Input Optimization and Crop Management Using Decision-support System GLYCIM/GUICS

V. R. Reddy[1] and Y. A. Pachepsky[2]
[1]Remote Sensing and Modeling Laboratory, USDA:ARS, Building 007, Room 008, BARC-West, Beltsville, Maryland, USA
[2]Duke University Phytotron, Duke University, Durham, North Carolina, USA

Agricultural decision-aids have to be flexible enough to handle a multitude of management practices available to farmers. Mechanistic crop simulators can be an essential part of such tools. We developed an on-farm decision-aid using the mechanistic, process-level soybean crop simulator, GLYCIM. This model has a generic modular structure and is organized in modules along disciplinary lines. In 1991, GLYCIM was released to soybean farmers and scientists at experimental stations for crop management and agricultural input optimization. Presently, GLYCIM is being used by farmers in nine Southern and Midwestern states of USA for preseason decisions, like the selection of a cultivar for a particular soil, planting date, and row spacing, and for post-planting decisions, like estimating the timing and amount of irrigation, harvest time and final yield. In a survey by Mississippi State University, the soybean growers indicated a 14-29% increase in yield and a 400% increase in irrigation efficiency from using GLYCIM to manage irrigation. A continuous feedback from the growers guided us in equipping the DSS with Graphical User Interface for Crop Simulators (GUICS) running under Windows 95, with a module to access remote weather stations and modules to simulate various practices. Cultivar parameters were developed using the data from growers' fields. This enhanced model applicability for a range of soybean cultivars. A survey of the users allowed us to phase out the development of new modules for managing weeds, analyzing the economic efficiency, and adding GIS capabilities to the DSS.

INTRODUCTION

The use of decision-support systems (DSS) in crop management and input optimization continues to increase and becomes an integral part of farm operations. Decision-support systems that are being used include expert systems, simulation models and databases. To compete at the global market place, growers have to optimize inputs and maximize yields and profits. The complexity of farm operational decisions, especially the input optimization which itself depends on changes due to the ever changing factors like weather, soil and cultivar characteristics, requires a decision-support system capable of accounting for this complexity. Since early 1980s, we have been developing such decision-support systems (Baker et al., 1983; Reddy et al., 1995) containing mechanistic crop models, a user-friendly interface to facilitate input/output and a rule-based reasoning system to interpret results of simulations.

Crop simulation models which are backbone of these decision-support systems are capable of bringing new research information on crop physiology, genetics, soil science, entomology, and pathology from a scientist to a farmer in a quantitative form. These models offer great potential for numerous improvements in crop production efficiency and crop management. The new knowledge can arrive to the farmer's computer even before it is published in refereed research journals by using the models for research information transfer. Crop simulation models can predict the growth of a crop from emergence to maturity, account for major physiological and morphogenetic processes, and describe primary relationships in the soil-plant atmosphere system.

To our knowledge, GOSSYM/COMAX was the first model-based reasoning system used widely by cotton producers for input optimization and management of resources (Baker et al., 1983; Lemmon, 1986). A model-based decision-support system, WINGLY, has been in use by selected soybean growers in the United States since 1991 cropping season (Reddy et al., 1995). Between 1991 and 1996 cropping season, 70 data sets comprising information on soils, crop growth and development, weather and crop management were collected. This database was collected in the fields of collaborating farmers and comprised of several cultivars grown under various climatic conditions, soil types, and management conditions. The GLYCIM/WINGLY was replaced in 1997 growing season with GLYCIM/GUICS and released to farmers. This paper describes the development of GUICS, cultivar parameter files and the on-farm application of the soybean model, GLYCIM.

GENERAL DESCRIPTION OF GLYCIM

GLYCIM is a dynamic simulator of soybean crop growth, development and final yield. The model is mechanistic at the level of the physical and physiological processes involved in the mass and energy transfer in the soil, plant and atmosphere. It is organized into modules in accordance with a generic modular structure and runs in hourly timesteps. Documentation, including a FORTRAN listing, definitions of variables, description of theory, and details of input and output files has been published elsewhere (Acock et al., 1985). The mechanisms involved in the physical and physiological processes in the plant and its environment are mathematically described in the model. These processes include light interception, carbon and nitrogen fixation, organ initiation, growth and abscission, and flows of water, nutrients, heat and oxygen in the soil.

All of the important factors known to influence these processes are included in the model along with information about how the factors interact. Carbon dioxide concentration in GLYCIM has a direct effect on gross photosynthetic rate and on photorespiration rate. Carbon dioxide concentration, both in the real plant and the model, has the potential to affect every aspect of plant growth and development. Carbon availability affects the expansion and dry weight gain of all organs on the plant. Root growth influences water uptake, plant water relations, and stomatal conductance. Since the model was originally designed to examine the interactions between CO_2 and other environmental factors, all the processes in the model have been brought to approximately similar level of mechanistic detail.

The environmental inputs necessary to run GLYCIM are solar radiation, maximum and minimum air temperature, rainfall, and wind speed. The model also uses wet and dry bulb temperature if available and has the capability to use either hourly or daily environmental input data. GLYCIM also needs information on the physical and hydraulic properties of the soil, maturity group of the variety, latitude of the field, date of emergence, row spacing, plant population within a row, row orientation, irrigation amount, method and date, and CO_2 concentration in the atmosphere.

The model has been designed to simulate the growth of any cultivar on any soil and at any location and time of year. All soil process modules are mechanistic, and soil characteristics by horizon are required as input for the model. Simulations are initiated at the cotyledonary stage with appropriate data on the number, size, and weight of organs on the plant. Plant growth in size and phenological stage are predicted by the model. During simulation, the model provides predicted values for most of the physiological variables. It also simulates the nitrogen content in various organs on the plant, and water and nitrogen status of the soil. The model provides dry weights of all plant parts and final seed yield.

The generic modular structure of GLYCIM is presented in Figure 1. The module SOILIN uses data on the characteristics and initial conditions of soil in various horizons of the profile to calculate characteristics and initial conditions in each cell of the soil profile. The module WEATHER uses meteorological data and celestial geometry to calculate daylength, effective photoperiod, mean day and night temperatures, and hourly values of some environmental variables, including air temperature and vapor pressure deficit. The module LYTINT calculates hourly values of the total photosynthetically active radiation that can be intercepted by the crop canopy. Volumetric water content, water potential, hydraulic conductivity, oxygen concentration, temperature, and concentrations of ammonium and nitrate in each cell in the soil profile are calculated in SOILEN. The vegetative and reproductive developmental rates are calculated in module PHEN. PNET uses single-leaf photosynthetic characteristics to calculate canopy characteristics and canopy gross photosynthetic rate. Photorespiration rate and maintenance respiration rate are

ENVIRONMENTAL PROCESSES

SOILIN	INITIATE SOIL ENVIRONMENT		
WEATHER	AERIAL ENVIRONMENT		
		Celestial Geometry	
		PAR & Diffuse Radiation	
		Water Vapor Pressure	
		Temperature	
LYTINT	LIGHT INTERCEPTION		
SOILEN	SOIL ENVIRONMENT		
		Soil Water	
			plant uptake
			evaporation
			profile recharge
			soil water potential
		Soil Nutrients	
			plant uptake
			fertilizer additions
			chemical transformations
			leaching
		Soil Mechanical Impedance	
		Soil Temperature	
		Soil Oxygen	

PLANT PHYSIOLOGY

PHEN	STAGE OF DEVELOPMENT	
PNET	CARBON FIXATION	
		Photosynthesis
		Respiration
POTGRO	POTENTIAL GROWTH OF ORGANS	
		Vegetative Shoot & Root
		Reproductive Organs
		Storage Organs
PARTIT	CARBON LIMITATIONS OF GROWTH	
		Initial Carbon Partitioning
WATERS	WATER LIMITATIONS TO GROWTH	
		Potential Transpiration
		Actual Water Uptake
		Leaf Water Potential
NUTRTS	NUTRIENT LIMITATIONS TO GROWTH	
		Plant Nutrient Supply & Demand
		Distribution of Nutrients in Plant
ACTGRO	ACTUAL GROWTH OF ORGANS	
		Vegetative Shoot & Root
		Reproductive Organs
		Storage Organs
TISLOS	TISSUE LOSS	
SOYPLT	MORPHOLOGY	
		Plant Geometry

Figure 1. Generic modular structure for plant simulators. Names of modules are capitalized. Subdivisions of modules are in upper/lower case.

calculated and subtracted to get net photosynthetic rate, which is corrected for the stomatal closure caused by water stress. The net carbon fixation rate and the rate of carbon translocation out of the leaves are also calculated in PNET. The module POTGRO calculates potential rates of growth for all organs on the plant at a given air temperature assuming that carbon, water, and nutrients are plentiful. PARTIT calculates an initial partitioning of carbon to various organs based on priorities that change with stages of growth. WATERS maintains a functional balance between root and shoot by growing roots as necessary to meet transpiration demand. It calculates potential root water uptake for a number of key shoot water potentials and compares these with the potential transpiration rate to estimate shoot water potential. Depending on shoot turgidity, the shoot or root, or both, may grow. Stomatal conductance is a function of both shoot turgidity and soil water availability.

THE INTERFACE GUICS

Starting from 1991 growing season, GLYCIM with a user-friendly interface, WINGLY, was released to soybean growers for crop management. The on-farm experience of 1991-96 made us realize that we need a more robust interface. This led to the development of GUICS (Graphical User Interface for Crop Simulators) which runs under WINDOWS 95 and WINDOWS NT and can support many crop models simultaneously. The hierarchy of information units in GUICS is based on the fact that one run of any crop simulator makes predictions for a particular combination of weather, soil, crop cultivar, and farm operations. Such a combination is referred as a scenario. Data on weather, soil, weed control, etc., are referred to as data set of a scenario. Several related scenarios may be combined in a group that is called a project. Any scenario belongs to some project. Similar data sets, e.g., weather data, belong to the same data category.

GUICS runs a crop simulator after arranging the input data for one or for several scenarios according to the user's request. GUICS displays the results in graphic, tabular, and text forms. If several scenarios are of interest, the tables and graphs will display results of all scenarios simultaneously to facilitate a comparison of results. Several ways to visualize the results are available. A toolbar is included to simplify viewing results.

Copying, deleting, and editing functions are available at all levels of the 'project-scenario-data set' hierarchy . Several additional functions are specific to a level of the hierarchy. At the scenario level, a user can vary the scenario, that is generate a set of scenarios differing in one data set only. At the data set level, calling a weather station to update the current weather data set is possible.

Each information unit (a project, a scenario, a data set) has a name, and may have an icon and a memo. A memo is a text description of a unit. Both the icon and the memo are meant to simplify recognizing a unit.

The interface has a set of wizards to guide a user through all stages of project development, scenario assembly, viewing results, and editing data sets. On-line help is included and a guided tour will be included eventually.

GUICS interacts with a crop simulator as with a standalone code. Scripts have to be written to plug a simulator into GUICS. These scripts describe the structure of input and output data sets specific to a particular simulator. Authors may want to modify the output of their simulators to take advantage of the capabilities of GUICS in viewing results.

There are no standard data sets for crop simulators. GUICS allows different simulators to have different data sets for the same data category, for example different soil files for the same field.

GUICS has a fully object-oriented design and implementation. It is open to enhancements and further development, e.g., using maps, displaying animation, using data bases to store data sets, etc.

DEVELOPMENT OF CULTIVAR PARAMETER FILES

The soybean simulation model GLYCIM was developed by Acock et al., (1985) and was initially validated using data collected on cultivar Forest at the Plant Science Farm at Mississippi State University (Acock, et al., 1985; Gertis, 1985; Aung, 1989). Since 1991 growing season GLYCIM has been used by farmers for crop management and input optimization. The model is being used for selecting cultivar, row spacing, plant population and planting date prior to planting, and for post-planting decisions such as irrigation scheduling, insect control, harvest timing, and forecasting of final yield. The model helps farmers to optimize inputs, maximize profits, and minimize environmental pollution. Soybean growers are increasingly planting new cultivars and using GLYCIM for crop management. These cultivars differ in their response to various inputs from the Forest cultivar with which the model was originally developed and calibrated. It has become evident that, in order to use the model for maximum benefit to the growers and with better predictions for a range of cultivars and maturity groups, a set of cultivar dependent parameters are needed as input data.

A cultivar parameter file was developed containing 25 parameters called PARM1-PARM25. The differences in growth and developmental rates of soybean cultivars can be generalized in the following broad groups: differences in rate of vegetative node production (PARM2, PARM3, PARM4, PARM16), differences in the rates of progress through reproductive stages (PARM5 to PARM15), differences in the rates of stem and petiole extension and dryweight increments in various plant parts (PARM17 to PARM25). The cultivar parameters were developed for several cultivars, but only a few of these parameters had to be changed to simulate growth, development and yield for each of the cultivars.

RESULTS AND CONCLUSIONS

Model Validation

Every year prior to release of the model to growers, the model is validated by simulating 70 data sets in the database and comparing the simulated plant variables against measured plant variables.

The observed and GLYCIM simulated data for vegetative stages, reproductive stages, plant height and dryweights of leaves, stem and pods are presented in figures 2, 3, and 4. The observed data representing Mullens farm were collected during the year 1994, on Dundee soil with Hutcheson cultivar compared well with simulated data for all the plant parameters (Figure 2). A similar data set from McCain farm on Alligator soil and Hartz 5164 cultivar was found to compare well with GLYCIM simulated plant parameters (Figure 3). During the cropping season 1995, the data for dry weights were not collected from Hood's farm. The soil type was Robinsonville 2 with cultivar DPL 415. The simulated data on vegetative and reproductive stages and plant height compared well throughout the season (Figure 4). Similar comparison are carried out for all the data sets each year after any changes to the model to test the validity of the model under a range of conditions. This validation is a necessary step prior to the release of a new version of the model to maintain and assume a quality product that can help a grower for management decisions.

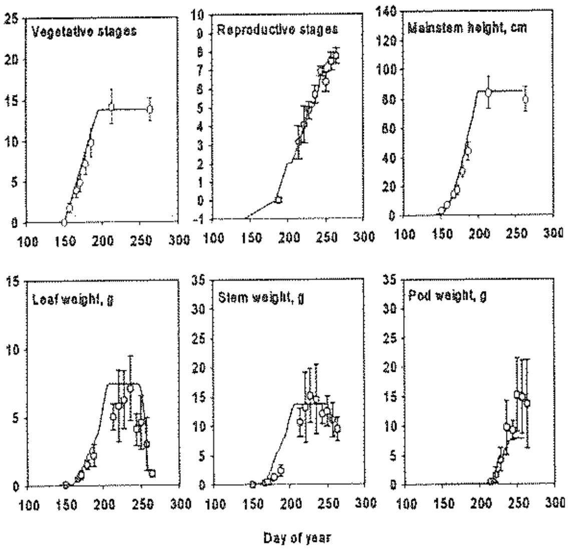

Figure 2. Comparison of simulated and observed seasonal development of vegetative and reproductive stages, plant height and dry weights of leaves, stems and pods for soybean cultivar Hutcheson grown on Dundee soil at Mullens farm in the Mississippi Delta during 1994.

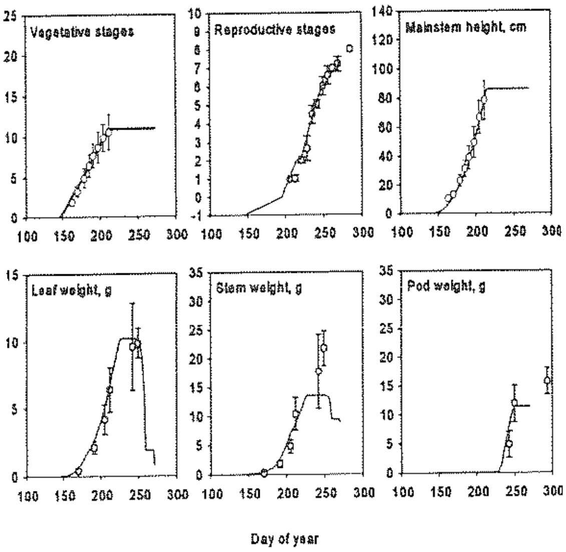

Figure 3. Comparison of simulated and observed seasonal development of vegetative and reproductive stages, plant height and dry weights of leaves, stems and pods for soybean cultivar Hartz 5164 grown on Alligator soil at McCain farm in the Mississippi Delta during 1995.

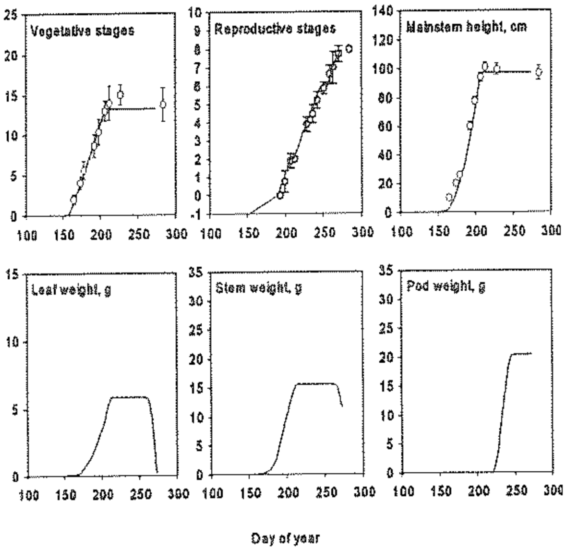

Figure 4. Comparison of simulated and observed seasonal development of vegetative and reproductive stages, plant height and GLYCIM simulated dry weights of leaves, stems and pods for soybean cultivar DPL 415 grown on Robinsville soil at Hood farm in the Mississippi Delta during 1995.

Model Application and Impact

After the development of GUICS and cultivar parameter files for GLYCIM (Reddy et al., 1997, Reddy et al., 1995) and several improvements in growth and phenology of GLYCIM (Acock et al., 1997), both farmers and scientists continue to use the model for input optimization. The introduction of cultivar parameter files for GLYCIM provides soybean farmers with a new tool for selecting cultivars, planting time, and soil type for maximum yield. The development of GUICS and several models for crops like cotton, wheat and rice which are under development will facilitate the prediction of crop rotation, intercropping, weed and pest control. In a recent survey by Mississippi State University, the soybean growers using GLYCIM with new cultivar parameters for crop management have reported a 14-29% increase in yield and a 400% increase in irrigation efficiency (Whisler et al., 1993).

The farmers indicated, "By using the model's historical weather data and soil classification information, we can use GLYCIM to make pre-season decisions for the best varieties for various soil types, best row spacing for maximum yield, optimum number of seeds per foot of row, optimum planting dates, highest projected yields based on the criteria, and projected harvest dates" (Remy, 1994). The farmers have also indicated that the in-season decisions such as time and amount of irrigations can be done more precisely for maximum yields with lower costs and reduced groundwater pollution (Remy, 1994). In addition, with the new cultivar parameter files, GLYCIM can be used to study the effect of climate change on soybean production and yield potential for many of these cultivars.

REFERENCES

Acock, B., V.R. Reddy, F.D. Whisler, D.N. Baker, H.F. Hodges, and K.J. Boote, The soybean crop simulator GLYCIM, Model documentation 1982, PB 851163/AS, U.S. Department of Agriculture, Washington, D.C., Available from NTIS, Springfield VA, 1985.

Acock, B., Ya.A. Pachepsky, M. Acock, V.R. Reddy, and F.D. Whisler, Modeling soybean cultivar development rates using field data from the Mississippi Valley, *Agron. J.* (in press), 1997.

Aung, K., Development rates of soybean cultivars within maturity groups V through VIII as compared to prediction by crop model GLYCIM, M.S. Thesis, Agronomy Dept., Mississippi State University, Mississippi State, 1989.

Baker, D.N., J.R. Lambert, and J.M. McKinion, GOSSYM: A simulator of cotton growth and yield, South Carolina Agricultural Experiment Station, Technical Bulletin 1089, 1983.

Gertis, A.C., Validation of GLYCIM: a dynamic crop simulator for soybeans. M.S. Thesis, Agronomy Dept., Mississippi State University, Mississippi State, MS, 1985.

Lemmon, H.E., Comax: An expert system for cotton crop management, *Science*, 232:29-33, 1986.

Reddy, V.R., B. Acock, and F.D. Whisler, Crop management and input optimization with GLYCIM: differeing cultivars. *Computers and Electronics in Agriculture*, 13:37-50, 1995.

Reddy, V.R., Y.A. Pachepsky, F.D. Whisler, and B. Acock, A survey to develop decision-support system for soybean crop management, vol, IV, pp. 11-18, Proc. 1997 ACSM-ASPRS Annual Convention and Exhibition, April 7-10, Seatle, WA, 1997.

Remy, K., GLYCIM soybean model proves its worth, Research Highlights, MAFES Publ., 57, Mississippi State, MS, 1994.

Whisler, F.D., A. Trent, V.R. Reddy, P. Amonson, H.F. Hodges, and B. Acock, On-farm validation of the soybean simulation model, GLYCIM, ASA Meetings, Cincinnati, OH, 7-12 November, 1993.