI.

Garland, E., Marth, N., and Shanholtz, V.O. 1990. Integrating Land Use/ Land Cover Data Into a GIS. Paper No. 90-3025. American Society of Agricultural Engineers. St. Joseph, MI.

Godwin, D.G., Thornton, P.K., Jones, J.W., Singh, U., Jagtap, S.S., Ritchie, J.T. 1989. Using IBSNAT's DSSAT in Strategy Evaluation. Proceedings of the IBSNAT Symposium: Decision Support System for Agrotechnology Transfer. October 17. Las Vegas, Nevada. pp. 59-70.

Halliday, S.L. and Wolfe, M.L. 1990. Assessing Groundwater Pollution Potential from Agricultural Chemicals. Paper No. 90-3023. American Society of Agricultural Engineers. St. Joseph, MI.

Hoogenboom, G., White, J.W., Jones, J.W., and Boote, K.J. 1990. BEANGRO VI.00: Drybean crop growth simulation model user's guide. Department of Agricultural Engineering, University of Florida, Gainesville, FL.

Hoogenboom, G. and Thornton, P.K. 1990. A Geographic Information System for Agrotechnology Transfer Applications in Guatemala. Unknown publisher.

IBSNAT Project. 1989. Decision Support System for Agrotechnology Transfer (DSSAT)--User's Guide. IBSNAT Project, University of Hawaii, Honolulu, HI. 317p.

Jones, J.W. and Ritchie, J.T. 1990. Crop Growth Models. In: Management of Farm Irrigation Systems. G.J. Hoffman, T.A. Howell, K.H. Solomon (eds.). American Society of Agricultural Engineers. St. Joseph, MI.

Jones, P., Hwang, Y., Jones, J.W., Bucklin, R.A. 1988. Greenhouse Environmental Control Using a Tomato Model. Paper No. 88-4058. American Society of Agricultural Engineers. St. Joseph, MI.

Lal, H., Jones, J.W., Beinroth, F.H., and Peart, R.M. 1990. Regional Agricultural Planning Information and Decision Support System. Proceedings of Conference on Application of Geographical Information Systems, Simulation models, and Knowledge-Based Systems for Land Use Management. November 12-14. Virginia Polytechnic and State University, Blacksburg, VA. pp. 51-60.

Ritchie, J.T. 1987. Using Crop Models as a Decision Support System to Reduce Nitrate Leaching. In: Rural Groundwater Contamination. F.M. D'Itri, Lois G. Wolfson (eds.). 11: 179-190.

Singh, U., Tsuji, G.Y., and Godwin, D.C. 1990. Planting New Ideas in DSSAT: The CERES-Rice Model. Agrotechnology Transfer. January 1990. 10: 1-7.

Thompson, S.J., Peart, R.M., and Mishoe, J.W. 1989. Expert System Coupling of Model and Sensor Based Technique for Irrigation Scheduling. Paper No. 89-7585. American Society of Agricultural Engineers. St. Joseph, MI.

USDA-SCS. 1980. Universal Soil Loss Equation--Technical Notes, Caribbean Area. USDA-SCS, GPO Box 4868, San Juan, PR.

Ventura, S.J., Chrisman, N.R., Connors, K., Gurda, R.F., and Martin, R.W. 1988. A land information system for soil erosion control planning. Journal of Soil and Water Conservation. May-June 1988, Volume 43, Number 3.

Wischmeier, W.H. and Smith, D.D. 1978. Predicting rainfall erosion losses. USDA Agricultural Handbook No. 537. 58p.

Wood, D.B., Covington, W.W., Tecle, A., Fox, B.E., and Gordon, C. 1989. Use of a Computer-Aided Decision Support System in Forest Plan Implementation. USDA Forest Service - Rocky Mountain Forest and Range Experiment Station. Fort Collins, CO 80526. General Technical Report RM-185. pp. 228-236.

Zhang, H., Nofziger, D.L., and Haan, C.T. 1990. Interfacing a Root-Zone Transport Model with GIS. Paper No. 90-3034. American Society of Agricultural Engineers. St. Joseph, MI.