SIMULATION IN CROP ECOSYSTEM MANAGEMENT

Robert M. Peart and
John R. Barrett, Jr.*

Agricultural Engineering Department
Purdue University
West Lafayette, Indiana 47907

ABSTRACT

A crop ecosystem includes crop, soil, environment, weeds, diseases, insects, nutrients, water, solar radiation and cultural practices.

Simulation of the response of this system to weather and to man's inputs can provide the basis for a dynamic information system to help a manager choose between alternative courses of action. Such a system requires near real-time data acquisition and a relatively fast-running model of the system. Then, the crop growth and development can be calculated within a few hours of the data acquisition. Simulation of the current status of the actual system has many advantages over visual observation of the crop alone. Visual observation often does not provide accurate soil moisture data, early warning of nutrient deficiencies, or counts of insects and fungal spores too small to see.

In addition, weather forecasts and historical weather data can be used with a crop simulation to project future status and determine optimal management plans.

A dynamic crop management information system has three parts, 1) a near real-time data acquisition system, 2) a fast-running model of the crop ecosystem, 3) a fast, but human-oriented system to get the resulting information to the farm manager. This paper gives an example of an early version of such a system at Purdue University.

INTRODUCTION

Decision-making in the production of agricultural crops should be visualized as the management of an ecosystem. The crop is influenced by solar radiation, air and soil moisture, insects, weeds, diseases, cultivation, chemicals, etc. The crop ecosystem is driven by the environment. The processes are somewhat similar to industrial processes, but many of the variables are stochastic, weather-dependent and are not under man's direct control. Also, many of the influences are not normally measured, easily measurable, recorded or stored for reference. Actually, many cause-effect relationships are not yet clearly understood.

Management of crop production is continually improving, however, and as we learn more about the crop ecosystem and the important interactions among soil, crop, weeds, diseases, insects and weather, we can improve our control of the system. Food production is rapidly becoming an enormous optimization problem. World food needs now and in the future demand that we do our best. In this paper, we discuss how simulation and near real-time data acquisition can be combined to give a dynamic management information system to help the farmer produce food with optimal use of resources.

CROP ECOSYSTEM MODELING

While a reasonable amount of literature exists on crop modeling, it is in an early stage of research and the literature appears in widely-scattered sources. The International Biological Program (IBP) resulted in a number of detailed models of biological systems (26), but agricultural crops (monocultures) were generally excluded from this work.

Cotton has received more modeling attention than any other crop due to a project of the Agricultural Experiment

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*The authors are, respectively, professor, and assistant professor and agricultural engineer, U S D A Agricultural Reasearch Service.

Stations of the Southern Region of the U.S. Professor H.N. Stapleton, an innovative agricultural engineer now retired from the University of Arizona, won the first Engineering Concept of the Year award from the American Society of Agricultural Engineers in 1975 for his pioneering work on a cotton ecosystem simulation (43,44). Duncan, Hesketh, and Baker (15) and Jones and Threadgill (27) made major contributions to the cotton model called SIMCOT and related simulations.

Duncan is also an early leader in modeling of the corn (maize) crop (14,16). He first studied and modeled the effects of corn leaf angle, area and height in the canopy, taking account of solar angle, direct and diffuse radiation and reflections from leaves and the soil surface back to leaves. Duncan also modeled the difficult and important seed production phase of crop growth for a direct yield output of the simulation. He noted the importance of the complex and critical "trigger" that switches the plant abruptly from vegatative to reproductive growth. He is currently working with peanuts or ground nuts, a major human protein source in many parts of the world.

Soybeans have been modeled with increasing yield output as the goal by Curry (7,8,9) and that work is continuing. It may help solve the yield barrier problem of soybeans. Lambert (2) developed a very significant tobacco model with the objective of optimizing irrigation timing, not for maximum production but for maximum net economic return. The key was a yield loss function for water stress, a very complex relationship in many crops.

Alfalfa forage production has been modeled by Miles, Bula, Holt, Schreiber and Peart (35) with time steps short enough to show diurnal fluctuations of carbohydrate concentrations in leaves, stems and roots. The model has a forage yield output and handles regrowth after each harvest cutting, which occurs several times during the growing season. Miles (33) then developed a generalized, crop simulation language (CROPS) for use by modelers of plant growth. It uses the GASP IV language of Pritsker (40).

Major contributions to crop ecosystem modeling have been made by deWit and his co-workers at Wageningen (10,11,12,13) and his first model of grass growth was called ELCROS, Elementary Crop Simulator.

Insects are an important part of the crop ecosystem, and models of their growth, feeding and reproduction have been developed, often for the purpose of devising controls using less chemical methods. Stinner is a leader in cotton insects (46), and Guitterez (22) has modeled the effect of defoliating insects on California cotton, using SIMCOT. Loewer, Huber, Barrett and Peart developed SIMECOB, (29,30) a simulation of the European Corn Borer that is currently being validated by Barrett. Brewer (4) has applied numerical and probabilistic methods to insect population growth modeling. Hartstack and Hollingsworth (24) have developed a well-researched model of the cotton bollworm, second in importance only to the boll weevil as a cotton pest.

Waggoner and Horsfall (47) have developed important models, EPIDEM and EPIMAY (48) of two similar fungi that cause diseases of crops. Shaner, Peart, Newman, Stirm and Loewer (42) reported on runs of EPIMAY done in the summer of 1972 concurrently with large-scale ground level field observations and remote sensing by multi-spectral scanning from aircraft for detecting Southern Corn leaf Blight.

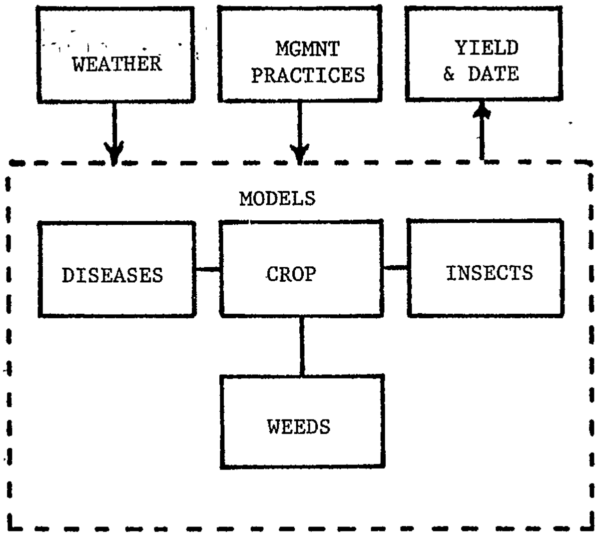
HIERARCHY OF MODELS

The output of a crop model is a continuous description of the growth and development of the population of plants. The output of an insect model is a continuous description of insects which will attenuate the crop system, and which will in turn be affected by the state of development of the crop.

Similar interactions exist between all the major parts of the ecosystem as shown in Figure 1.

A number of the crop, insect and disease models described previously are too detailed to be combined into an ecosystem model that could provide fast simulation runs. Miles (34) calls these "element" models and places them one step below ecosystem models in the hierarchy of models. Element models are more detailed and are often designed to provide output similar to plant physiology research data. Crop ecosystem models provide output data more nearly like the results of field plot or farm field demonstration results. Models such as those for leaf stomata or plant biochemical reactions are even more detailed and thus closer to the base of the modeling hierarchy, as shown in Figure 2, while farm management models combining several ecosystems and enterprises would represent a higher level with a broader scope and less detail. These distinctions do not imply higher importance for any level of modeling, but rather serve to emphasize the appropriate selection of a

FIGURE 1
CROP ECOSYSTEM RELATIONSHIPS



model based on the desired use of the model.

SIMULATION AS A MEASUREMENT TOOL

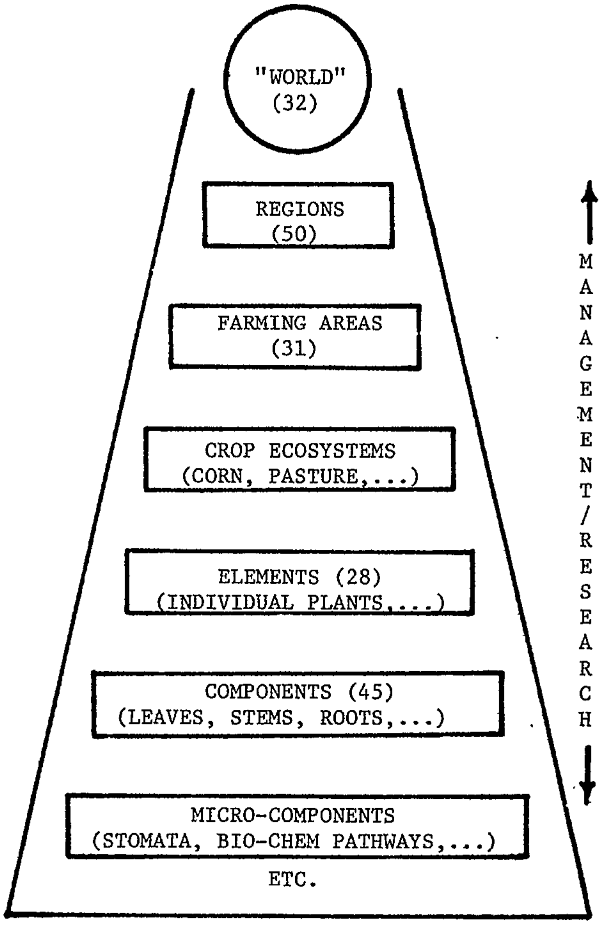
In the basic model of a crop ecosystem that is to be managed, the simulation is part of the descriptive measurement system which is driven by an index of energy accumulation and attenuated by such factors as temperatures, availability of moisture, intensity of rainfall, etc.

Thus, one might say that these are not really simulations but that this is a method of describing the crop growth processes with computer assistance. Actually, the simulation is a part of the measurement procedure. From a farm management standpoint, this is what is needed, as many important state variables in the crop ecosystem are not easily observable. Further, the application of the procedure comes when management interacts through choosing one of a ranked group of alternatives that will help to most efficiently produce our food and fiber.

DATA ACQUISITION

An agricultural crop is basically a complex biological system, with man interacting. Recognize that all of the data used in simulating crop ecosystems are invariibly from the real world, stochastic in nature, descriptive of life processes, and that these data include all the biological variability inherent with the system to be simulated. Also, recognize that only recently have most biologists and agriculturalists begun to take time oriented data. Rates and accelerations are new concepts, and most literature contains only descriptions or point-in-time observations of the status of a system.

FIGURE 2
HIERARCHY OF MODELS
OF AGRICULTURE



Simulations of crop ecosystems require several types of data for use at different times during the modeling process. These data are used in developing, calibrating, validating and running crop ecosystems simulations, and they are different from the data usually used in pure industrial engineering simulations of process flows over time. Biological growth and physiological development are usually indexed to a variable representative of an energy level that changes over chronological time. For example, air dry-bulb temperatures are frequently used to index the overall state of the energy balance through heat unit or degree-day accumulations. This index usually considers only 24-hour maximum and minimum temperatures and is limited to a reference base below which no decelerated growth or development occurs. An upper limit sometimes fixes the maximum rate of accumulation. This indexing system in some form is presently the basic scheme used to tie together and drive simulations of the subsystems of the crop ecosystem.

USES FOR DATA

Environmental and crop status data are needed to develop a historical base which is continuously changing. This base is primarily used in developing a crop simulation. Current growth-year data are needed on a near real-time basis to form the current status of a particular crop ecosystem simulation, and projected conditions are needed which allow a manager to see what is to be expected if he chooses a certain alternative. Thus, by using current meteorological data and incorporating forecasts of future events, either weather or management practices, the course of future crop and insect growth and development can be predicted.

TYPES OF DATA

The environment of a crop influences life processes both continuously and discretely. As example of a continuous relationship is the functional association between the accumulation of heat units and corresponding growth and development. On the other hand, discrete relationships are like logical yes-no points during growth and development, as critical temperatures above or below which processes are either stopped or started or their rates modified. These thresholds may not remain the same over a complete life cycle, nor are they the same for each individual in a population. This is a source of error that is difficult to quantify.

An interactive continuous-discrete situation is represented by plant or animal growth and development that continues at a specific rate until an event occurs; e.g., rain or insecticide application. Afterward, life processes change.

Environmental data used in crop simulations represents and indexes the complex energy flows to and from plants and animals. The use of these data should influence the formats of collection and the variables monitored.

Various existing data collecting systems are described by Barrett, Huggins and Stirm. (3) A systematic approach to environmental data reduction is presented in another paper of this conference by Wong, Mahler, Barrett and Huggins. (51)

SOURCES OF DATA

Data for use in simulating the subsystems of a crop ecosystem come from three sources: 1) human observation of growth and development patterns which is frequently centered about the staged physiological development (rather than mass accumulation) or about abnormal occurences, 2) historic environmental descriptions which are usually strip chart records or human observations and records, and 3) current environmental descriptions that are at best hybrid strip-chart, microprocessor based systems.

In agricultual application, real-time or near real-time means weekly, daily, hourly and infrequently continuous, data packets. This is a compromise of that which is available, computer processing time allowable, and need.

The desired characteristics of an automatic data acquisition system for environmental data are: 1. Low costs for transducers and components. 2. Operational reliability over environmental extremes without attendance. 3. Prevention of time registration errors between recorders. 4. Use of a digital format wherever possible. 5. Operation on battery power to minimize downtime from power outages and to allow monitoring at remote locations. 6. Maximum compatibility with existing strip-chart recorders and associated transducers to allow rapid integration with existing instrumentation and cross-referencing of data. 7. Availability of output in standard max-min, point-in-time, or summation format, along with integral, rate, and acceleration formats.

U.S. DEPARTMENT OF COMMERCE SYSTEMS

Data collection systems that are operational within the National Weather and Environmental Data Services of the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce (18) are designed for immediate weather forecast needs and for long-term data-base development.

Surface weather data are collected and reported hourly from 300 first- order stations in the United States, primarily at airports, and twice daily from 70 locations that take upper-air soundings to heights of 30 km. Supplemental daily (sometimes hourly) observations are made by 3,000 river and agricultural stations that report daily. An additional 5,000 climatological stations are required to provide an adequate sample to describe the climate. Fifty of these stations are high-quality bench-mark stations that monitor long- term climatic change.

The hourly data consists of instantaneous values of air temperature, dew point, pressure, wind, sky cover, and humidity, recorded at the beginning of each hour. Also recorded as accumulated hourly totals are solar radiation, precipitation, and sunshine date.

At stations that record daily values only, one observation is made for each 24-hour period ending at 7 or 8 AM, at 6 or 7 PM, or at midnight. Time of observation is determined by the purpose of the station (river, agricultural, climatological). At daily-recording stations, the format for each parameter is represented by maximum, minimum, and observation time values for air and soil temperature and humidity; 24-hour totals for precipitation and evaporation; and departures from normals.

Upper-air-sounding data are instantaneous values measured at standard and supplementary heights for air temperature, pressure, dew point, and wind direction and speed.

The primary problems with the use of NOAA data in agricultural applications are the limited number of observations; the limited number of parameters recorded; and the slowness of publication, especially when on-line files are desired. The primary advantage is the availability of a long-term data base from a large network of stations.

ACQUISITION OF DATA WITH MICROCOMPUTERS

Near real-time acquisition of data by microcomputer is implemented experimentally for agriculture weather station observations at the National Weather Service-Purdue Micrometeorological Station. A prototype, entitled MICROS (Meteorological Information Computer Remote Operating System), was developed in 1975 (23). The essential components are: 1. 115-v power. 2. A microprocessor to permit the reading and writing of stored variables. 3. A multiplexing unit for scanning analog inputs. 4. A real-time clock. 5. A differential operational amplifier. 6. An integrating analog-to-digital conversion unit. 7. A contact pulse counting unit. 8. A serial switching device for dataphone transmission and/or an on-site recorder with a magnetic or paper punch. 9. Telephone service. 10. Availability of a computer system for central data collection and processing.

The MICROS system scans multichannel analog signals from transducers once each 15 seconds, amplifies the signals, performs analog-to-digital conversion, and collects the digital values in random access memory (RAM) as controlled by programmable read-only memory (PROM). A routine in the PROM updates time and provides for storage of the averaged (by integration) and accumulated data at the end of each hour. The memory stacks in the microcomputer holds 29 consecutive hours of data.

An interface permits either local or remote access to the stored data. A dataphone coupler and a private phone line allow access by an off-site processing computer. On-site acquisition is accomplished by periodically dumping hourly data onto magnetic or paper tape. Four of these units are now operating in Indiana and more are planned.

The MICROS system automates an hourly-recording agricultural weather station. This frequency is sufficient for many applications but not for some research and storm associated forecast needs.

INCREMENTAL INTEGRAL METHOD

The incremental integral method is an experimental alternative to standard strip-chart hand procedures and automated fixed-time sampling methods. This approach involves recording the time at which a variable has changed by a preselected amount. A digital event recorder is connected to various transducers that supply the input signals whose changes constitute a stream of events, such as the accumulation of 1 mm of rain or a fall or rise of 1/2 deg. C in temperature. The summation of events defines a parameter level at any point in time. Differences between points in time give rates, and changes in rates give accelerations.

Such a system is manufactured in Australia by RIMCO, Rauchfuss Instruments and Staff Pty., Ltd. and is in extensive use by Commonwealth Scientific and Industrial Research Organization, Division of Land Research, Australia. (21) It is used in collecting field data over extended periods in remote locations where no shelter or electrical power is available. Its battery is either solar, wind, or line trickle-charged.

Four primary advantages are offered by the incremental integral concept. Of greatest significance is the assurance of recording high-frequency changes that might be missed when they occur between the sampling points of time-interval based systems. The second advantage, an extension of the first, is the prevention of redundant data. Third, a simplified format is usable because only a single stream of characters that represent changes is generated. These original data may be stored in a very compact form.

SIMULATION IN OPERATIONAL MANAGEMENT

Three examples of the possible use of simulation in crop ecosystem management are: 1) Estimating supplemental fuel for solar corn drying, 2) Double-cropping of soybeans after wheat, and 3) Alfalfa management system. The last one, alfalfa management, has been in operation with cooperating farmers in Indiana for three years.

ESTIMATING SUPPLEMENTAL FUEL FOR SOLAR CORN DRYING

Solar energy use in a corn dryer after harvest has been extensively tested in recent years. (19) Currently, adoption depends upon the variable cost and availability of LP Gas, natural gas or electricity and the annual fixed cost of a solar heat collector facility. Beyond that, however, a solar collector and drying design that works well one year may be unsuccessful in another year. Corn maturity date varies from year to year according to planting date, weather and variety of the seed. Following physiological maturity, some drying occurs in the field, and this drying rate varies with weather. Thus, a solar drying system designed for starting harvest at a given corn kernel moisture content may not be satisfactory in a year when maturity is late and field drying is slow. If the farmer harvests earlier at a higher moisture content, his system will not dry the corn quickly enough, and if he waits for more field dry-down, ears drop and stalks break to cause costly losses. In addition, in one of these sub-standard years, later harvest means less solar energy availability due to shorter days and more clouds.

We have been testing solar drying systems and simulating solar corn drying for three years, and it now appears that a feasible solar drying system for the eastern Corn Belt will require supplementary energy during some harvest seasons. Thus, the farm manager and energy suppliers will need an accurate estimate of the need for and the amount of corn drying fuel to be required in a given year. Our models of corn growth, field dry-down, and solar drying system provide the basis for a simulator (SUNDRY) to make this estimate.

SUNDRY takes as input the planting date, the corn variety, the location in Indiana, and a number of variables relating to the solar collector and grain drying system design. In addition, data relative to the solar radiation for the historical year to be tested and temperature data throughout the growing season for that year are input. The simulator is currently being used with a number of past weather years to evaluate the design of a solar drying system. Corn growth and maturity are calculated by a simple model utilizing the Growing Degree Day concept (GDD). This method is described by Newman (38), and was described for use with a corn harvest simulator by Morey, Peart and Deason (37). Growing Degree Days are accumulated from the time of planting by the following rule:.

$$GDD = \sum_{days} ((TMAX + TMIN)/2 - 50F),$$

where TMAX is $\leq$ 86F and TMIN is $\geq$ 50F.

This relationship approximates the sigmoid growth rate curve as a function of average daily temperature. Agronomists have developed tables of total growing degree days required for maturity of corn varieties at various locations in the Corn Belt, and these are used to determine if the crop matures normally. If frost occurs before the required total growing degree days are accumulated, the model calculates an increased moisture content at this point which then is defined as maturity, since no further growth will occur.

The field dry-down model is then used to calculate the date when the corn will reach the moisture content desired for harvest. Bruns (5) has developed a field dry-down model based on the environmental variables of wind speed, temperature, relative humidity, solar radiation and the corn moisture content itself. Currently, however, SUNDRY has a simpler dry-down model based on calendar days with faster drying during the early part of the field dry-down period, with field dry-down stopping on November 1 in central Indiana. The model allows harvest to begin at the specified moisture content or at a specified calender date, whichever occurs first.

Grain drying begins on this harvest date with the solar collector and grain drying design as specified in the input. This is usually an air heating collector designed to raise air temperatures in the range of 15C (27F). The grain drying system is usually a bin with false floor and an air flow of approximately 2 cfm of air per bu of grain with a depth in the range of 3 to 5 meters. The grain drying model is based on laboratory tests of the rate of drying of thin layers of grain with air supplied at various temperatures and relative humidities. For computational purposes, the bin is divided into thin layers and the drying of the bottom layer is calculated based on the air inlet conditions. Then the moisture removed from the bottom layer during the first time period (usually 1 hour) is averaged over that hour and added to the exhaust air from the first layer making the input air to the second layer, etc., throughout the depth of the bin. Moisture condensation of warm moist air on cooler grain in upper layers is possible, and rewetting by the condensation mode and re-absorption of moisture by dry grain from wet air is also allowed. The solar collector model is over-simplified in that it merely assumes a fixed collector efficiency. The output energy is a function of the collector surface area and the solar radiation received during that hour according to the input data from the historical weather year.

An important part of the grain drying simulation is the program to calculate the rate of spoilage. If conditions are not good for drying, spoilage can occur in the last layers to be dried by the growth of micro-organisms, principally molds. Saul (41) has measured the rate of carbon dioxide production due to respiration of the corn kernels and the micro-organisms in the grain, and these data serve as the basis for a model of spoilage rate as a function of grain temperature and moisture content. An upper limit on his total carbon dioxide production sets a limit to the allowable storage, and the simulation program accumulates this as a percentage of the allowable storage life or as the total dry matter loss due to this respiration process. If the spoilage level is exceeded, the test is labeled a failure, and a printout is given of the corn moisture contents at various levels so that an estimate of the severity of the problem can be made by observation. That is, if only the very last layer to dry is subject to this spoilage, the problem is not nearly as serious as if spoilage occurs before half the bin of grain is dry.

To use SUNDRY during a particular year before corn has reached maturity or the dry-down moisture, we would use the actual weather data up to the current time, then substitute the weather forecast for the next 5 to 10 days, and then the average historical weather data from the past to project the model and estimate corn maturity dates. Similarily, historical data would be used to estimate the dry-down rate in the field and the air conditions and solar radiation for the time when harvest is predicted by the model. The Statistical Crop Reporting Service (1) collects estimates of the amount of corn planted in various areas of the state each week during the planting period. Using these data, the simulation can estimate corn harvest dates and the probability of successful solar grain drying for all areas of the state ahead of the harvest season. This information is important for energy suppliers (LP and natural gas) so that they may have an estimate of the demand for crop drying fuel. This will be particularly important as the change-over is made to more solar grain drying, as the corn drying demand could vary from zero to a very significant amount of LP gas late in the season when competition with other industries and residences is a problem. For example, it is estimated that currently each fall season in Indiana, corn drying uses the equivilent of 60,000,000 gallons of LP gas. About one-fourth of this is in the form of natural gas, but this is now being cut back by limitations on use.

Farmers in the future could make use of this system with the development of additional software for accepting individual user inputs and providing outputs in a form usable to the farm manager. In addition, a computer-based management information system would make this simulation package available to the farmer at his own county Cooperative Extension Service office. This type of management information system is visualized in a current project just now underway at Purdue and supported by the Kellogg Foundation. The project will develop a computer network called FACTS with terminals available at county extension offices and a wide variety of information will be available over the terminals, ranging from simply reproducing computer file copies of the latest up-dated conventional types of recommendations to the running of simulations specific to the particular user and the weather in his area. While most of the research and development has been done for a program for farmer use on estimating corn drying fuel usage, the remaining software developing a usable system for non-computer programmers is an important need which we discuss further later in this article.

DOUBLE CROPPING OF SOYBEANS AFTER WHEAT

A growing practice in parts of the Midwest is to plant a second crop of soybeans immediately after wheat is harvested around July 1. Normally single crop soybeans are planted before the middle of June in the Midwest, but by proper selection of variety, and with adequate soil moisture either before or from rain immediately following planting, soybeans planted on July 1 as far north as the central Midwest have a good chance of being a profitable second crop. The profit return for this management method is approximately the same as for high-yielding corn. Success depends on correctly making a series of timely decisions and having suitable weather conditions.

There are risks involved, as the recommended practice is to plant the soybeans directly into the wheat stubble with a minimum tillage planter. Direct planting occurs at a time when each day is critical to insuring a growing season long enough for the soybeans. The risk involves considerable capital because with the planting equipment and labor, herbicides, and seed the farmer has about $50 per acre invested. His break-even yield depends upon the soybean price, another uncertainty in the picture. It is not uncommon for second crop soybeans to yield as low as 10 bushels per acre. Thus, a price of $5 per bushel would be required to break even. And, in central Indiana 1 year in 5 is unsuitable for double cropping due to bad weather. The farmer usually has many other more profitable uses for his capital than just to break even, so he wants a relatively high probability of making more profit than simple interest on his investment. However, making $25-30 per acre additional profit per year is a viable result to an alternative that should be considered.

A management oriented model of the wheat-soybean system, with interactive simulations and decision-maker input is being developed. The following discussion covers the 12-month process showing when decisions must be made and what the controlling factors are. Economics are not a part of the program and a human interface is necessary between the computer and the farm manager.

In the fall, if wheat is to be planted and if double-cropped soybeans are a possibility for consideration, planting date and variety selections are critical. Planting must occur late enough to miss a potential damaging population of Hessian fly adults; must be after the potential for barley yellow dwarf and other disease infections are past; must be while soil conditions are suitable; and timed so the wheat is well established, but not with excessive growth, by winter. Variety is selected according to ecological region, considerating past and expected weather, yield potential, and rate of spring maturity. Fertilizer application differs between wheat only and wheat/soybeans crop ecosystem. Suitable labor and land use rotation are parts of management and are not programmed.

Winter factors control whether wheat is allowed to go to maturity, is grazed by cattle, or is plowed under and a higher potential profit crop is planted in the spring. Snow mold, sheets of ice, freeze-thaw heaving, excessive growth during mild periods, etc., influence the condition of the wheat when spring comes.

While weather data are coninuously input to the program, the first simulation is of the wheat crop and this begins at the time of head formation. A critical factor is freezing or frost that occurs after this head formation stage of physiological maturity begins. The time of head formation varies by variety as influenced by weather.

The wheat crop simulation continues to maturity through field dry-down to a harvest date. Moisture content at harvest and management of the grain are user inputs. If double-cropping is potential, drying after harvest may be required. The interface between the two crops is critical and here many factors must be considered, including soil moisture to germinate soybeans, storage and drying facilities available, the need for heat in drying, quality and test weight of grain needed, etc.

A drying simulation interacts for a two week period. The output of this gives information to help the decision-maker manage the operation. Possibilities are: sell direct from the field; harvest and store with natural air, solar heat or no drying; dry and sell or store and wait for better prices; or store for seed.

Critical to planting beans in late June or early July are several factors. Included are the date the land is available after wheat harvest, available or expected moisture to germinate the seed, available no-till planting equipment, and predicted fall frost date. Variety selections, herbicide application, labor availability, and land use plans are left for consideration by the manager. Modern data acquisition systems for weather data along with simulation of the wheat and soybean crops and estimation of rainfall probabilities can give the farm manager a much better basis upon which to make decisions. We are working now with wheat breeders to determine varieties of wheat that might mature earlier without a loss in yield. We are also studying solar drying of wheat in the bin to allow harvest about 1 week earlier, thus improving the possibilities for the second soybean crop. A necessary requirement for this management system is the model of the winter wheat crop which is used for estimating time of maturity. An early estimate will allow the farmer more time to make his decisions and to obtain equipment and supplies for planting a second crop of soybeans if he chooses to do so. Current soil moisture data, soil type, and rainfall probabilities in the particular area for the important germination and early growth period are important inputs for an overall crop ecosystem simulation.

Work on this problem is still in the early stages of development, but we are rapidly putting together the requirements for this simulation, as we have this very specific use for the simulations defined. This is another problem solving tool to be added to the FACTS system to be available to any farm manager at his county extension office.

ALFALFA MANAGEMENT SYSTEM

This third system is in operational use and has completed three seasons with selected farmer cooperators in the northern and in the southern areas of Indiana. This program has been reported by Giese, Peart and Huber (20), Peart, Huber, Blake, Wolf and Miles (39), Edwards, Wilson, Meyer and Morihara. (17) The data gathering part of the system is of two kinds, weather data collection and observation and counting of insects at critical times. The weather data is collected in the two areas by manual means and by one of the previously described MICROS automatic weather stations. The second method of obtaining data is for trained entomological observers to visit the fields of cooperating farmers with sweep nets to make counts of alfalfa weevils and record their stage of development. A simulation program for following the growth and death of alfalfa weevils was developed by Miles, Hintz, Wilson, Pritzker and Peart. (36) The model was used to determine when scouts should go out into the fields to observe insects. It was found that a particular stage of development of an insect could occur on a calender date as much as 40 days different from one year to the next, and the model of the insect utilizing weather inputs gave us a good estimate of when scouts would be able to find third-instar larvae in the field, for example. The model is not able to calculate the absolute number of insects, however, without some base point to begin calculations, and the scouting reports were used to give this basis. Also, the scouting reports were used to continually adjust the actual status of the insect if it was found to vary from the simulated status. The scouts also observe the height of the alfalfa crop and this data goes into the alfalfa simulation model. (35) After initialization, the insect and alfalfa programs are run on a weekly basis, and the extension entomologists follow these simulation reports to watch for a critical insect pest build-up. This usually occurs in May, and recommendations will generally be of one of three types, 1) no control necessary because insect populations are not too high, 2) spray on or near a specificied date for control of weevils, of 3) harvest the crop by a specificied date. This latter solution destroys a large population of the weevil larvae and this recommendation is made if populations are high and the crop simulation shows that the crop is reaching a satisfactory stage for early harvest.

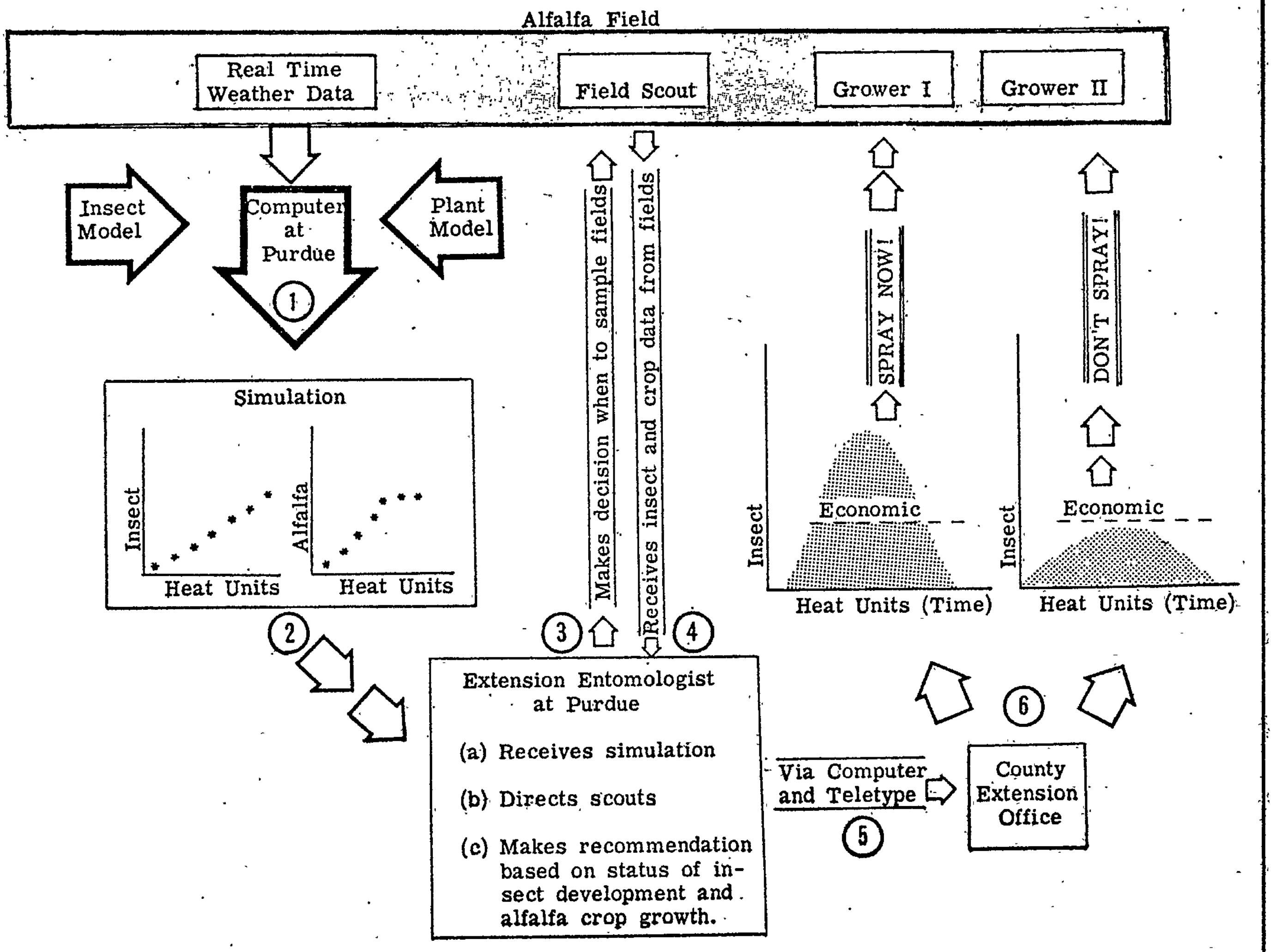
These recommendations are put on the computer data bank by the extension specialists, copies are sent to the cooperating farmers, and copies can be called for by the county extension agent on his terminal. Thus, the county extension agent can use the information to give advice to other farmers in the area. In addition there are several other files on the terminal system that can be called for, including up-to-date spray recommendations, amounts, and warning of hazards to operators, fertilizer recommendations, and an updated three day weather forecast for the particular area. Provision is made for messages to be placed on the system from the county so that the extension specialist at the state office can answer questions, but this has not been used extensively so far. We expect this to be a major advantage of the new FACTS system.

While not implemented over a wide area, we do have an example of an hierarchical computer system looping from a micro-computer in the field interrogating weather instruments to a mini-computer on the Purdue campus calling for and logging this weather data and sending it to the large major computer facility on the campus for running of the complex simulation programs, results of which are sent back to the data acquisition mini-computer. After analysis of these results by the extension specalist and using his judgment and knowledge of the situation, he enters a message in the computer data file which then may be accessed back out in the field by a computer terminal linked by phone to the mini-computer data acquisition and information system. This concept is very exciting to us (Figure 3) and has stirred the interest of extension workers and farm managers alike. Haynes and his co-workers (25) and Watt (49) in an earlier paper laid the foundations and espoused such a concept.

ACCEPTANCE OF SIMULATION BY MANAGERS

We feel we are at a significant point in the development of the use of simulations as part of management systems. The hardware is available, the simulation languages are suitable, the technology of developing simulation models is well-known, and there is no apparent limitation in software. Now, however, the feasibility of simulation as a routine management tool must be proven, taught, and/or demonstrated. Human factors must be taken into account very thoughtfully in this process. A natural aversion to a "de-personalized computerized system", to an unknown and apparently very complex

FIGURE 3 PURDUE ALFALFA MANAGEMENT PROGRAM (17)



technology, are very real obstacles to acceptance. In addition, realistic managers want to be firmly convinced that such a new system is valid and proven and that it can operate in a way complementary to his judgment developed over years of experience.

These are all valid reasons for viewing "computerized management" with suspicion. We do not characterize this concept as computerized management, but rather as provision of an improved information and data base to help the manager make better decisions on his own.

We feel it is important that during the development of a management information system the user should have input into the process, so his viewpoint, perspective, needs and wants are considered. The system is being developed for the user, not for the systems engineer. We try to leave the decisions in the hands of the managers, not the modelers.

THE FUTURE OF SIMULATION IN MANAGEMENT

We have reviewed what we believe to be pioneering work in this field. Current applications are experimental and we expect much wider use to develop. However, development will probably be at a moderate pace, rather than rapid. The hardware and the system software are available, but the crop ecosystem software development will take considerable resources.

The development of crop ecosystem software will encourage and demand much more physiological research. Much past work has been with just one element or micro-element of a plant, and the need is for information about the interactions not only among plant parts, but between the plant and other elements in the ecosystem.

Different uses will demand simulation software written at different levels in the hierarchy of models. Political and economic decision-makers will need information about broader systems than will the manager of an individual farm. Most of the current experimentation in crop ecosystems is with the major crops such as cotton, corn and soybeans, but major benefits are potential with the application of these ideas to the many speciality crops which are often high in value per acre and may be very vulnerable to the environment.

In conclusion, we feel that simulation has a prominent place in future crop ecosystem management. It will be part of the measurement system, relating measurable variables, such as weather, to the state variables such as disease development, number of insects and potential yield, about which the manager needs better information in order to make better decisions. Simulation will also be a part of predictive systems so that the manager can obtain an estimate of the likely results of actions he could take in the future for more efficient crop production. These uses will be of major importance in helping feed the people of the world in the future.

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