AEGIS/WIN: A Computer Program for the Application of Crop Simulation Models Across Geographic Areas

Thomas Engel, Gerrit Hoogenboom,* James W. Jones, and Paul W. Wilkens

ABSTRACT

Computer-based biological simulation models have been used to calculate the effects of different management practices and land-use systems on agricultural production and to assess the impact of these practices on the environment. Using spatial visualization techniques to display simulation results can significantly improve the presentation and interpretation of these analyses. The objective of this study was to develop a computer program for the spatial application of crop models as well as the analysis and visualization of modeled results. The Agricultural and Environmental Geographic Information System for Windows (AEGIS/WIN) links the simulation system Decision Support System for Agrotechnology Transfer (DSSAT) v3 with the geographic mapping tool ArcView 2. The interface between the two systems was programmed using Avenue, an object-oriented macro programming language. This interface handles automatic data and command transfers between the simulation system and the mapping tool and does not require any modifications of DSSAT v3. The main spatial input for AEGIS/WIN is a coverage in the form of a digital map of a farm, a region, or any other area. DSSAT is used to create model input files and to execute the various crop management scenarios for the selected coverage. The crop model outputs can be imported and joined with the original selected land-use map in ArcView. The simulation results can be analyzed with AEGIS/WIN using simple statistics and bar charts. AEGIS/WIN's most important feature is the display of thematic maps of simulated crop yield, yield components, and other related agronomic and environmental variables. The system was applied to study the spatial yield variability of peanut (*Arachis hypogaea* L.) for a research farm in Georgia. AEGIS/WIN was shown to be an effective tool for the spatial application of crop simulation models and for the analysis and visualization of simulated outputs.

AGRICULTURAL LAND-USE PLANNING involves the determination of land-use practices that optimize economic as well as ecological conditions. These practices could be applied at a field, farm, watershed, regional, or other scale. To determine the best land-use practices, one must take into consideration the economic sustainability of the farmer as well as the ecological conditions of the environment. Among the tools that can be used to help solve some of these issues are computer-based biophysical simulation models. Such crop simulation models calculate crop growth and yield, as well as the soil and plant water and nutrient balances, as a function of environmental conditions and crop management practices. Traditionally, these models have been applied to point data, and the data inputs of most models do not represent the spatial variability of the environment. However, most of the simulated results usually have a spatial dimension, as they are obtained for multiple fields or other regional scale. The visualization of simulation results by using maps of farms or regions could significantly improve the understanding and interpretation of these simulation results. This requires a computer system that can organize data, define land-use practices across a spatial scale, simulate responses to alternative agricultural practices, and analyze and present simulated results.

During the last few years, decision support systems have been developed that evaluate the impact of agricultural practices at a regional context. Usually these systems combine databases and expert systems with a geographic information system (GIS). Some of these systems, such as the Jamaica Geographic Information System (JAMGIS; Batjes, 1989) and the Dominican Republic Expert Agricultural Geographic Information System (DREAGIS; Mendez and Grabski, 1992), contain only databases and maps. They are specifically designed for land-use evaluation in these countries. The

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Abbreviations: AEGIS, Agricultural and Environmental Geographic Information System; AEGIS/WIN, Agricultural and Environmental Geographic Information System for Windows; DSSAT, Decision Support System for Agrotechnology Transfer; ESRI, Environmental Systems Research Institute; GIS, geographic information system; IBSNAT, International Benchmark Sites Network for Agrotechnology Transfer; MB, megabyte; RAM, random access memory; v, version.

Agricultural and Environmental Geographic Information System, AEGIS (Calixte et al., 1992; Lal et al., 1993), includes crop models to calculate the impact of different land-use strategies, but is limited to three regions of Puerto Rico. AEGIS_2 (Papajorgji et al., 1993) is a more generic system for use in different geographic areas and combines the crop models of DSSAT v2.5 (Hoogenboom et al., 1995) with the GIS software ARC/INFO[1] (ESRI, 1993). Hoogenboom et al. (1993) and Wei et al. (1994) developed various GIS and crop model linkages for application of crop models at the scale of research or farmers' fields.

Other GIS and crop model linkages have been reported by Bachelet et al. (1993), Carbone et al. (1996), Han et al. (1995), Magnusson and Söderström (1994), Singh et al. (1993), and Stoorvogel (1995). For the crop modeler, a disadvantage of most of these systems is that they require considerable GIS knowledge. Some systems also use Unix-based ARC/INFO (Carbone et al., 1996; Wei et al., 1994), DOS-based PC-ARC/INFO (Han et al., 1995; Hoogenboom et al., 1993), or other GIS software packages that are very expensive for users without major institutional support.

The main objective of this project was to develop a computer system that links existing crop simulation models with a geographic mapping tool to create a new decision support system for the analysis and visualization of spatially varying land characteristics, land-use management, and agricultural production. The resulting software was named AEGIS/WIN (an acronym for Agricultural and Environmental Geographic Information System for Windows). This paper describes the design and functionality of AEGIS/WIN and presents an application.

[1]Trade names and company names are included for the benefit of the reader and do not imply endorsement or preferential treatment of the product by the Technische Universität München, the University of Georgia, the University of Florida, or the International Fertilizer Development Center.

SYSTEM DESIGN

AEGIS/WIN is a decision support system that links the geographic mapping tool ArcView 2 (ESRI, 1994a) with the Decision Support System for Agrotechnology Transfer v3 (DSSAT) (Hoogenboom et al., 1994a; Tsuji et al., 1994). The main components of AEGIS/WIN are shown in Fig. 1. AEGIS/WIN is run from the Microsoft Windows (MS-Windows) interface, and handles the user's selection of the land-use map and management scenarios, as well as the data exchange between spatial data of coverages and the crop model input and output data. The system allows the use of existing digital maps (ARC/INFO polygon coverages) or creation of new maps by tracing field borders of background maps, photographs, or satellite images. Within the system, the user can access DSSAT v3 to create management inputs for each individual field of a selected land-use map, store this information in an experimental details file, and run simulations with the crop models. After the model runs have been completed, the user can perform statistical analysis of the simulation results for all important agronomic variables, display the individual variables in thematic maps, and create tables or charts. A list of crop model calculated variables that can be analyzed and displayed is presented in Table 1.

DSSAT v3 is a well-validated crop simulation system that has been used worldwide in research, teaching, and extension programs (Bowen et al., 1996; IBSNAT, 1993; Thornton et al., 1995a; Tsuji et al., 1994). It contains 11 crop models, including the grain cereal CERES and the grain legume CROPGRO models, all of which use a standard format for crop model inputs and outputs (Hoogenboom et al., 1994b; Jones et al., 1994). These standard crop model data formats have also been adopted by other groups, including the International Consortium for Agricultural Systems Applications (ICASA), the Free-Air CO_2 Enrichment (FACE) project, and the Global Change and Terrestrial Ecosystems (GCTE) group of the International Geosphere–Biosphere Programme (Jones and Tsuji, 1996; Kimball et al., 1992). The output data as described

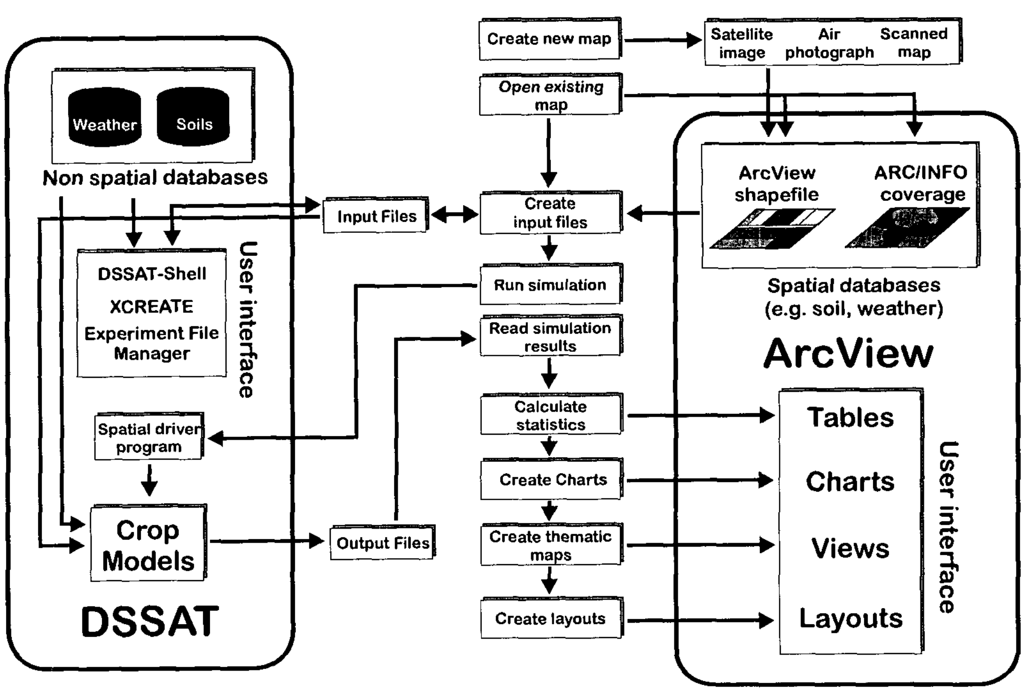

Fig. 1. Main components of AEGIS/WIN (the Agricultural and Environmental Geographic Information System for Windows).

in Table 1 have been used by Thornton and Hoogenboom (1994) for the seasonal application of crop models and by Thornton et al. (1995b) for crop rotations.

ArcView is a geographic mapping tool developed by Environmental Systems Research Institute, Inc. (ESRI, 1993). It is an easy to use, low-cost system and is available for different computer platforms, including MS-Windows and UNIX. ArcView supports existing ARC/INFO coverages and includes tools to create new polygon coverages based on the ArcView shapefile format. ArcView provides functionality to develop new applications through the use of Avenue, an object-oriented macro scripting language (ESRI, 1994b).

AEGIS/WIN is written in Avenue and contains more than 80 unique scripts that are compiled and stored in a project file. The unique features of AEGIS/WIN consist mainly of linkages between DSSAT v3 and ArcView (Fig. 1). These linkages include automatic data and command transfer between DSSAT v3 and the mapping tool. When the user starts DSSAT for the creation of management input files, AEGIS/WIN allows access only to the information for the selected map. The ArcView environment was modified to allow for land-use evaluations and to improve user interactions. Many functions of AEGIS/WIN, such as changing legends (classification, colors, etc.), joining result tables, or creation of thematic maps, were modified and enhanced through Avenue and are more user-friendly than in the standard ArcView 2 environment.

PROGRAM OPERATION

Maps and Spatial Data

Digital spatial data are the most critical part of an AEGIS/WIN application. Spatial data are georeferenced data that store the geometric location of particular features, along with attribute information describing what these features represent. A digital map consists of a graph of a two-dimensional planar region subdivided in polygons; there is a one-to-one correspondence between the polygons and a record in a database file called polygon attribute table. The map can be viewed in a variety of ways that highlight similarities and differences between polygons. The polygons correspond to the individual fields of a farm or plots and are defined individually in the field section of the experimental details file of the DSSAT crop models.

ArcView supports ARC/INFO coverages (ESRI, 1993) and ArcView shapefiles (ESRI, 1994a) as spatial data formats. ARC/INFO coverages are topological data structures for geographic features. Their format is one of the most popular and widely available data formats in digital mapping and GIS applications. They contain size, perimeter and geographic coordinates for each polygon. ArcView can use existing ARC/INFO coverages or other compatible GIS (e.g., by digitizing or overlaying existing maps). ArcView shapefiles are simple, nontopological formats for storing geometric location and attribute information of geographic features. The disadvantage of the shapefile format is that it does not store topological information, such as the size (i.e., area) of the polygon. The advantage of shapefiles is that one can create new digital maps by tracing or drawing polygons on the computer monitor if the user has no access to other digital geographic data sources.

The first step in working with AEGIS/WIN is to im-

Table 1. Variables calculated by the crop simulation models that can be used for analysis and visualization.

Variable name	Short description	Units†	Long description
TNAM	TREATMENT NAME		Treatment title
FNAM	FIELD NAME		Field name
SDAT	SIMULATION DATE	YrDOY	Simulation starting date
PDAT	PLANTING DATE	YrDOY	Planting date
ADAT	ANTHESIS DATE	YrDOY	Anthesis date
MDAT	MATURITY DATE	YrDOY	Physiological maturity date
HDAT	HARVEST DATE	YrDOY	Harvest date
DWAP	SOWING WT	kg DM ha^{-1}	Weight of planting material
CWAM	TOPS WT	kg DM ha^{-1}	Weight of aboveground biomass at maturity
HWAM	MAT YIELD	kg DM ha^{-1}	Yield at maturity
HWAH	HAR YIELD	kg DM ha^{-1}	Yield at final harvest
BWAH	BYPRODUCT	kg DM ha^{-1}	Dry weight of harvested by-product, such as straw
HWUM	WEIGHT	mg DM unit^{-1}	Individual weight of harvest product at maturity
H#AM	NUMBER	no. m^{-2}	Number of harvest products at maturity
H#UM	NUMBER	no. unit^{-1}	Number of harvest products per unit (e.g., no. seed pod^{-1})
IR#M	IRRIG APPS	no.	Total number of irrigation applications
IRCM	IRRIG	mm	Total amount of irrigation applied
PRCM	PRECIP	mm	Total amount of precipitation
ETCM	ET TOTAL	mm	Total amount of evapotranspiration
ROCM	RUNOFF	mm	Total amount of surface runoff
DRCM	DRAINAGE	mm	Total amount of drainage from the profile
SWXM	EXTR WATER	mm	Total extractable soil water at maturity
NI#M	N APPLICATION	no.	Total number of N fertilizer applications
NICM	TOT N APP	kg N ha^{-1}	Total amount of inorganic N fertilizer applied
NFXM	N FIXED	kg ha^{-1}	Total amount of N fixed during season
NUCM	N UPTAKE	kg N ha^{-1}	Total amount of N uptake during season
NLCM	N LEACHED	kg N ha^{-1}	Total amount of N leached during season
NIAM	SOIL N	kg N ha^{-1}	Total amount of inorganic N present in the soil profile at maturity
CNAM	TOPS N	kg ha^{-1}	Total amount of N in aboveground biomass at maturity
GNAM	GRAIN N	kg ha^{-1}	Total amount of N in the grain at maturity
RECM	RESIDUE	kg ha^{-1}	Total amount of organic residue applied
ONAM	ORGANIC N	kg ha^{-1}	Total amount of organic N in the soil profile at maturity
OCAM	ORGANIC C	t ha^{-1}	Total amount of organic C in the soil profile at maturity
PO#M	P APPLICATION	no.	Total number of P fertilizer applications
POCM	P APPLIED	kg ha^{-1}	Total amount of P fertilizer applied
CPAM	TOPS P	kg ha^{-1}	Total amount of P in aboveground biomass at maturity
SPAM	SOIL P	kg ha^{-1}	Total amount of P in the soil profile at maturity

† DM, dry matter; YrDOY, year and Day of Year.

port a polygon coverage or create a shapefile for the farm or the area which will be used for the crop model application. The user has to add codes to identify soil and weather stations to the polygon attribute table. The soil code represents the soil profile characteristics for a polygon; the weather station code represents weather or climatic conditions for that particular polygon. It is assumed that both the soil conditions and weather conditions are homogeneous within each polygon. If this assumption is incorrect, the size of the polygons has to be reduced until this condition is met. The details of soil and weather or climate also have to be defined in the DSSAT system before the crop models can operate.

A user without access to geographic data sources can create (draw) a new map based on a shapefile format. An image (such as a scanned map, aerial photograph, or satellite image) can be used as a background on the computer monitor for drawing polygons or tracing boundaries of fields. A record is automatically added to the attribute table for each newly drawn polygon. This record contains empty fields for a primary key (e.g., the number of the field), soil profile code, weather station code, and size of the polygon. If the areas of the fields are known, they should be entered as well, so that the area-weighted statistics for simulation results can be computed.

Management Input Files

The user must define crop management scenarios for each polygon of the map. AEGIS/WIN uses DSSAT v3 for the creation of crop model input files. DSSAT has a special option and associated data directory to handle crop management input files needed for AEGIS/WIN. When a map is opened in AEGIS/WIN, a pointer is set to make sure that DSSAT accesses only the corresponding data of the selected map or coverage. One file, referred to as the experimental details file, contains crop management information for any or all fields (or polygons) of a map. This file contains information on when crops are grown in each field, as well as how each field is managed. One land-use map can have several experimental details files associated with it, each representing different land-use plans. The experimental details file can be created using a special program provided in DSSAT v3 (or, if one is familiar with the format of this file, using any text editor). The primary key in the polygon attribute table of the map must be used as field identifier in the *FIELDS section of this file. AEGIS/WIN can handle up to 999 fields and their corresponding management inputs for a single land-use map.

Simulation Runs

After the crop management input files have been created for a particular coverage, AEGIS/WIN can run either a selected number of fields or all fields. AEGIS/WIN uses a modification of the seasonal analysis program of DSSAT v3 (Thornton and Hoogenboom, 1994) to run the crop simulations. The user has to select a spatial management plan from a list that contains a brief summary of all defined crop management scenarios. AEGIS/WIN reads the selected crop management input file and writes soil and weather codes from the polygon attribute table into the crop management input file. For each individual field, the particular model for the crop being grown is called and one or more simulations are made, depending on how many years have been selected. Fields can be selected either through the map or the attribute table associated with that map. Because the DSSAT crop models are DOS-based programs, the progress of simulation runs and the final simulation results can be viewed in a DOS window in AEGIS/WIN.

Simulation Outputs

The summary output file of the crop simulation models is an ASCII file, defined in the DSSAT v3 output format (Jones et al., 1994). For further analysis and visualization of these data, the summary output file has to be imported into two internal INFO tables. These INFO tables have descriptive headers and are required for the statistical analysis. The simulation result table usually contains several result lines for each field, because most simulations are run for more than one year or for multiple single seasons. Each weather year is considered a different environment and is treated as an individual replicate in the analysis. A second table is automatically created that contains the simulation results averaged for each individual field.

Statistics

AEGIS/WIN can calculate simple statistics (e.g., average, standard deviation, maximum, minimum) for each individual polygon, as well as area-weighted statistics for the entire coverage. The result tables of the statistical functions can be used for the creation of charts, because they already contain summarized and condensed information (the original simulation result tables usually contain too much information to produce an easily understandable and clear chart).

Creation of Thematic Maps

One of the main objectives for the development of AEGIS/WIN was to be able to create thematic maps, which help the user to understand and interpret the simulated results. This component is, therefore, the most important and extensive part of AEGIS/WIN. Before the simulation results can be displayed for a particular map, its attribute table has to be joined to the simulation result table. After joining of the tables, the title of the map is changed to indicate which table was joined. Results of different simulations can be compared in two different ways. The user can open one map, join it to the table of the first set of simulations, and study the results; the user then unjoins this table and joins to the table with the second set of simulations and studies these results. The second option is to open the same map twice and to join one map with the first set of results and the other map with the second result table. This latter method is much more convenient. After joining the tables, thematic maps can be created for all

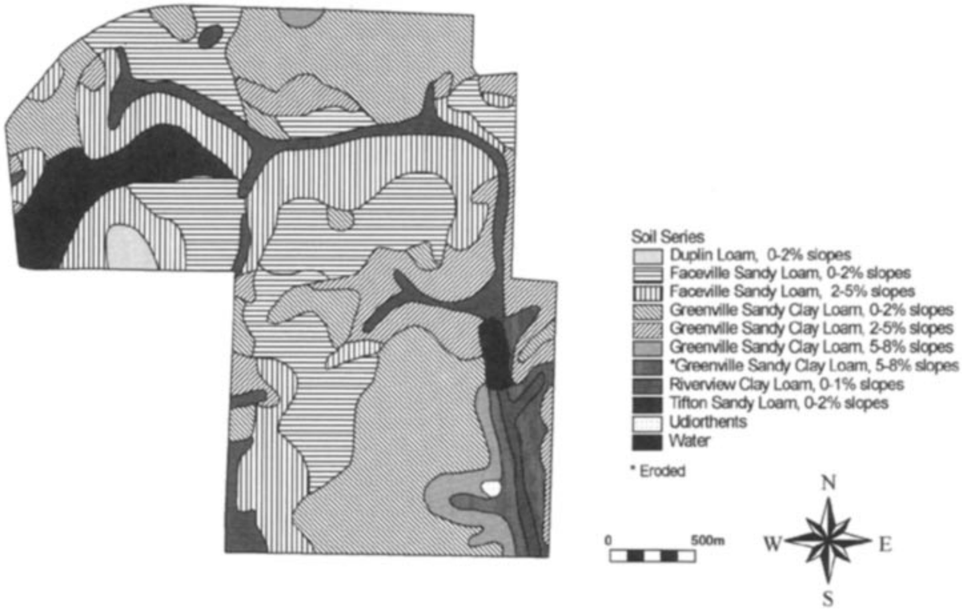

Fig. 2. Soils map of the Southwest Exp. Stn. at Plains, GA. Soil series: Duplin l (Aquic Paleudults); Faceville sl (Typic Kandiudults); Greenville scl (Rhodic Kandiudults); Riverview cl (Fluventic Dystrochrepts); Tifton sl (Plinthic Kandiudults).

variables of the simulation result table simply by clicking on menu items of the Simulations Results menu. Examples for the use of thematic maps are given in the application section.

APPLICATION

Experimental Design

To illustrate the use of AEGIS/WIN, a simulation experiment was performed using DSSAT's peanut simulation model CROPGRO–Peanut (Boote et al., 1989; Hoogenboom et al., 1992, 1994b) for the Southwest Experiment Station at Plains, GA. A detailed soils map presented by Perkins et al. (1978) was digitized by Wei et al. (1994) (Fig. 2). The land-use or experimental plot map of the same farm was scanned and also digitized using ARC/INFO (Fig. 3). ARC/INFO for Unix was used to overlay the two maps; this resulted in a map or coverage that included 173 homogeneous polygons with the same soil type and the same land use within each individual polygon, but different soil types and land uses between the polygons. For each unique soil type, a one-dimensional soil profile data set was created, using the soil data entry program of DSSAT v3 (Tsuji et al., 1994). The file that contains the soil data, representing both the physical and chemical characteristics of the soil surface and soil layers, was kept external to ArcView in an ASCII file that could be used directly by the crop models. In addition, a crop management file was created, containing management information for all indi-

Fig. 3. Field plot map of the Southwest Exp. Stn. at Plains, GA. Numbers correspond to individual plot identifiers; No. 15 is the irrigation pond.

Fig. 4. Average spatial yield variability (1975–1994) for a rainfed peanut crop grown at the Southwest Exp. Stn. at Plains, GA.

vidual plot units. Historical weather data collected by the National Weather Service and by weather stations of the Georgia Automated Environmental Monitoring Network (Hoogenboom, 1996) were converted into yearly weather files, containing daily maximum and minimum air temperature, precipitation, and solar radiation, for use with the DSSAT crop models.

Experimental data provided with CROPGRO–Peanut showed that the model adequately responds to various levels of irrigation management (Boote et al., 1989; Fortson et al., 1989; Hoogenboom et al., 1991; Hook, 1994). Because drought can be a serious problem for peanut production in Georgia, two different scenarios were run. The first one was rainfed, with no supplemental irrigation. The second scenario assumed that the crop was irrigated, using an automatic irrigation procedure that is included in the crop models (Hoogenboom et al., 1991). Only a limited set of 36 fields was selected, resulting in a total of 125 homogeneous polygons out of 173. Twenty years of weather data (1975 through 1994) were used for the simulations. Each simulation was started on 1 January, to allow the soil profile to reach a soil water equilibrium. The crop was planted on 1 May, at a row spacing of 0.75 m and a plant density of 12.5 plants m^{-2}. The cultivar was Florunner. These management conditions correspond to those used in regular field trials for peanut (Raymer et al., 1995).

Results

Fields 7, 8, 11, 38, 42, and 43 (Fig. 3) were not cropped and are therefore not shaded in the thematic maps for yield, irrigation demand, and N leaching (Fig. 4, 5, 6, 7, and 8). Spatial seed yield variability of the rainfed crop

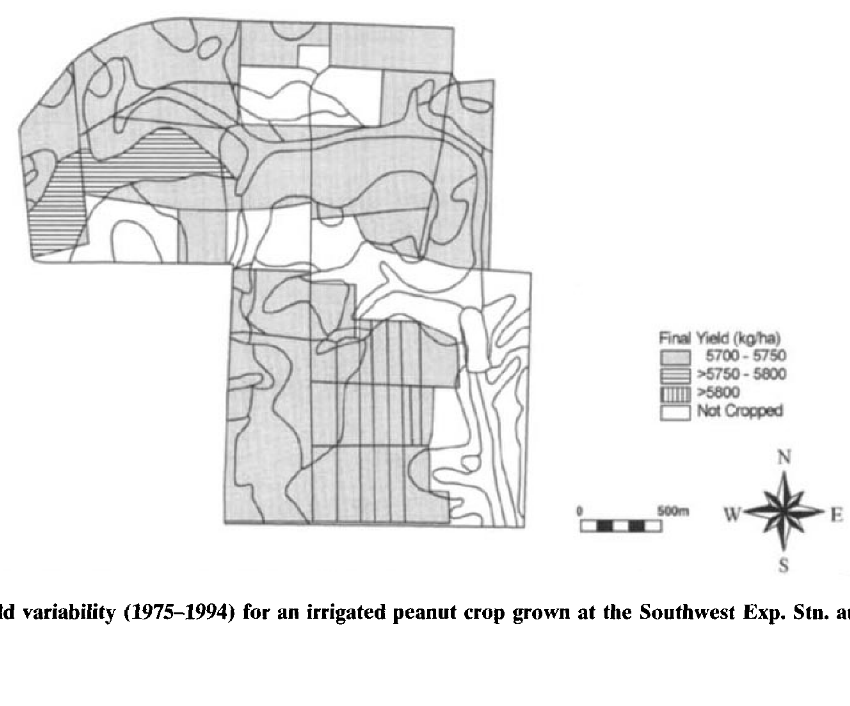

Fig. 5. Average spatial yield variability (1975–1994) for an irrigated peanut crop grown at the Southwest Exp. Stn. at Plains, GA.

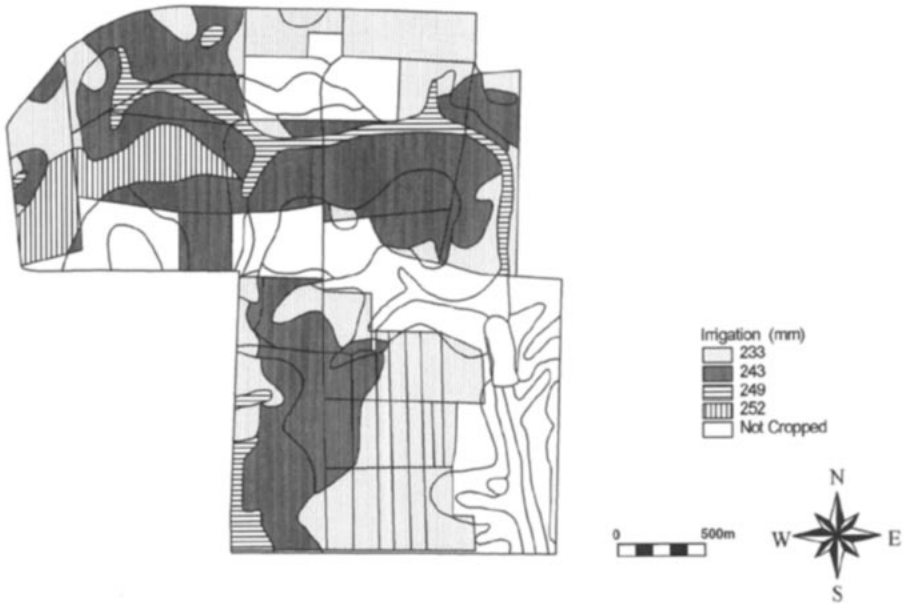

Fig. 6. Average irrigation demand (1975–1994) required for an irrigated peanut crop grown at the Southwest Exp. Stn. at Plains, GA.

was produced by AEGIS/WIN and is presented in Fig. 4. Seed yields averaged over 20 yr varied between 3200 and 3600 kg ha^{-1}. These results give the impression that the soils of the Southwest Experiment Station are fairly similar, with only small differences in water-holding characteristics. The lowest yields were found on the Faceville sandy loam, and the highest yields were found on the Tifton sandy loam and on the Greenville sandy clay loam with a slope of 0 to 2% (Fig. 2 and 4). This information should be verified with field-measured data, although continuous yield data for 20 yr do not exist for this location. Table 2 presents summary statistics for the farm as simulated by AEGIS/WIN. The average seed yield was 3380 kg ha^{-1}, with a minimum and maximum yield of 1206 and 5611 kg ha^{-1} and a standard deviation of 1249 kg ha^{-1}. This shows that, under rainfed conditions, yield can vary significantly from year to year and can create a high risk for farmers, especially during dry summers.

Average seed yield for the irrigated conditions varied between 5700 and 5800 kg ha^{-1} (Fig. 5). Yields for all soil types varied only between 5700 and 5750 kg ha^{-1} except for the Tifton sandy loam (Fig. 2 and 5). The overall average yield was 5739 kg ha^{-1} (Table 3), about 2360 kg ha^{-1} higher than for the rainfed conditions. Annual average seed yield varied between 4863 and 6434 kg ha^{-1}, with a standard deviation of 353 kg ha^{-1}. As expected, irrigation reduced the yearly yield variability and therefore the risk for a farmer. The average number of irrigation applications was 10, with an average of 239 mm irrigation applied per season (Table 3). Total irrigation demand to grow peanut under nonstress conditions was a correlated to soil type (Fig. 6). The lowest amount of irrigation required was for the Green-

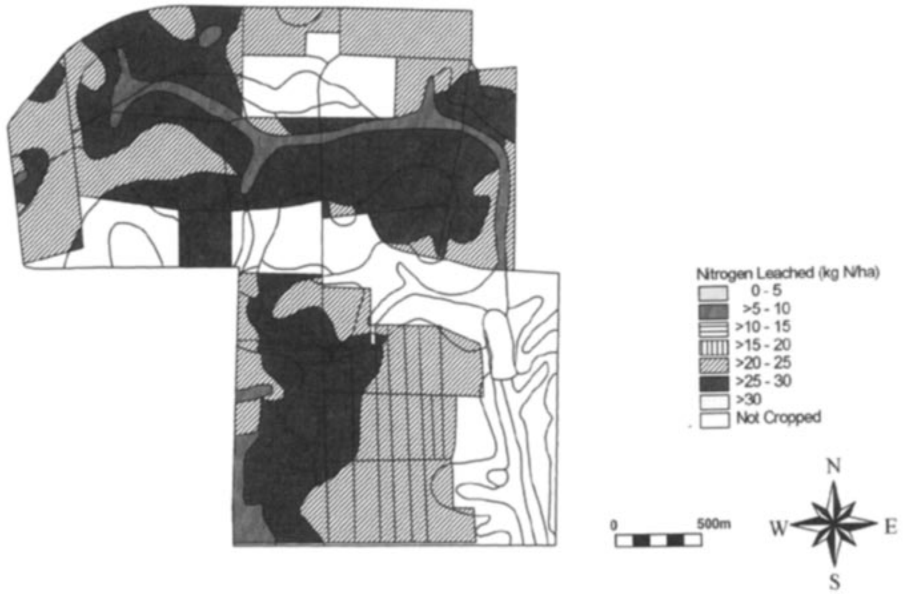

Fig. 7. Average N leached (1975–1994) for a rainfed peanut crop grown at the Southwest Exp. Stn. at Plains, GA.

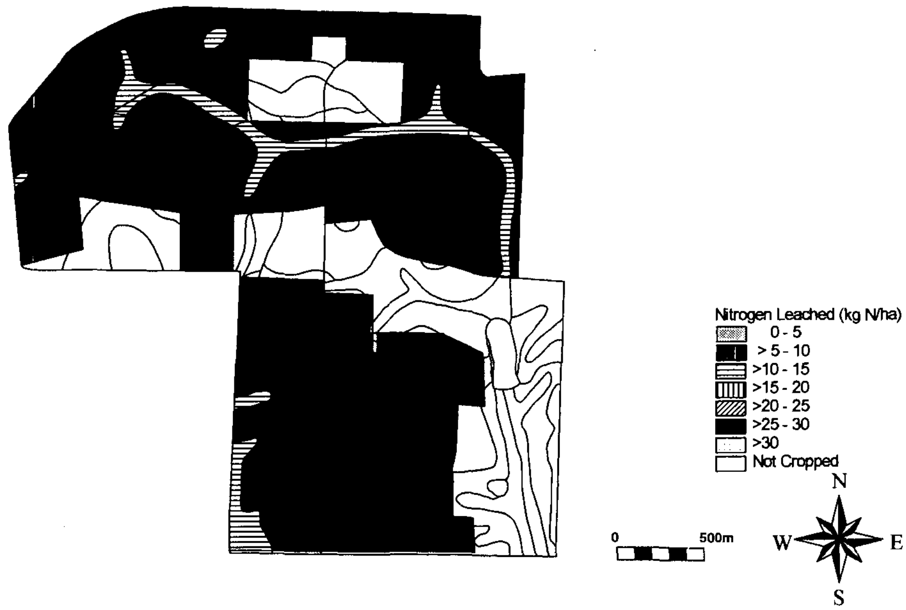

Fig. 8. Average N leached (1975–1994) for an irrigated peanut crop grown at the Southwest Exp. Stn. at Plains, GA.

ville sandy clay loam with a slope of 0 to 2%; the highest amount of irrigation required was for the Tifton sandy loam (Fig. 2 and 6). These two soils were the highest-yielding soils for the rainfed conditions (Fig. 2 and 4).

AEGIS/WIN also allows the user to evaluate the environmental impact of certain management scenarios. Although no supplemental N fertilizer was applied to the peanut crop simulated in this example, some N was leached to the ground water. For the rainfed conditions, the Riverview clay loam had the least amount of N leached and the Faceville sandy loam had the highest amount of N leached (Fig. 7). For irrigated conditions, all soil types showed the same leaching potential, except for the Riverview clay loam, which had a slightly lower amount of N leached to the groundwater (Fig. 8). There does not seem to be a relation between total amount of supplemental irrigation applied and N leached (Fig. 6 and 8).

DISCUSSION

All tabular data were created directly by AEGIS/WIN, although it would have not been necessary to use a geographic mapping tool to produce statistical outputs. However, the maps of AEGIS/WIN contain much detailed information and can demonstrate the potential interaction between soil type or other environmental variables and the management scenarios applied to those conditions. The maps showed the spatial distribution of yield for the different fields, as well as for the different soils (Fig. 4 and 5). The user can immediately recognize that the effect of the soil characteristics on yield is much higher than the influence of the man-made field boundaries. The maps also can show the effect of applying supplemental irrigation to avoid drought stress (Fig. 5 and 6). It can be recognized from the maps that the Faceville sandy loam (Fig. 2), which is a sandy soil with low water capacity, has the lowest yield under rainfed conditions (Fig. 4). In the irrigated scenario, the yield for this soil increased significantly and no differences were found, except for the Tifton sandy loam (Fig. 3 and 5). Thus, the visualization shows quickly that irrigation was more effective for some soils than others, and shows clearly which soils these are. Additional thematic maps that show irrigation demand can also help the user find an explanation for some of these interactions between soil type and yield. Other soils, such as the Riverview clay loam and Tifton sandy loam, actually received more supplemental irrigation (Fig. 2 and 6).

The main objective for the development of AEGIS/WIN was to provide a tool for the application and visualization of crop simulation results based on available simulation and geographic mapping tools. The system combines the widely used DSSAT v3 system (Tsuji et

Table 2. Calculated summary statistics for peanut production under rainfed conditions for 1975 through 1994 at the Southwest Experiment Station at Plains, GA.

Variable†	Avg.	SD	Max.	Min.
Final seed yield, kg ha^{-1}	3 380	1 249	5 611	1 206
By-product harvest, kg ha^{-1}	10 159	2 550	15 029	5 121
Anthesis, DAP	38	2	44	34
Harvest, DAP	140	4	149	133
Final seed number, no. m^{-2}	673	198	971	299
Seed size, mg seed^{-1}	493	64	609	493

† DAP, days after planting.

Table 3. Calculated summary statistics for peanut production under irrigated conditions for 1975 through 1994 at the Southwest experiment station in Plains, GA.

Variable†	Avg.	SD	Max.	Min.
Final seed yield, kg ha^{-1}	5 739	353	6 434	4 863
Aboveground biomass, kg ha^{-1}	15 896	890	17 438	13 878
Anthesis, DAP	38	2	44	34
Harvest, DAP	143	3	152	138
Final seed number, no. m^{-2}	1 007	57	1 119	861
Seed size, mg seed^{-1}	570	26	645	509
Season irrigation, mm	239	6	252	233
Irrigation applications, no.	10	1	11	10

† DAP, days after planting.

al., 1994) with the geographic mapping tool ArcView 2 (ESRI, 1994a). AEGIS/WIN proved to be an easy to use and powerful tool to study the effect of different management scenarios for a given spatial environment using tables, charts, and thematic maps. In particular, the visualization of simulation results using thematic maps helps the user to better understand and interpret different scenarios in an efficient way.

The use of GIS is often limited by the availability of geographic data sources (Lathrop et al., 1995). In linked GIS–model systems, the scale of the application could also become a problem (Wagenet and Hutson, 1996). It is very difficult, very expensive, and often impossible to obtain coverages or georeferenced data such as soil or land use maps at the farm level. With recent improvements in global positioning systems (GPS), generating digital maps has become easier. AEGIS/WIN, however, offers an important additional option: The user can create a shapefile for his farm or region. The shapefile format does not contain topological details, such as the size of the polygon; however, this is no disadvantage for the visualization of simulation results using thematic maps, because the user is mainly interested in the spatial distribution of parameters. With AEGIS/WIN, the user can scan a map or an air photograph, load it into AEGIS/WIN as a background image, and then trace the field borders to obtain polygons of all the fields. These capabilities, as well as the user-friendly interface of ArcView, increase the functionality for potential users, especially in comparison with older AEGIS versions (Calixte et al., 1992; Lal et al., 1993).

A user who wants exact georeferenced data still has to use a GIS, such as ARC/INFO, to digitize and overlay maps (similar to the procedures discussed in our example section, above). The next revision of ArcView GIS (version 3.0) is expected to remove these limitations of AEGIS/WIN by adding digitizer support and a spatial analyst (used to calculate the area of polygons, for example). We are planning to upgrade AEGIS/WIN to operate in ArcView GIS 3.0 in the near future, so that AEGIS/WIN can function as a true GIS system.

Older versions of AEGIS used the crop simulation models of DSSAT v2.1 (Hoogenboom et al., 1992; Lal et al., 1993). AEGIS/WIN includes the DSSAT v3 crop models that are written in Fortran and use the standard crop model inputs and outputs as defined by the IBSNAT Project (Jones et al., 1994). Therefore, it is easy to adapt AEGIS/WIN for use with other crop simulation models, as long as they use the same standard input and output format. As part of the ICASA initiative (Jones and Tsuji, 1996), crop models for sunflower (*Helianthus annuus* L.), sugarcane (*Saccharum* spp.), and tomato (*Lycopersicon esculentum* Mill.) have also been integrated with DSSAT v3. Any model that operates under the DSSAT modeling system will work with AEGIS/WIN.

AEGIS/WIN is used to visualize the results of the DSSAT crop models. These crop models include soil modules that simulate only vertical water and nutrient flow in the soil profile. It is assumed that the simulation results are valid for homogeneous areas with the same conditions; lateral fluxes are not considered in these models. This simplification is reasonable for flat areas, but it can cause erroneous results for sloping or hilly fields, where runoff from upper areas of the field can be an input for the lower areas. Other limitations concern the use of the DOS-based DSSAT for data handling and simulation in combination with different user interfaces for the various DSSAT components. A useful further development would be to create a Windows-based program for the creation of input files. Potential users are also reminded that the quality of the program results will depend on the integrity of the models used and on the quality of the available input data.

It is easy for experienced users of DSSAT v3 or ArcView 2 to learn to work with AEGIS/WIN (Bowen et al., 1996). Furthermore, ArcView 2 provides the user with a quick and comfortable environment for the development of spatial crop model applications. It is possible to customize ArcView 2 and to develop applications in a short period of time using the Avenue programming language (ESRI, 1994b).

DOCUMENTATION

Detailed documentation is presented in a user's guide distributed with AEGIS/WIN (Engel and Jones, 1995) and DSSAT v3 (Tsuji et al., 1994).

Hardware and Software Requirements

AEGIS/WIN runs on a DOS-compatible microcomputer (80386 or higher). It requires at least 30 MB of free space on the hard disk. This includes space necessary for the installation of DSSAT v3 (20 MB), ArcView 2 without sample data (9 MB), and AEGIS/WIN and the included sample data (1 MB). (Disk space requirements may increase considerably as new coverages and weather data files are added to AEGIS/WIN.) ArcView 2 requires a minimum of 8 MB random access memory (RAM), but 12 to 16 MB are recommended for satisfactory performance. A Microsoft-compatible mouse is necessary. The operating systems and software required for the operation of AEGIS/WIN are DOS 3.1 or higher, MS-Windows 3.1 or higher, DSSAT v3 (Tsuji et al., 1994) and ArcView 2 (ESRI, 1994a). AEGIS/WIN also runs under the Windows 95, Windows NT, and OS/2 Warp operating systems.

Availability

AEGIS/WIN v2 software, together with a user's manual and sample input files, are distributed as part of DSSAT v3. Contact the IBSNAT Project (Dep. of Agronomy and Soil Science, Univ. of Hawaii, Honolulu, HI 96822; e-mail ibsnat@hawaii.edu) for information about ordering AEGIS/WIN and DSSAT.

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