CROP MODELS – IN OPEN FIELD

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Summary

Farmers need to make informed assessments in order to manage their farms efficiently. Strategic and tactical decisions are frequently made based on rules-of-thumb, grower experience, and advice from agricultural consultants. Risks associated with uncertain weather forecasts, the potential for disease and pest problems, unpredictable market conditions, and increasing legislative and public pressure to more efficiently manage natural resources increase the need for farmers to make informed decisions based on large and disparate amounts of information.

Crop models and decision support systems that quantify and analyze complex soil, plant, and atmospheric relationships can be very useful for supporting or supplementing such decisions by providing predictions and guidance that could improve existing practices. Crop models are also well suited for addressing agricultural, environmental, and natural resource systems issues at scales larger than the individual farm.

Crop modeling has been a significant focus of agricultural research since the 1960s, and consists of mathematical equations and computer code that quantify knowledge of plant growth and developmental processes and their interactions with the plant, soil, and atmospheric interfaces. Crop models have been successfully used as tools to aid in farm

management, regional-use issues such as yield-decline assessments, policy planning, and land use issues, including assessing the impacts of global climate change, scientific investigation, and educational activities. Future work in the development of crop models and decision support systems will continue to positively impact sustainability and management of agricultural systems and natural resources.

1. Introduction

Farmers need to make informed assessments in order to plan and manage their farms efficiently. Strategic and tactical decisions such as when to plant, what cultivar to use, when and in what manner to fertilize and irrigate, and when to harvest, are frequently made based on rules-of-thumb, years of grower experience, and advice from agricultural consultants. Risks associated with uncertain weather forecasts, the potential for disease and pest problems, unpredictable market conditions, and increasing legislative and public pressure to more efficiently manage natural resources increase the need for farmers to make decisions based on large and disparate amounts of information. This challenge becomes increasingly difficult to manage as farming operations increase in size and complexity. Crop models and decision support systems that quantify and analyze complex soil, plant, and atmospheric relationships can be very useful for supporting or supplementing farming decisions by providing predictions and guidance that are an improvement over existing practices. Information predicted by these modeling tools is also well suited for addressing agricultural, environmental, and natural resource systems issues at scales larger than the individual farm.

Crop modeling has been a significant focus of agricultural systems researchers since the 1960s. Sparked in part by rapid development and availability of desktop computing power, crop models have become sophisticated, powerful tools for on-farm management, regional land-use issues, policy planning, scientific investigation, and educational activities. Crop modeling can be viewed as a tool for (1) integrating scientific knowledge on whole plant responses to environmental and management variables, and (2) for presenting information to support the decision making processes of agricultural practitioners. In the former case, models quantify knowledge in a format that can provide scientists with techniques and methodology for evaluation and additional experimentation of related theories. In the latter case, computer software programs are frequently developed around the crop model in order to simplify access to simulations and results that are usable by both scientists and non-scientists. These programs typically serve as decision support systems, where simulated outputs can be used to support management decisions at the farm level and land-use decisions at the policy level.

Crop models consist of lines of software code and mathematical equations, based on certain assumptions derived from natural laws or empirical observations, that attempt to mimic the complex functionality and behavior of real-world plant processes. Because of the diverse and complicated interactions involved in biological systems, crop modeling is a highly interdisciplinary endeavor, relying on knowledge of various academic fields including agricultural and systems engineering, biochemistry, molecular genetics, plant physiology, soil science, and statistics. Equations are constructed by accurately transforming experimental data and theoretical ideas about various plant processes into mathematical expressions. These expressions are then linked together via code in computer programming languages, such as FORTRAN, in order to solve the expressions and output the model predictions in a format easily interpretable by the end-user. The accuracy of the assumptions used in building the model is revealed through comparisons between the model predictions and real-world data. Additional tests, such as sensitivity-analyses, are typically performed to evaluate the reasonableness of the models, where the response of model outputs, such as crop yield, is compared against changes in model inputs, such as light intensity or temperature. [Sensitivity analysis typically involves that for the model parameters, not driving variables] Discrepancies between simulated and expected 'real-world' values indicate the need to re-address some of the modeling assumptions and the process described above is repeated as needed.

Models are built with respect to specific stages of hierarchy. For example, levels of hierarchy in cropping systems range from field, plant or crop, organ (e.g. leaf, stem, root, ear), tissue, cell, and molecular scales, in order of increasing levels of detail. Crop models typically function by predicting phenomena at the plant or crop level of organization based on an integration of responses at the organ level. Thus, the types of crop models that are the focus of this chapter simulate whole plant growth and developmental processes by focusing on the individual organs. These outputs are usually extrapolated within the model code from a g plant^{-1} level to the kg ha^{-1} level in order to represent average crop production on a grower's field.

Most crop models are dynamic and deterministic. These characteristics mean that (a) the model predicts changes in plant growth and development over time throughout the production season, and (b) there is no probability distribution included in the model output (e.g., a single average value for yield, such as 28 kilograms of soybeans per hectare, is provided instead of the average values plus standard deviation, such as 28 +/- 8.1 kilograms per hectare). As opposed to dynamic ones, many static agricultural models have also been developed. Static models typically output a single value, such as maturity date or total yield at maturity, as opposed to the time series information (e.g. yield at each day of growth) provided by dynamic crop models.

Models can be further classified as empirical or mechanistic based on the manner in which information is quantified. Empirical approaches consist of curve-fitting or regression type equations that quantify observational data, usually without providing insight into underlying mechanisms. Mechanistic models tend to be reductionist in nature, explaining phenomenon at one level of biological organization, such as plant growth rate, by integrating responses at lower levels, such as knowledge of individual leaf photosynthetic processes. In practice, however, all crop models tend to integrate empirical curve fitting with mechanistic approaches and have frequently been called 'explanatory' to denote this convergence.

A typical explanatory crop model accounts for relationships between crop growth and developmental processes and between the atmospheric and soil interfaces (Figure 1). Models relate crop processes to atmospheric and soil conditions by quantifying the relationships among descriptive input variables at these interfaces, such as temperature, carbon dioxide concentration (CO_2), soil water content, hydraulic conductivity, and the plant. For example, an equation that estimates the distribution and availability of light throughout the plant canopy would be a necessary component of the model. A second equation or series of equations could then be used to estimate how this quantity of light is involved in producing carbohydrate through photosynthesis. Additional modeling components or subroutines would be developed for the other processes shown in Figure 1. Depending on the scope of the model, other inputs and parameters would be included for management practices (e.g. tillage, weeding, fertilizer application, etc.), genetic parameters, and additional soil attributes. Explanatory models typically simulate plant phenology, or developmental progress, throughout the growing season as well, so important events such as flowering, initiation of yield-bearing organs, canopy senescence, and maturity can be estimated.

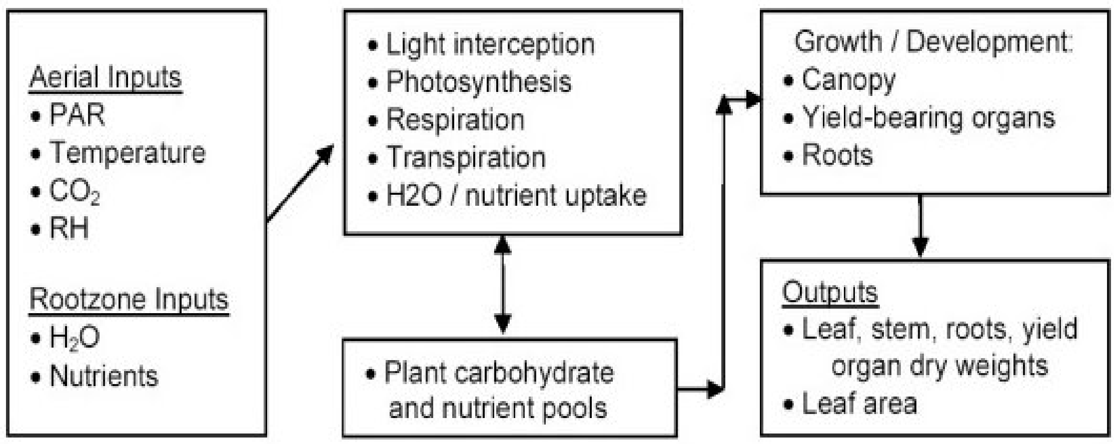

Figure 1: Components of a possible mechanistic model for crop growth and development. Aerial inputs, including light (PAR), temperature, atmospheric carbon dioxide concentration, and relative humidity (RH), and soil rootzone inputs, such as water availability and nutrients, influence processes including photosynthesis and transpiration of water vapor. These processes generate building blocks for plant growth and development, including carbohydrate and nutrients, which are converted to structural components of organ growth and development. Model outputs include organ dry weights and leaf area over the course of the simulated growth season.

Explanatory crop models can provide the user with simple and fast assessments of the crop at various levels of detail. This may include information on yield, maximization of profit, minimization of risk, plant stress, projected duration of the growing period, optimization of natural resources and crop maturity date.

Crop models have been utilized by growers, crop consultants and scientists to make both tactical and strategic decisions. Strategic decisions refers to management decisions prior to the growth season, and may address topics such as what cultivar to use, when is the best time of year to plant, etc. Tactical decisions are made within or during a growing season and would include information about when to irrigate, fertilize, or apply pesticide application. This chapter primarily focuses on the explanatory type of crop model, with particular attention on the history, approaches, application, and future directions.

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Biographical Sketch

Dr. David H. Fleisher is an agricultural engineer in the Agricultural Research Service within the United States Department of Agriculture (USDA). Dr. Fleisher received an interdisciplinary doctoral degree in Bioresource Engineering, Mechanical Engineering, and Plant Biology from Rutgers, The State University of New Jersey in 2001. Prior to joining the USDA, Dr. Fleisher was an assistant professor at Rutgers University until 2003. His current research focus includes the application of advanced systems theory towards the understanding and solution of complex soil, plant and atmospheric relationships. Dr. Fleisher develops computerized decision support systems for farm, research, and agricultural policy planning. His current research includes experimentation and mathematical modeling for development of mechanistic crop models for corn and potato.