CROP MODELS – WITHIN CONTROLLED ENVIRONMENT

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Summary

Controlled environment facilities impose an artificial barrier between plant production processes and the natural environment. This barrier provides the capability to exert control over various aspects of plant production.

Technology used in controlled environment facilities ranges from simple plastic row covers to sophisticated controlled and automated greenhouse and growth chambers. Crop models that estimate plant responses to climactic, nutritional, and other factors have been used to support controlled environment plant production at many of these technology levels. Such models typically consist of mathematical equations that encapsulate knowledge on the interactions between plant growth and development and soil and atmospheric interfaces. The models allow controlled environment users to more effectively organize, interpret, and analyze information from disparate sources to support design, planning, management, and operational decisions. Applications include automated climate control, design of cultural and production systems, and improvements in product marketability.

Empirical and mechanistic crop modeling approaches have enhanced the efficiency of greenhouse operations, reduced grower risks associated with controlled environment agriculture, and improved utilization of natural resources. The use of crop models in controlled environments will increase worldwide, particularly as knowledge gaps in crop models are addressed and computing power becomes more available.

1. Introduction to Controlled Environments

Controlled environments are a form of protected cultivation in which an artificial barrier or enclosure is placed between the natural environment and the plant or crop to be grown. The type of barrier used to protect the crop can encompass a range of forms and technology levels. Variations range from simple plastic row covers and high tunnels placed in the field during the early growing season to highly mechanized and computerized greenhouses and environmentally controlled growth chambers that maintain the climate at desired set points throughout the entire plant production schedule. Controlled environment technology can therefore be composed of components ranging from very basic to highly sophisticated. Crop models have been developed and used to support the design, planning, operation, and management of most of these forms of controlled environment technology.

1.1. Overview

Controlled environment agriculture (CEA) encompasses the use of plastics in the field (e.g. row covers and low and high tunnels), greenhouses (e.g. plastic, glass, etc.), and growth chamber technology. The use of controlled environments for plant production purposes originated with the need to generate plants or plant products of high quality during times when the natural environment was not conducive to plant growth. In most cases, these needs originated from marketing forces, such as the demand for food or ornamental plants. One of the earliest food production systems in controlled environments was the growth of cucumbers within ‘transparent stone’ by the Romans during the first century. Very few reports of other controlled environment applications have been recorded prior to the 17th century. During the 1600s, techniques were used to protect crops from cold weather including the use of glass type structures similar to those used in lanterns.

Greenhouses providing partial coverage with glass panes, sometimes referred to as ‘glasshouses’, were introduced in the 1700’s. These structures evolved over time to completely enclose the production environment. In the mid 20th century, the use of plastic material, polyethylene, for greenhouse cover material (‘glazing’) was introduced as an alternative to more expensive glass covers. In modern times, particularly within the last 10 – 20 years, the use of plastics in field applications and greenhouses has expanded tremendously, with the result that forms of controlled environment agriculture can be found throughout the world.

Greenhouses are an important component of CEA and have been a significant focus of CEA research. The majority of glasshouses are in northwestern Europe, while plastic greenhouses can generally be found worldwide at varying levels of technology. Land area coverage estimates in 1995 for glasshouses and plastic greenhouse / high tunnels were 41,000 ha and 265,800 ha respectively. The greenhouse industry is an important agricultural component for many nations – it is estimated in the United States alone to account for nearly $30 billion (U.S. dollars, 2002) per year. Many advances have been made in the past few decades in greenhouse technology. These include improvements in structural design and materials, environmental control systems, sensing and automated data acquisition systems, computerized monitoring and decision support equipment, cultivation systems and practices, and labor saving systems.

These advances have also led to the development of growth chambers, arguably the most highly controlled form of CEA. Growth chambers range in size from small 'reach-in' chambers with a production area of less than 1 m^2 to large 'walk-in' chambers with growth areas over 20 m^2 in area. Growth chambers are more or less completely independent of external weather conditions, and provide control over lighting and photoperiod through the use of artificial lamps. Some specialized chambers in use today offer the capability to monitor carbon dioxide and water fluxes in the aerial and root zones of the plant or lower the atmospheric pressure inside the production area. The majority of growth chambers are used for research purposes, but there is some use of growth chambers in highly specialized industries such as transplant production.

1.2. Research

The primary goal of plastic use in fields is to prevent extreme fluctuations in moisture and temperature from damaging young plants. Basic greenhouse facilities provide the capability to maintain air temperature and humidity within a certain range of values. More sophisticated greenhouses have additional capacity to provide supplemental lighting, enrich the plant canopy with elevated atmospheric carbon dioxide, and can provide tighter control over temperature and humidity set points within 1-5% of the desired value. Many growers use cultural systems that also allow control and monitoring of soil temperature and can precisely add desired quantities of water and nutrients to plants throughout the production cycle. Most growth chambers provide the capabilities described for greenhouses but with additional control over the quantity and quality of light available for plant growth.

Commercial greenhouses are widely used for growing horticultural plants including ornamentals, vegetables, and fruit trees. Less common, but other important uses also include the production of food crops such as potato and rice, trees for reforestation activities, plants for biological fuel production, plants for ground cover applications, medicinal or pharmaceutical plants, and phytoremediation (the use of plants to remove toxins from the environment). CEA technology is also used in transplant production. In this case, seedlings and vegetatively propagated plantlets are produced under tightly controlled environmental conditions. The products are then sold to other commercial growers in horticultural, agricultural, and forestry-based industries in order to produce high-yielding uniform plants and / or trees. Controlled environment plant production technology is also used in research being conducted in the United States, Europe, Japan, and the former Soviet Union for the purpose of developing life support systems for space exploration.

The driving force for the majority of research in controlled environment systems, particularly in greenhouses and growth chambers, is the need to produce a certain quantity and quality of plant material or product according to a given schedule. This schedule is typically driven by commercial situations. For example, a grower might plan production of poinsettia so that the plants would flower in time for the Christmas season. As a result, a large amount of research has been focused on studying various aspects of plant production in an effort to achieve better control of the process.

Research activities in controlled environments can be categorized according to their contribution to automation, cultural, and environmental aspects. Automation research addresses the evaluation and development of systems that decrease the need for human labor. Examples include designing movable greenhouse benches, developing a novel production system for tomatoes in order to facilitate robotic harvest of vine-ripened fruit, and the development of sensors that non-destructively assess health of the plant. Cultural research includes the understanding of plant responses to environmental and nutritional systems, the development of different plant production systems or methods, and activities such as transplanting, rooting, watering, and pesticide application that are conducted during the production cycle. Environmental research includes the physical and mechanical components of the controlled environment itself and the interaction of external and internal factors upon the actual structure of the facility. The ability of the greenhouse to maintain a certain interior temperature or atmospheric carbon dioxide concentration is an example of environmental research. Crop modeling has played a significant role in all of these categories.

Advances in controlled environment design and reliability have generally followed progress in agricultural tools and machinery, structural design and materials, sensing and instrumentation, and knowledge of plant physiological requirements. Some of the most significant examples that focus on climatic and biological requirements include hydroponics, the production of crops in soil-less systems, environmental control systems that can maintain or alter the climate of the controlled environment facility at optimal or near-optimal conditions throughout the production cycle of the crop, and integrated pest management approaches. Computers and automated data acquisition systems are now common in the United States, Europe, and Japan and in addition to constantly updating the grower with information on the operational status of the facility, have been used to manage irrigation, fertilization, and climate control. Adoption of this technology by growers is primarily perceived to improve management, reduce risks associated with plant production, and improve the economics of the operation.

2. Crop Modeling

Crop modeling has been a significant focus of agricultural systems researchers over the past 40 years. The majority of the research has been devoted toward open field production but there is considerable overlap with controlled environment applications. Sparked in part by rapid development of desktop computing power, crop models have been used by growers and consultants for management and operating activities (e.g., decision support), land-use issues, policy planning, scientific investigation, and education activities. Models quantify knowledge in a format that can provide scientists and end-users with techniques and methodologies for evaluation and additional experimentation of related theories. Historically, modeling approaches for controlled environment agriculture tend to be more focused on end-user or grower application. However, many growth chamber studies, and in certain cases, the design of such chambers, have been conducted to provide data for the sole purpose of developing and improving crop models. The focus in this section is primarily on the application of models within CEA and not on their development.

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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.