AGRICULTURAL SYSTEM MODELS

in Field Research and Technology Transfer

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CHAPTER 4

Experience with On-Farm Applications of GLYCIM/GUICS

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CONTENTS

INTRODUCTION

Agricultural producers need to make informed decisions in order to manage their enterprises efficiently. These decisions are based on experience and available information as well as on input from agricultural consultants. As their enterprises grow in size and complexity, it becomes more difficult for growers to manage large amounts of information. Furthermore, uncertain weather conditions increase risk. As personal computers have become more widely available, there has been an effort among agricultural researchers to provide computer-based tools to help manage and synthesize information. The main reason for using tools such as computer models on farms is to increase profit and manage resources, although learning more about how crops respond to environmental factors, and help in complying with governmental regulations are also important. Furthermore, the ability to compare the probable outcomes of different decisions can help a producer

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make a more informed choice and reduce risk in the face of future uncertainties. These computer-based tools have become known as decision support systems (DSS).

Early DSS tools, known as expert systems (McKinion and Lemmon, 1985), resulted from an effort to encapsulate information and experience so that the computer program could answer questions by synthesizing heuristic information that had been input and choosing the correct answer from a knowledge base. Crop simulation models were incorporated in DSS to account for dynamic seasonal and interannual interdependencies of weather, plant characteristics, and soil. Computer simulation models mimic crop response to environmental variables because they calculate photosynthesis, carbon partitioning, water and nutrient uptake, and yield using equations developed from experimental data. The level of detail varies from empirical/mechanistic (Hammer et al., 1995; Jones and Kiniry, 1986) to highly mechanistic models [GOSSYM (Baker et al., 1983)]. Crop simulation models can estimate the growth of a crop from emergence to maturity, account for major physiological and morphogenic processes, and describe primary relationships in the soil–plant–atmosphere system.

GOSSYM was one of the first simulation model-based DSS for crops. Since the early 1980s it has been widely used by cotton producers for water and nitrogen management as well as for timing harvest operations (Baker et al., 1983; Landivar et al., 1989). GOSSYM was also combined with an expert system and called GOSSYM-COMAX (Lemmon, 1986), where rule-based reasoning was used to interpret simulation results.

The soybean model, GLYCIM, was developed after GOSSYM and shared some design components and modules. GLYCIM has highly mechanistic, dynamic representations of plant growth, development and yield, and soil and weather processes. The mechanisms involved in the physical and physiological processes in soybean and its environment are mathematically described in GLYCIM (Acock et al., 1985). 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. GLYCIM is organized into modules in accordance with a generic modular structure and runs in hourly time steps. Documentation, including the FORTRAN listing, definition of variables, description of theory, and details of input and output files has been published elsewhere (Acock et al., 1985; Acock and Trent, 1991).

The model GLYCIM has been designed to simulate the growth of any cultivar on any soil and at any location and time of year. 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 the simulation, GLYCIM provides predicted values for most of the physiological variables. It also simulates nitrogen contents of various organs on the plant and water and nitrogen status of the soil. The model provides the dry weights of all plant parts and final seed yield.

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 data. GLYCIM also needs information on the physical and hydraulic properties of the soil, maturity group of the cultivar, 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.

Currently, 26 parameters define growth and development rates, and yield components (Table 4.1). Three parameters define the rate of vegetative development, 12 parameters define the rates of reproductive stage progress from R0 (floral initiation) to R8 (podset), six parameters define the rate of stem extension and number of branches, one parameter defines root growth, and four parameters define dry matter partitioning.

Since the 1991 growing season, GLYCIM has been used by farmers for crop management and input optimization in the Mississippi Valley. 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 (Reddy et al.,

Table 4.1 Vegetative and Reproductive Development Rate and Yield Component Parameters Used in GLYCIM

Vegetative
Slope of the vegetative (V) stage dependence on growing degree days (GGD day^{-1})
Maximum vegetative (V) stage
Correction factor for the early vegetative stage progress rate to account for clay content
Reproductive
Progress rate toward floral initiation (R0) at solstice (day^{-1})
Daily rate of the progress to R0 before solstice (day^{-1})
Daily rate of the progress to R0 after solstice (day^{-1})
Progress rate from R0 toward R2 (day^{-1})
Slope of the dependence between the end of R2 and emergence date
Intercept of the dependence between the end of R2 and emergence date
Progress rate from R2 toward R6 (day^{-1})
Length of the plateau R5 (day)
Length of the plateau R6 with no water stress (day)
Rate of decay of the R6 plateau as the water stress increases (day^{-1})
Rate of the progress toward R7 (day^{-1})
Reproductive (R) stage to stop vegetative growth
Stem Elongation and Height
Potential stem elongation per dry weight increase of petioles (cm g^{-1})
a in the dependence ($h = a(v)^b$) between height and vegetative stages
b in the dependence ($h = a(v)^b$) between height and vegetative stages
Stem weight per unit stem elongation (g)
Increment in leaf area per increment in vegetative stage
Number of branches per unit plant density
Roots
Potential rate root weight increase (g day^{-1})
Yield Components
Increase in pod weight as a function of progress in R stages
Increase in seed weight per seed fill rate
Number of seeds per bushel
Seed fill rate g day^{-1}

1995). The model helps farmers to optimize inputs and maximize profits. Since 1991, USDA scientists have collected 156 data sets on soils, crop growth and development, weather, and management conditions (planting and harvest date, and irrigation). These data come from the fields of cooperating growers and include numerous cultivars grown under various soils, and weather and management conditions. As GLYCIM was used on-farm, an interface was developed and evolved over time. This paper describes the experiences of the cooperating growers and researchers involved in the GLYCIM on-farm project, and the current interface (GUICS — Graphical User Interface for Crop Simulators) developed to facilitate use of GLYCIM by the growers.

ON-FARM TESTING OF GLYCIM

GLYCIM was originally evaluated using data collected on the soybean cultivar "forrest" at the Plant Science Farm at Mississippi State University (Acock, et al., 1985; Gertis, 1985). All model equations and parameters came from experiments in growth chambers and greenhouses; soybean plants were mainly grown in pots and in small plots. On-farm testing began in 1991 when a soybean grower, Kenneth Hood of Pershire Farms, Gunnison, Mississippi, agreed to allow researchers to plant strips of different soybean cultivars and take measurements on growth, development and yield. The purpose of the field trials was to collect data on phenology, dry matter production, and yield to validate the model.

On-farm research with GLYCIM was expanded to the Mississippi Delta farms of Edward Hester and Jay Mullens in 1992 and to the Fletcher Clark farm in 1993. Because two of these growers had been involved in the project to evaluate the use of GOSSYM/COMAX, they had weather stations close by and some familiarity with simulation models for irrigation scheduling. An ongoing program to characterize soil hydraulic properties for the cotton model, GOSSYM was continued for the GLYCIM testing (Whisler, 1982). Soil samples have been taken across the Cotton Belt and analyzed for their physical and hydrological properties. After 1993, additional growers from Mississippi, Alabama, Missouri, Louisiana, Tennessee, and Arkansas joined the project. Some of these growers had experience with GOSSYM. Others came by word of mouth based on contact with growers already using GLYCIM. By 1997, we had 12 growers in the program, and all requested the model again the next year. This allowed us to test GLYCIM at a wide variety of locations.

Participants represented a variety of farm operations for the Mississippi Valley (Reddy et al., 1997). Farm size ranged from medium (300 ha) to large (6000 ha), and ages from 23 to 75. All operations were family farms where cotton and rice were the primary crops. Soybeans were usually a secondary crop.

Field Sampling Protocol

The sampling program was carried out to collect data on vegetative and reproductive stages, dry matter and yield. Most of the plots were irrigated because that was the growers' practice, but, as researchers, we tried to include non-irrigated plots, when available, in order to compare irrigated and non-irrigated yields. Data were also collected on as many soybean varieties as possible to provide a wide variety of input data for growers.

The field plots were laid out in the spring of each year after the soybean plants emerged. The plots were usually 12.1 m wide and 176.8 m to 192 m long (0.12 to 0.16 ha) in the form of a transect. Three replicates (transects) were laid out in each field. Crop management was the same at all plots but different varieties were planted. Planting dates were also varied. This allowed data collection for a number of different varieties in the same location. Sampling was bi-weekly to weekly depending on growth stage. Height and developmental stages were measured on the same plants to minimize variability due to soil and plant. Destructive samples for dry matter determination were taken from outside the plots. A 7.6 m (25 ft) strip was harvested from each transect using a plot combine trailered from Mississippi State University.

Modifications to GLYCIM Based on On-Farm Testing

The on-farm experience with GLYCIM in farmers' fields helped identify several weaknesses in the model from 1991 to 1993. These weaknesses were in the prediction of soybean phenology, especially floral initiation and anthesis and soybean response to short-term cold injury. A series of experiments were conducted in controlled-environment plant growth chambers and in the field to supplement data collected from growers' fields. As a result, we incorporated new algorithms in the model that improved GLYCIM's predictive capability for phenology (Reddy et al., 1995; Acock et al., 1997; Reddy et al., 1998) and yield under a range of conditions. More than 80 data sets were assembled during the period of 1993 to 1996.

Initially, GLYCIM had only two user-selectable parameters for crop growth and development. These were parameters for maturity group and determinacy. Parameters for growth, development, and yield processes such as progression of vegetative stages and seed fill rates were hard coded in the program. There were a total of 24 of these. In 1993, many of the parameters were made into variables and grouped by plant cultivar (Reddy et al., 1995). The number of user-selectable parameters was reduced to 18 (PARM1 to PARM18 in Reddy et al., 1995) of which only 15 were varied among cultivars (Table 4.1). The remaining three parameters included an evapotranspiration pan factor, and parameters that defined the number of branches per unit plant density, and root growth rate that are not varied unless data are available. The use of cultivar related parameter files allowed us to simulate cultivar specific rate processes better and easily modify parameters for new cultivars. Later, after 1996, based on results in growers' fields, four new parameters were added. One was used to adjust the vegetative stage for soil clay content and another three were used to calculate floral initiation (R0) based on summer solstice (Table 4.1) (Acock et al., 1997).

Other modifications were made to GLCYIM to adapt the model better to user requirements as the project progressed. Irrigation was originally simulated by augmenting the rainfall data. Several growers used flood or furrow irrigation that was not compatible with the capacitance-based infiltration component of GLYCIM. When infiltration is modeled this way, water input as rainfall or irrigation fills the surface soil layer instantaneously to some upper limit, usually termed field capacity. Additional water moves to the next layer finally becoming drainage if the soil's water-holding capacity is exceeded. To handle furrow or flood irrigation, the water infiltration code was modified to include gradient-driven infiltration using the Green-Ampt equation (Pachepsky and Timlin, 1996).

Several growers preferred to plant narrow row soybeans with a grain drill but the model could not simulate the yields and phenology well. Two years of experiments used different population densities (10 to 60 plants per m^2) to develop equations to describe the effects of plant population density on branching (Reddy et al., 1999). These were added to GLYCIM and several growers now experiment with row spacing in the simulations to evaluate planting strategies for different soils.

The GLYCIM validation study was an on-farm trial, not a complex research-designed experiment. On-farm experiments can be difficult to manage with potential problems in logistical support, analytical needs and farmer participation (Lightfoot and Barker, 1988). The farmers were left to experiment with GLYCIM, and the research goal was to collect validation data sets and improve the model. Researchers monitored the irrigation schedules closely and duplicated model runs of GLYCIM made by the farmers and conveyed the results back to them. Meetings were held with the participants to insure that improvements in GLYCIM performance would be relevant to their needs.

Graphical User Interfaces

GLYCIM was used on farms in 1991, before it had a user interface. The model ran from a command line, and input and output data were supplied in files edited by a simple text editor. The primary use of GLYCIM was to provide a tool for growers to estimate yield using current weather data and a standard weather file for forecasting, and to gain further data for GLYCIM with different soils and varieties. Initially the intended use of GLYCIM was to predict crop yield and harvest date.

Developed as a research model, the initial version required a user to edit the input files manually and did not provide a visual representation of the output or easily interpreted tables. There was an obvious need to develop a user interface. Without the interface, the potential of a model may be lost and assembling input data can be formidable. Most users would probably have neither the time nor inclination to learn and/or perform tedious procedures for entering data and displaying results.

In 1993, a Microsoft Windows™ 3.1-based user-friendly interface, called WINGLY, with a "point and click" design was released to the growers. There was little user input. Most of the input in the WINGLY design was through manually editing files. The interface managed the arrangements of the input files to allow a user to run simulations with different soils and varieties. It was also programmed to call the weather station, and download and manage the weather data, and it had a simple graphical output interface to assemble tables and summary data that allowed users to view the output information in a readily understandable format.

WINGLY was also designed as a simple DSS. Each day during the growing season a grower would begin by downloading daily weather data over a telephone line. Then WINGLY would add weather data from a standard weather file that contained averages of 20 years of daily weather data for a nearby location. These average weather data were used to fill in rainfall, radiation and air temperature for the remainder of the season. The grower would enter the file name corresponding to the proper cultivar, initialization, soils, and irrigation data. These files were prepared by the authors, the model developers. GLYCIM would predict yield given the weather data to date, no rainfall in the next five days, and a selected year's rainfall until the end of the season. This would allow the grower to project yield given no irrigation and to decide when to irrigate.

An alert to the user would be triggered if a rule-based analysis of the simulation results detected moisture stress. This expert rule was developed from field trials of GLYCIM on farms in the Mississippi Valley and grower experience from 1991 to 1993. While running the command-line version of GLYCIM, grower Kenneth Hood noticed that one of the output files contained information on water stress and tried to irrigate according to the indication of stress. He found this was successful. Based on this experience, the model developers defined a trigger point based on a period when the plant could not take up sufficient water to meet transpiration needs for three or more consecutive hours and continuing for three or more consecutive days. If irrigation were necessary within the next five days, the model would alert the user: *"Irrigate before mm/dd if there is no rainfall in the next three days."* The grower would add the irrigation amount to an irrigation file and rerun the model with varying irrigation amounts until the water stress was alleviated. Additional information provided by WINGLY included warnings of the time to harvest and a summary of the seasonal simulation that a grower could use to evaluate an irrigation or other management strategy such as cultivar selection or row spacing.

In 1995, the authors began development of a new interface, GUICS (Graphical User Interface for Crop Simulators) (Acock et al., 1998). Previously, WINGLY relied on entering text and not on drop-down menus, and could not manage multiple scenarios nor easily allow a user to make comparisons of scenarios. It was a product of Microsoft Windows 3.1, 16-bit technology and was also limited to one model — GLYCIM. Surveys of on-farm use of computerized DSSs, both simulation- and nonsimulation-based, have shown that the complexity of DSS use is one of the most limiting factors (Greer, 1994). Furthermore, the Microsoft Windows 95 operating system provided a new environment for data management and visualization as well as 32-bit processing.

GUICS was designed as a usable generic user interface that could manage several models. The ability to manage several different models provides a tool to study the effects of crop rotations, or to compare models. The usability paradigm includes features such as:

1. Effectiveness of task performance or user productivity
2. Learnability, including the primary learning time and relearning time in intermittent use
3. Flexibility, adaptable to changing tasks or a changing environment
4. Attitude, defined in terms of the users liking or disliking the interface (Acock et al., 1999)

Icons help users recognize by pattern rather than by recalling information. Wizards are used to guide the user through the task of assembling data into a scenario and making a simulation run. One data category is shown at a time. The interface also features forgiveness to facilitate exploration, allowing a user to back out of a selection without losing information. Further, the interface has automated weather data downloading and a minimum number of active buttons to reduce memorization and display a minimum amount of text to reduce clutter.

The data presentation in GUICS is greatly simplified over that presented in WINGLY. Output is presented in tables and summary files rather than a detailed listing used for research and debugging. GUICS also stores the output from the scenarios separate from the input data. In order to run the model, the user selects the button for "View Results." There is no "Run" button; the path to view the output or run the model is the same button. This was an attempt to isolate the user from the mechanics of running the model and decouple the concepts of a simulation run and simulation result. The results would be available only after the simulation ended.

GUICS has tools to help a user to obtain weather data through phone lines, assemble a simulation scenario and view results. Developing GUICS involved research in the hierarchies (i.e., projects contain scenarios and scenarios contain model runs) of information use in simulators, and in system requirements for different groups of users. GUICS has a fully object-oriented design and implementation (Acock et al., 1999). It is open to enhancements, e.g., using maps, using databases to store datasets, and working with suites of models. Users of crop simulation models often need to work with several models to study the effects of crop rotations, to compare models, or to obtain information for decision making within a farm operation.

A survey was carried out during the early design stage of GUICS (Reddy et al., 1997) to:

1. Assess user satisfaction with WINGLY.
2. Predict user acceptance of the new interface.
3. Research future user needs.

Hand-drawn panels of the interface's initial screen design were prepared to help evaluate the appearance of the interface. Later, a computer mockup was designed and presented to users while the program itself was plastic enough to allow major changes without requiring extensive modifications to code. The GUICS prototype was evaluated by giving hands-on experience to a group of end users, including seven farmers from five southern states who already had experience with WINGLY.

Evaluation of the GUICS Interface

Employing the general guidelines of usability testing (Rubin, 1994), the authors evaluated GUICS. In observational interviews (Martin and Eastman, 1996), they

1. Outlined the new features of the interface.
2. Demonstrated how to get warnings of stress effects on yields.
3. Asked the users to go through the whole process of crop simulation on their own and recorded all difficulties experienced.
4. Asked users to point out any inconveniences and discussed with them the usability of GUICS.
5. Asked whether the users would prefer to keep WINGLY or to use GUICS.

Acceptance was of concern, because users often prefer a familiar interface to the one that is supposedly improved (Rudisill et al., 1996). The interviewers also asked about the need for mapping tools for input and output, and about the need for resources to be accessed through the Internet.

GUICS was amended as a result of these interviews, and the amended version was used on 15 farms in 1997 and 1998. The only serious problems encountered were errors in downloads of weather data leading to faulty weather files being used in simulations.

GROWERS' EXPERIENCES

Experience with the Interface, GUICS

Two of the growers were able to put together a scenario and obtain simulation results immediately after the demonstration. Wizards appeared to be a big help. Lack of consistency in implementing Windows shortcut conventions and not including consistent error messages in the wizards were reported as problems by the growers. Two users found the icons confusing. Guidelines on naming datasets and scenarios and on writing memos were requested. None of the users saw an advantage in combining various scenarios into projects for on-farm use. One of the users indicated that the accumulation and collection of garbage data might become an issue as data manipulation becomes easier. The ability to have several crop models running under the same interface was welcomed (although this has not been implemented yet). None of the users objected to replacing WINGLY with GUICS, provided they were given a converter to transform WINGLY data files to GUICS data files.

Many of the requested enhancements centered around the need to manage weather files. An automated update of ASCII weather files was requested. Tools to generate several predicted weather files were desired. Most users felt an advisory system on weed control would be useful. Some of the growers had yield monitors and all the growers agreed there was a need for mapping tools in the DSS. A mapping unit from NRCS soil survey reports could be used as a kernel to link soil, weather, management, and cultivar data.

Discussion of the need for mapping tools revealed a variety of interests, mostly related to the familiarity of the users with precision farming technology. All agreed it would be convenient to use a mapping unit as the kernel of a project relating soil, weather, management, and cultivar data. Two users thought soil mapping units could be kernel units, whereas one thought a field might be the more appropriate unit. Three users had yield monitors and thought that crop simulation should be related to yield map analysis, and that the appropriate tools should be integrated into GUICS. One user pointed out that the accumulation of data eventually might make desirable a database to support complex queries. None of the users were aware of Internet resources that could help them use GUICS as a decision support tool, although all them expressed interest in information on such resources.

Despite the development of GUICS, many users still find the output too time-consuming to interpret. There is still, probably, too much reliance on graphs displaying a time course of the simulation, a holdover from the paradigm of research and a scientist's eye toward information. The problem is time, and most growers are limited in the amount of time they can devote to understanding all the information. Growers are also looking for diagnostics and other information that will help them meet specific goals. Based on results of a survey carried out with the participating growers (Reddy et al., 1997), the output variables given of most interest were irrigation timing, yield, and maturity date. The preferred output was a single number. A short summary of the main parameters of crop development was the second choice, and the full model output was least desired. The users mentioned that the percent canopy and early warning of impending moisture stress would be useful but are not now available in the graphical and summary output of the DSS. GLYCIM gives output data on more than 20 characteristics of the developing crop, but only one grower was interested in this information. Two users expressed interest in seed protein content. Economic information was mentioned but the users were not enthusiastic about bookkeeping with a DSS. Heavy users of GLYCIM/GUICS felt that graphs were useful as they allowed a user to compare scenarios. The users were primarily concerned that the initial compilation of the information needed for a simulation would be beyond the resources of most farmers.

On-Farm Applications of GLYCIM/GUICS

The growers use GLYCIM for preplant (strategic) planning decisions such as the selection of cultivar/soil type combination, planting date, row spacing, and postplant (tactical) decisions such as irrigation scheduling, harvest timing, and yield prediction. Researchers did not envision the use of GLYCIM for cultivar selection in the early project development stages. One grower found that the interface allowed him to make yield and growing season comparisons among varieties and soils and began using the model to make preplant decisions (Remy, 1994). Another grower reported he does not plant a field that he has not tested with model runs beforehand (Remy, 1994). He runs scenarios and compares estimated yields and harvest dates to test for soil, cultivar, and row spacing interactions. The grower uses different weather records and irrigation schedules from his farm to optimize simulated production.

According to the cooperating growers, the use of the GLYCIM/GUICS for crop management decision making, and input optimization has increased profits and resulted in more efficient water use by the growers (Remy, 1994). In a survey by Mississippi State University, the soybean growers using GLYCIM/GUICS attributed an increase in soybean yields of up to 29% and irrigation use efficiency of up to 400% to the use of GLYCIM (Remy, 1994). Many of the soils in the Mississippi Valley are shrinking and swelling clays (i.e., Sharkey series, very fine smectitic thermic Chromic Epiaquerts). Large cracks form as these soils dry. Traditionally, growers would not irrigate until they began to observe cracks, although the soybean plants were already beginning to be stressed. The model alerts the farmers to irrigate earlier than their traditional practice. Growers reported that before using GLYCIM to schedule irrigation they started watering too late and quit too early (Manning, 1996). By irrigating earlier, water stress to the soybeans is alleviated and less water is lost to deep drainage through the cracks. The soil also wets up faster and takes less time to irrigate; this increases irrigation efficiency. One grower reported that irrigation time on a cracking clay soil went from 4 to 5 days to 30 hours by irrigating earlier as recommended by GLYCIM/GUICS. Another grower, after noticing how much yield loss the model was predicting due to moisture stress, purchased an additional irrigation system realizing that it would pay for itself through increased yield.

An interesting side benefit of the DSS was that it provided incentive to the growers to go out to their fields and critically observe their soybean plants. Many growers, after viewing simulation results during the growing season, would go to their fields often to check their crop growth stage and compare to GLYCIM's predictions of phenology. As a result, they would be more aware of details of their fields and crops, and the crops' responses to the environment. There is also a learning component to using the DSS this way. After time, growers would recognize plant stress stages and critical soil moisture levels where irrigation would be necessary. A DSS might be less important for management at this stage.

RESEARCH EXPERIENCES

Phenology predictions for two farms in the Mississippi Valley are given in Figures 4.1 and 4.2. The data in Figure 4.1 are from 1997, 4 years after we calibrated the soybean cultivar files. Predictions of vegetative (Vstage) and reproductive (Rstage) stages are close to the measured values. The error bars suggest the wide range in variability in phenological development on the farms.

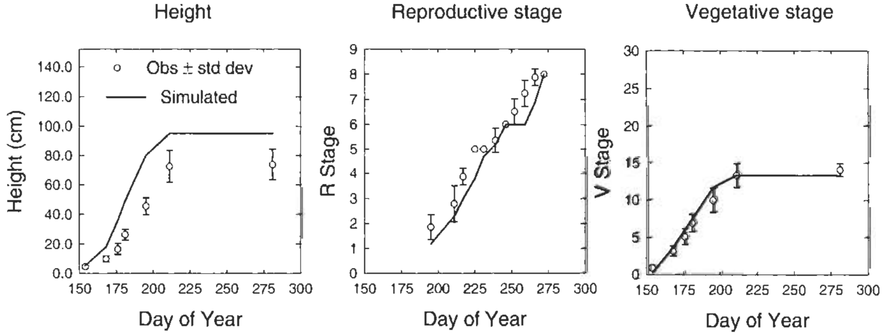

Figure 4.1 Predicted and measured phenology data for irrigated soybeans grown on the Hester farm in 1997. The cultivar is DPL3588 and soil is Sharkey clay loam (very-fine smectitic thermic Chromic Epiaquerts).

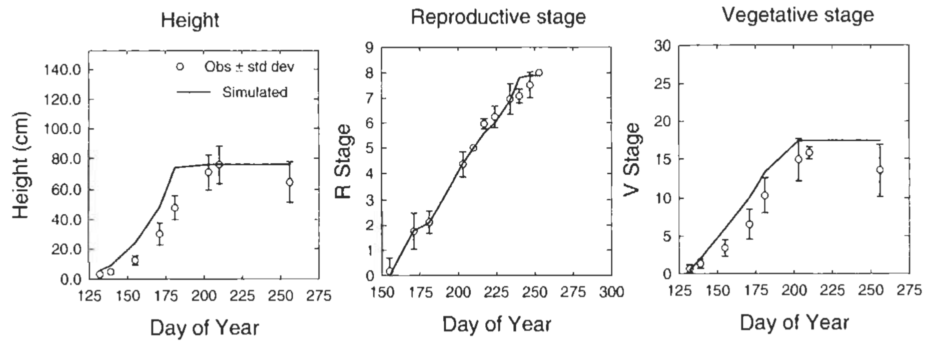

Figure 4.2 Predicted and measured phenology data for irrigated soybeans grown on the McCain farm in 1997. The cultivar is Asgrow 4922 and soil is Dubbs sandy loam (fine silty, mixed, active, thermic Typic Hapludalfs).

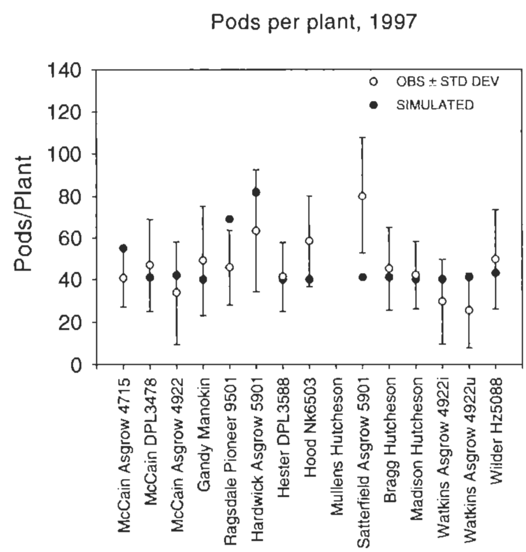

Figure 4.3 Simulated and measured pods per plant for seven different soybean varieties grown at various locations in the Mississippi Valley.

Plant height seems to be the most difficult variable to capture. In some cases, GLYCIM overestimates plant height. These data are typical of most of the measurements collected on the farms. The cultivar parameters also appear to be stable over years and sites. Predictions of pods per plant for a number of varieties and sites for 1997 are given in Figure 4.3. The variation for the GLYCIM calculated numbers appear to be less than for the measured values and some predicted values are outside the range of the measured. Nevertheless, GLYCIM does a reasonably good job of prediction especially given the range in varieties and farms (Reddy et al., 1995).

Predicted and measured soybean grain yields are shown in Figures 4.4 to 4.6. These data represent 3 growing seasons, six to 10 varieties, and 12 growers. In some cases, predicted yields are close to measured, in others they are off by as much as 50%. The relative variation in measured yields appears to be considerably less than that of the phenology data. On the whole, GLYCIM is more likely to overestimate soybean yield than underestimate it. In recent years weather was warmer than usual, and GLYCIM yield estimates were generally much higher than the measured yields. GLYCIM appears to estimate biomass correctly and seed number per pod (Figure 4.3) but has

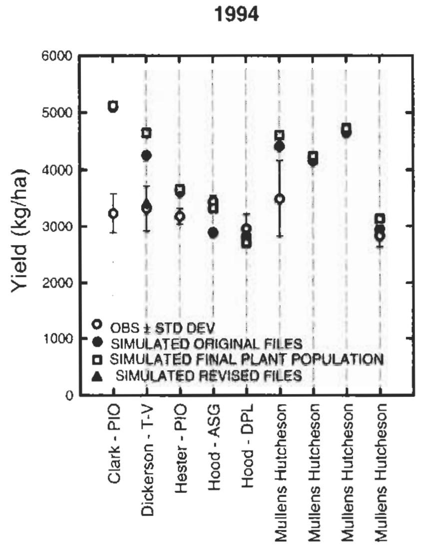

Figure 4.4 Simulated and measured yields for soybean varieties grown in 1994 on several farms in the Mississippi Valley; and differences in predictions using measured and simulated plant populations.

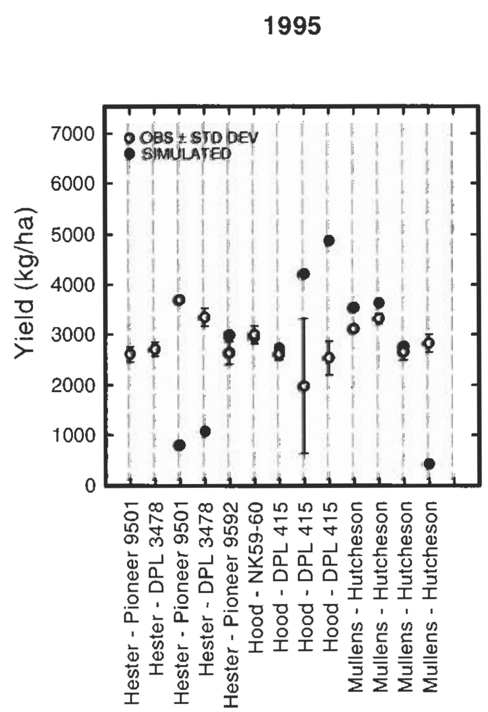

Figure 4.5 Simulated and measured soybean yields for several varieties grown on three farms in the Mississippi Valley in 1995.

problems simulating the correct seed weights. This may indicate a problem with carbon allocation and is currently being investigated.

Currently, measured soil hydraulic and physical properties are used in GLYCIM. These properties include saturated hydraulic conductivity, parameters to describe the relationship between soil

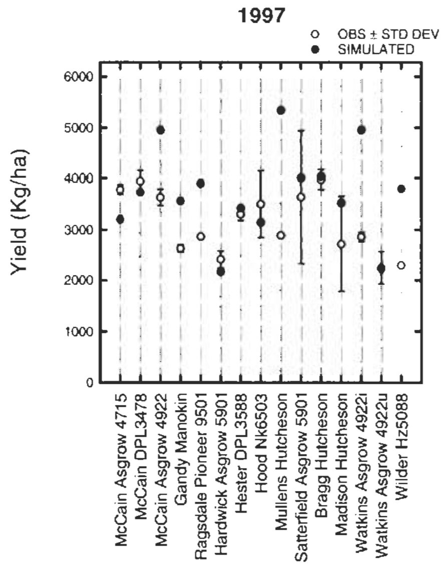

Figure 4.6 Simulated and measured soybean yields for the varieties tested on the cooperating farms in 1997.

matric potential and water content, and sand and silt percentages. Timlin et al., 1996 investigated the use of soil hydraulic properties that were estimated from soil texture. They reported large differences in yields predicted using measured and estimated soil hydraulic properties for single season simulations. Differences in long term averages of simulated yields were less. GLYCIM was most sensitive to the value used for available water content (currently the difference between the 30 kPa and 1500 kPa water contents) and less sensitive to saturated hydraulic conductivity.

Understanding the uncertainties involved with the model, the growers were not overly concerned with the quality of the predictions by GLYCIM/GUICS as long as the differences between simulated and observed yields were not too large. They were mainly concerned with how well the model predicted relative effects of water stress and the other variables to allow them to evaluate comparative management strategies. Irrigation timing predictions seemed to be correct, within 1 to 2 days, and were considered to be satisfactory. The maturity dates were correct about 80% of the time, though the worst error was 10 days. If parameters were not available for a particular cultivar, the use of parameters for a similar cultivar resulted in increased error.

ROLE OF CONSULTANTS

An early assumption of the research team was the expectation that the grower or a member of the family and/or associates would run the model. As farm operations are becoming larger and more complex however, the grower does not have time to make the many runs and analyses necessary to get the most benefit from the model. It would appear that, a consultant advisor could be a target group to service growers by delivering and interpreting the model's output. Cotton growers are accustomed to having such advisors for pest management and do not hesitate to use them for plant growth regulator and irrigation advice. That is not the case, however, for soybean and other small grain producers. In the mid-South, generally, a cotton grower also is a soybean and small grain producer and therefore is likely to use the services of consultants. North of the Cotton Belt, however, small grain producers are less likely to use consultants. At this point, costs cannot be realistically supported by user fees since the economic benefits are not always clear. About 50% of consultants and agricultural extension agents in the Great Plains believe that growers would pay for the service of running a simulation model and managing input (Ascough et al., 1999).

Another area of concern is reliance upon the Extension Service or agricultural consultants in each state to train model users. Computer use among agricultural consultants in the Great Plains area of the U.S. is high at 94% but only 79% use computers for their clients (Ascough et al., 1999). Models such as GLYCIM/GUICS are very different from WordPerfect, Excel, or most of the other computer tools that are rarely updated and even more rarely changed in format of input and output. Plant growth models, however, will probably be updated regularly and input and output requirements changed as new information from research on the target crop is integrated into the model. This seems to be a difficult concept to grasp for trainers who are used to the other types of computer tools.

Use of an Intermediary

Much of the progress and success of the GLYCIM/GUICS project could be traced to the presence of an intermediary to facilitate communications between the researchers and the growers. Whisler, one of the authors of this chapter, was such a facilitator. He had developed a trust relationship with the growers through the previous GOSSYM/COMAX project, and that trust was extended to GLYCIM/GUICS. He and his students were geographically close enough to carry out extensive data collection necessary to improve the model. Because they were close to the farms, they could maintain the consistent and frequent grower contact which helped the project avoid stagnation. The facilitator also often ran the model for the growers and many of the enhancements were made to ease the use of the model by the facilitator for a number of growers.

SUMMARY AND CONCLUSIONS

The USDA research team worked with soybean growers in the mid-south region of the U.S. for 10 years collecting data for model testing and evaluation, and developing a decision support tool for soybean management. The decision support tool included a simulation model (GLYCIM) and an interface (GUICS), an intuitive, easy–to–use tool to assemble the relative data and run the simulation model. The interface also served as an expert system to summarize important information from the simulations, allowing growers to make informed preplant decisions on cultivar selection and row spacing or postplant decisions on irrigation and harvest scheduling. Researchers found that growers preferred to view results of the simulations in terms that are most meaningful such as simple graphs and short, succinct tables.

The absolute estimates of yield by GLYCIM were sometimes very different from measured yields and often too high. The relative responses of GLYCIM to row spacing differences, varieties and irrigation, however, were reported to be realistic and useful. Growers reported a 14 to 24% increase in yields and up to 400% increase in water use efficiency by using GLYCIM/GUICS. Experience with the model encouraged the growers to visit their fields more often which provided important feedback to them.

On-farm research is critical to model development efforts and should not be delayed until the final stages of model development. The development of a working relationship with the growers early in the program helped the team develop a relevant interface. At the early stages the design of the interface was still plastic and modifications did not require major structural changes in the design. Most of the features and uses of GLYCIM/GUICS came not from developers, but from the growers, and were incorporated into the design of the DSS during development. In retrospect, the importance of involving extension agents and consultants in modeling work, especially at the design stage, is crucial. They could then become intermediaries between the growers and the DSS developers.

Decision support systems are very complex, and it is still difficult to promote their widespread use among growers. They are still not easy enough for growers, who have many other tasks competing for their time, to use. The growers most often involved in the use of models are those who are early adapters of technology and are willing to accept more risk. Agricultural extension agents and consultants still do not appear to be very supportive of simulation-based DSSs, as their use grows and agents become more familiar with them perhaps their acceptance will also grow. From the researcher's standpoint, it is difficult to find time for support, providing help with problems, and updating cultivar and soil files. At this point it is not clear if the costs of these models can be realistically supported by user fees.

Nevertheless, DSS systems, such as GLYCIM/GUICS, have been useful and therefore have definite potential to increase profits and reduce resource use. The future still holds promise as computers become faster and software technology allows developers to design "smart" systems that can reduce the complexity of the interfaces. At the same time, researchers are increasing their knowledge of plant growth and development and improving their models.

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