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NEW VISTAS IN MODELING AGRICULTURAL SYSTEMS

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Panelists experienced in modeling in the areas of timber harvesting, hydrology, pests and crops will address the questions:

What are current trends in your area of interest?

How does modeling of agricultural systems differ from modeling of industrial processes?

What modeling problems are unique to agricultural systems which could better be resolved by the development of additional quantitative tools?

What new challenges in systems simulation lie ahead?

ABSTRACTS

Timber Harvesting & Computer Simulation Modeling - Daniel V. Goulet

With the growth in mechanized timber harvesting operations came the question of how best to use men and machines in a complex interactive environment to produce a timely flow of wood to the mill at a reasonable cost. The failure of analytical techniques, i.e., linear programming, queueing theory, etc., to answer this question has led to a great interest and investment in computer simulation to address the

problem.

Initially, harvesting simulation modeling focused on machine simulators. However, machines in a harvesting operation do not function singly, but in conjunction with others both in sequence and in parallel. Today, there is much emphasis on the total system, and the component interactions that effect costs and production. The movement to the systems concept has produced modeling problems that are non-trivial: How does one account for and validly represent the sequencing of operations having great variability?, What elements significantly contribute to the performance variables of production and cost?, Can the modeling constructs used be mathematically verified?, and more. Most of these problems are still unsolved. In addition, the models have grown in size, so that for many, a medium to large computer system is necessary for their execution.

The presentation will address the modeling problems that have developed in the rapid growth of timber harvesting simulation. Also, some directions for fertile research will be suggested, which if completed, would both put the strategy on a sound mathematical foundation, and make it more accessible to the user.

Approaches and Problems in Modeling of Agricultural Pests - R. E. Stinner

Modeling of insect populations (one might well add pathogens and plants also) has developed along three quite distinct lines, with unfortunately rather distinct gaps between them. These three approaches can be categorized as: (1) short-term predictors, (2) population dynamics models, and (3) evolutionary genetics models.

The first approach relies heavily on correlation and time-series analysis and is generally limited to short-time intervals (ca. 1 week) and single fields (or host crops). The second type of models are oriented to longer-term (growing season) and wider areas (local populations, e.g., county-wide) and take into account more behavioral and physiological attributes of the species. The concentration is on the dynamics of the species within the current or projected agroecosystem framework, but little consideration is given to prior or future evolutionary shifts. Finally, the latter approach concentrates on the very long term explanation of biological processes, but tends to consider the more proximial population changes as "noise" in the system.

Examples of all three approaches are discussed, with the general goals and assumptions of each elucidated. "Population dynamics" models are used to exemplify the types of problems which are posed by biological, as opposed to industrial, systems.

These problems include the "open" nature of the systems, in terms of both undefined relationships and arbitrary physical and geographic boundaries to the conceptualized systems. The evolving nature of the system presents limitation placed on this conceptualization due to organic evolution, changes in management practices and available options (introduced through both intrinsic feedbacks and externalities), and catastrophic events (e.g., war, flood, etc.).

Since all of these pest systems are weather-driven and highly heterogenous in time and space, additional problems are posed in weather prediction and simply in how to technically handle the spatial and temporal variation in the physical environment input.

Finally, there are the problems inherent in the blending of any two or more disciplines - semantics and misinterpretation of results.

Modeling Crops in Agricultural Systems - W. G. Rudd

Researchers are currently active in developing dynamic crop growth models in such crops as wheat, corn, alfalfa, soybeans and cotton. Agricultural models tend to be utilitarian in nature and are usually of one of two types. Detailed physiological models are designed to answer fundamental questions regarding basic physiological processes and how these processes and overall crop growth would respond to internal or external changes in conditions. These models tend to be large, complex and expensive to build. The other kind of crop model is designed to serve as a submodel of a model of a large system. For example, there are several crop models which were constructed specifically to predict the effects of insect pest damage on crop yield. These tend to be designed using a "top-down" approach, in which the objective is to construct the simplest model that makes biological sense and provides reasonably accurate results.

A major difference between agricultural system and industrial processes, from a modeller's point of view, is the extreme complexity of biological systems. This complexity has the following results:

1. There probably will never be a "complete" physiologically based crop model. Some curve fitting or "artwork" will always be required at the lower levels in the model structure.
2. Data are extremely "noisy" because of natural variations in local or micro-climate.
3. Adequate data with which to validate a model are virtually impossible to obtain. There is no such thing as a totally controlled experiment at the test plot level. Data are extremely expensive to gather; a large number of natural factors continually threaten to invalidate a whole growth season's worth of experimental work.

Since the discipline is really in its infancy, there is no tried and proven standard approach to take in developing a crop system model. There is no universally accepted set of mathematical techniques and formalisms in agricultural modeling; the requirement that modeller's be able to communicate readily with biologists about detailed modeling issues dictates that mathematical descriptions be kept fairly simple. For this reason, many crop models are constructed around computer program "boxcar" techniques.

Our current lack of real understanding of how crops grow is a far more urgent problem than lack of the traditional kinds of quantitative tools. The quantitative tools we have are more than adequate to allow us to model everything we know.

The real challenge is to learn how better to use the models we construct to indicate what new information must be obtained in order to construct better models. The development of new quantitative techniques that could help to resolve the inherent complexity of the systems by isolating fundamental processes by uncoupling interacting processes is the long range solution to the problem of agricultural system modeling. This identification problem is made more difficult by the noise in experimental data from the systems. But efforts in this area should be well repaid in the future of agricultural system modeling.

Hydrology Modeling - D. G. DeCoursey

Hydrologic models are more numerous than the number of individuals working in the field of hydrology. We have all developed one or more hydrologic models to answer specific problems we are working with. There are any number of ways in classifying the hydrologic models that have been developed. But rather than try to classify all models into a rigid outline, a listing of the types of models that have been developed will be presented.

The field of hydrology is the study of the movement of water (and now assumed to include sediment and contaminents or pollutants) from its source as rainfall to the ocean. Some of the first models were rather simple ones used to predict the amount of runoff that could be expected from rainfall. At the present time models of all of the specific processes have been developed. In each of the processes these models range from rather simple regression or parametric models to very complex models that attempt to include both spatial and temporal variability and many would be considered fundamental or basic research tools. The processes modeled include (1) the routing of water, sediments, and chemicals over land and through channel systems; (2) evapotranspiration and evaporation processes; (3) soil and ground water movement in saturated and unsaturated states; and (4) snow melt. These various processes have been combined to simulate an entire rainfall-runoff event or for continuous simulation of events over a period of time equivalent to many years.

These complete models are used for many purposes, thus, their complexity varies considerably. Some of the uses of such models are irrigation scheduling, water quality assessment, evaluation of land use management and watershed basin planning. Many simplified models that may not include all of the above components are used in design of bridges, culverts, channel alignment, canal design and flood plane assessment.

Stochastic models are also used extensively in hydrology. These include moving average processes, autoregressive processes, ARMA (Box-Jenkins), fractional Gaussian Noise processes, Broken line processes, shot-noise processes and disaggregation processes. These processes are used primarily to study hydrologic series or stochastic processes such as the space-time distribution of rainfall, and to develop synthetic sequences. The synthetic sequences can be either analyzed directly to aid in hydrologic design or as data input to process type models. In the last few years finite element models have also been used either as replacement for finite difference schemes or to study a particular phenomena in more detail.

In the future we will see more interface of agricultural models such as those of crop growth, insect growth, and hydrology that can be used to study entire agricultural systems. Limitations on size and speed of computers will be relaxed as improvements will enable use of very complex models that are not now feasible. Finite difference and variational optimization techniques will be combined and perfected to enable solution of systems not now envisioned.

Agricultural Systems: Models and Goal Structure - Harvey J. Gold

Agriculture is a goal-oriented human enterprise. The immediate result of this premise is that agricultural systems do not exist apart from this human enterprise. That is, agricultural systems are not "natural" systems; they are defined by the goal structure.

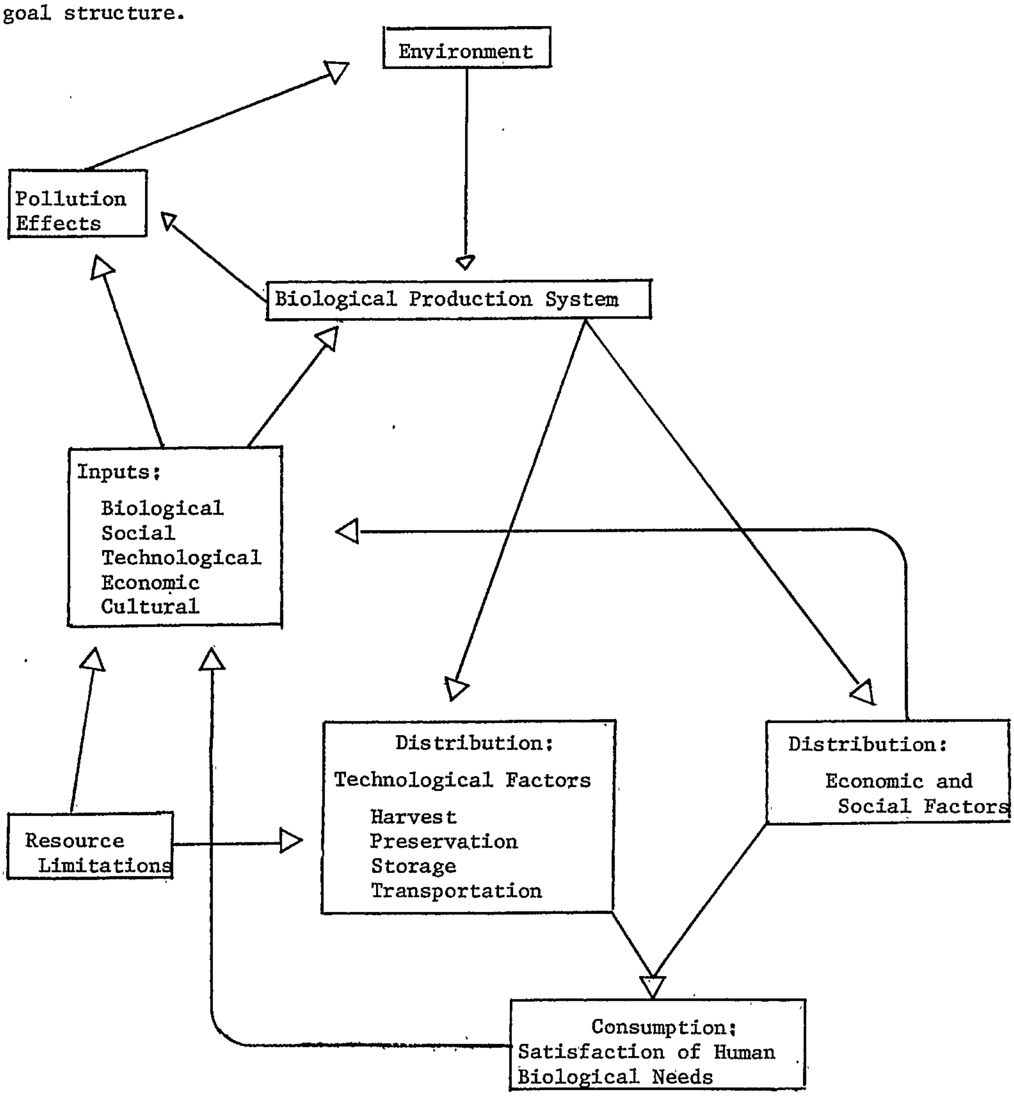
In this framework, agricultural science is that science which enables the more effective and efficient meeting of these goals.

The goal structure is inherently complex and includes the goals of adequate nutritional supply to urban as well as rural populations of varying economic status, the satisfaction of social and esthetic demands related to food consumption and other uses of agricultural products, economic return to those engaged in the overall enterprise, need to conserve natural resources and to avoid adverse effects upon the environment. To the extent that these goals conflict with each other, appeal must be made to social mechanisms for conflict resolution.

The goal structure requires that agricultural science be inherently multidisciplinary. The degree of multidisciplinarity required, and the complexity of the system to be studies are determined by the goal structure being considered. At one level, for example, we may focus on the primary biological production system, involving the plant, the soil, the environment, and possibly an animal component. A more expanded view of the primary production system might regard the system as a managed open ecosystem which includes other biological species (pest, for example) and other factors which are less completely under human control.

Broader consideration of the goal structure requires that we augment the system by including the distribution of system output, the inputs which are under human control, the decision processes (techniilogical and economic) which relate anticipated output to human inputs, and the constraints placed on the system by interaction with other human activities.

The accompanying figure diagrams the broad classes of these interactions, with particular attention to resulting feedback loops. The fundamental problem of agricultural science may be taken as that of improving the efficiency of this set of feedback loops, where efficiency must be defined with respect to the multiple goal structure.



A view of the overall agricultural system. Arrows indicate direction of influence.

The overall system diagrammed in the figure is clearly too complex for any single individual to grasp, or a single discipline to encompass. Mathematical and simulation models are essential: (a) in relating behavior of subsystems to each other and to behavior of the "overall" system; and (b) as a basis for collaboration between scientists.