OFFICIAL

NORTHEAST REGIONAL PROJECT

PROJECT NUMBER: NE-164 (Rev.)

TITLE: Decision Support for Design and Control of Plant Growth Systems

DURATION: October 1, 1998 to September 30, 2003

STATEMENT OF THE PROBLEM:

The economic advantage of Controlled Environment Agriculture (CEA) is rooted in it's continuously evolving, and increasingly technology driven, production systems. The development and implementation of such hi-tech production systems requires a detailed understanding of the interaction between the physical and biological components of these systems. Decision-support models that link plant performance with environmental variables must be developed and then coupled with efficient and economic control within an environmentally sustainable system. Because of the broad range of greenhouse crops and differences in prevailing environmental conditions associated with different climatic zones such decision support systems must be developed on a broad database. The interdisciplinary cooperation of horticultural physiologists and agricultural engineers is needed to address this problem.

JUSTIFICATION:

Most state experiment stations are ill equipped to individually address all of the problems associated with complex CEA production systems and the wide range of crops produced in these systems. Because of the limit on expertise and resources associated with individual stations and individual Hatch projects, a multi-state interdependent research collaboration is the most appropriate means of approaching the problem of developing useful CEA decision-support systems that require input from multiple disciplines and replication over different climatic zones. The regional approach also allows collaborative research to be conducted at individual institutions where expensive, complex, or unique facilities - that are not easily replicated - may reside; for example the indoor, artificial wetlands for phytoremediation (PA).

CEA is the most intensive, high technology form of agriculture in the U.S. High value crops such as flowers, vegetables, and culinary and medicinal herbs are produced in carefully controlled greenhouse environments in order to optimize horticultural practices. National Agricultural Statistics for 1995 indicated that U.S. floriculture crop production alone included 842 million ft^2 of covered structure and an additional 1,183 million ft^2 of open cultivation. The intensive productivity of CEA stands in contrast to other forms of crop agriculture; for example, compare the typical annual wholesale value (on a per acre basis) of cash grains \$300-\$500, field produced fruits and vegetables \$3000-\$5000, and ornamental nursery stock \$30,000-\$50,000, with that of greenhouse agriculture \$300,000-\$500,000.

CEA techniques are built upon an integrated knowledge of chemistry, horticulture, engineering, plant physiology, plant pathology, computers and entomology. Broad-based study involving these interrelated issues is important for industry growth and problem solving.

The greenhouse/nursery industry is large and represents the dominate form of agriculture in many of the urban/suburban states of the northeast. The greenhouse/nursery 'green' industries typically encompass all non-edible horticultural products, including floriculture, environmental horticulture, turf grass, and related products. Technologies used in edible and non-edible CEA production are similar enough so that advances in one area can often be applied to the other, and to other related applications such as specialized growth/germination chambers, NASA Advanced Life Support Systems, and protected cultivation in low and high tunnels.

As with other agricultural sectors, successful commercial CEA enterprises are operated by both family and corporate structures. These industries have historically been recession-resistant in our economy and continue to enjoy strong growth in sales.

Three technologies in particular have permitted crop production within CEA to evolve to today's sophistication: (1) computer control of the environment, (2) automation, and (3) advances in our understanding of the physiological responses of plant systems. The success of each technological advance has been dependent upon a systems approach to CEA production which recognizes the numerous interacting components. Future advances in CEA will also be dependent on an integrated approach to system development coupled with responsible environmental stewardship.

It is well understood that a constant flow of critical information is essential for maintaining a high level of competency and competitiveness. With modern communication technologies, it is relatively easy to access a vast amount of information. One real challenge is how to sort and synthesize the information for beneficial use. Therefore, the successful generation, presentation, transfer and application of information relevant to plant growth system planning, design, management, and operation is needed to facilitate the continued growth of the CEA industry.

A CEA crop production facility is a system that must be analyzed using systems techniques. Systems techniques are applicable to topics such as plant lighting, natural ventilation, wastewater treatment, and environmental control. All of these processes need to be understood and controlled in relation to the plant production system as a whole. Decision support is needed to address this management problem.

NE-164 has been the only <u>greenhouse design/crop production systems</u> regional project in the U.S. The membership includes plant scientists and agricultural engineers from eastern, mid-Atlantic and mid-western states and participation continues to expand. Most of the greenhouse engineering related research and extension work during the past 20 years has been from NE-164 members. This project has stimulated research collaboration, and national and international information exchange which is unique to the discipline. Several members are also members of NCR-101 (Committee on Controlled Environment Technology and Use) which enhances links to other regions and researchers with similar interests. At least one member from each state has Cooperative Extension responsibilities which enhances the transfer of technology into field application.

NE-164 has a strong history of technology transfer through both written and oral communication. The number of invited presentations at national and international workshops and conferences illustrates the level of regard the CEA industry has for the expertise of NE-164 participating members.

RELATED CURRENT AND PREVIOUS WORK:

The NE-164 collaboration features a strong interaction of horticulture and engineering with an emphasis on CEA plant growth systems. Since 1972, NE-164 and the previous numbered projects have been the only greenhouse design/crop production systems-related regional research project in the U.S. A regional communication committee, the NCR-101 has a similar interdisciplinary mix of participants but the members do not formally collaborate on common research objectives and the focus of the committee is not directed at supporting the commercial CEA industry. A search of CRIS files shows that most of the greenhouse engineering, greenhouse systems design, and decision-support model development involving greenhouse crops during the past 15-20 years was from NE-164 members. Research results were disseminated in over 375 research reports, extension articles, and invited national and international presentations by members of this project during the last five years.

CRIS reports only three greenhouse environmental control research projects in progress, all at the University of Guelph, Ontario. One project focuses on insect and disease control (B. Grodzinski, #7002351), another involves the fate of trace hydrocarbons and volatile organic compounds (from office building furniture and materials) in sealed indoor environments with various plant communities (M. Dixon, #7002350), and the third project tracks long term consequences of root exudates on hydroponic nutrient solutions on productivity (M. Dixon, #7002349). Both pest and hydroponic solution management are important to CEA but neither project duplicates NE-164 proposed research.

CRIS reported no ongoing projects involving decision-support of plant growth systems, or greenhouse ventilation. Nine projects involve lighting and some aspect of agriculture. DeCoteau at Clemson (#0161758) is investigating light quality effects from colored plastic mulch on field grown vegetable crop development. J.B. Hunter at Cornell (#0173232) is exploring the use of high intensity lighting for gardening on lunar and planetary colonies.

CRIS identified 28 projects that involved some aspect of phytoremediation. R.D. Berghage (Penn. St. Univ., #0168273) contributes to NE-164 and is involved in phytoremediation as a tool in greenhouse waste water management. Of the remaining projects, 14 involved phytoremediation as a tool for the clean up of sites contaminated with non-agricultural wastes such as radionuclides, heavy metals, PCBs, or aqueous toxins such as cyanide wastes. Two projects identified phytoremediation as a means to manage municipal runoff wastes on sensitive watershed sites.

Current research on environment-plant interactions for decision support has been an interdependent process. For example, replicated studies in MI and NH on floriculture crops have produced models for predicting the growth response of the ornamental crops lily and poinsettia (Fisher and Heins, 1996; Fisher et.al., 1996a; Fisher et.al., 1996b; Fisher et.al., 1996c; Lieth et.al., 1996; and Fisher et.al., 1997a & b). Still, many other important floriculture crops remain to be investigated. Similar replication and cooperative research in NY, NJ, and CT on greenhouse vegetables and herbs has contributed to the development of an empirical plant growth model for tomato based on light (Chiu et.al., 1996), a decision-support system for lettuce, and environmental optimization of important dietary phytochemicals in purslane and watercress. The decision-support system for lettuce has advanced to the point of commercial technology transfer (Albright, 1996; Controlled Environment Agriculture Program, 1996) but modules for additional leafy-vegetable crops must still be developed.

The overall objective to build an interactive internet database and decision-support tool that includes all of the crop/environmental decision-support modules derived from either replicated or complimentary initiatives by the individual NE-164 members is still under development (NJ, NY, MI, PA, CT, NE and NH). An essential tool for the information integration is a common communication platform to facilitate the flows of information from various sources and to appropriate users. The internet's distributed and multi-platform environment is perfect for this project. The world wide web utilizes a convenient information transfer protocol, called the Hypertext Transfer Protocol, that facilitates finding, retrieving, and displaying documents. As this project develops further, both NE-164 collaborators and industry users will use the networked information system as a common and interactive communication channel for the plant growth systems decision-support research and information retrieval.

Research at MI has provided insight into the effect of the Ratio of Radiant energy to Thermal energy (RRT) on plant quality, and NY has contributed innovative research in the use of Pseudo-Derivative-Feedback (PDF) for temperature control logic; a program that enables growers to avoid the use of ventilation and achieve temperature control during winter conditions, which means they can supplement CO_2 economically and maintain accurate levels.

OH has provided leadership in the automation of fertilizer delivery based on crop and environmental condition. NJ is also supporting research on automation and robotics for plant production and is using machine vision as a monitoring/diagnostic tool to estimate nutritional stress on lettuce; a project that is linked to the lettuce production work of NY and the fertilizer delivery system of OH.

OH is using a fluid dynamics program, Fluid Dynamic Modeling of Natural Ventilation (FLUENT) to evaluate and illustrate the natural ventilation patterns and air-flow rates of low cost, double-poly, gutter-connected greenhouse designs. Greenhouse cooling is essential for controlling the physiological response of a crop (MI, NY, NJ, CT) and the process is more complex when insect screening (NJ) or CO_2 conservation are dominant considerations (NY).

Dynamic optimization of supplemental lighting is important for both economic and cropping efficiency (Heuvelink & Challa, 1989). Dynamic optimization combines crop modeling with greenhouse environmental dynamics and energy considerations to determine an optimum level of greenhouse lighting. Such an objective is different from achieving a consistent daily PAR integral. However, even when dynamic optimization leads to a PAR integral optimized for the day, a means to control that integral is still required.

Albright (1995) presented an algorithm to control supplemental lights to provide a consistent (or prescribed) daily PAR target integral. As part of the computer simulation program that implemented the algorithm, the yearly cost of lighting is calculated (and minimized) based on input from the user regarding the local electric utility rate schedule and time-of-day options. Subsequent work added control of movable shade systems to the control algorithm to achieve year round control. The algorithm is currently in the patent process and will be available for licensing by Cornell University to greenhouse control system companies. Thus, the means to control lights and movable shade systems to achieve a consistent light environment has been developed through NE-164 efforts. However, more complete knowledge of how a consistent light flux can be optimized for other important greenhouse crops does not yet exist. The various stations that participate in the NE-164 project will address this need on a variety of crops.

NE-164 member institutions have taken the lead in initially quantifying the potential risks of environmental degradation from CEA production practices and the resulting wastewater (Mankin & Fynn, 1994; McAvoy, 1994; Wheeler et.al., 1994) and identifying environmentally responsible fertilizer delivery practices (Biernbaum et.al, 1995; Yelanich & Biernbaum, 1995). OH developed the basic decision model for selecting individual nutrients for fertigating greenhouse crops (Fynn, 1994); and a unique decision and risk model (HYTODMOD) for growing hydroponic tomatoes (El-Attal, 1995; Short, 1997). HYTODMOD was uniquely verified by four industry experts. OH has done significant research to characterize irrigation requirements by measuring and modeling transpiration of greenhouse and nursery crops (Fynn et.a., 1993; Hansen et.al., 1997; Mankin and Fynn, 1996; Mankin et.al., 1997; Yildirim, 1997). OH has also developed and tested a computer controlled fertigator designed to supply nutrients to multiple zones based on predicted crop needs (Anderson, 1997).

Most recently research efforts in PA and NJ have begun to move toward developing remedial systems for the biofiltration of green-industry wastes (Berghage, 1996; Mac Neal & Berghage, 1996; Wood, 1996; Wood et.al., 1996). Greenhouse and nursery production is high intensity, high input agriculture. Insecticides, fungicides, growth regulators and other chemicals are freely used to aid production. Fertilizer inputs, for example, can reach thousands of pounds per acre per year (Nelson, 1991). Fertility programs utilizing 200 ppm N or more in every irrigation are common. Peak water use, based on irrigation system design recommendations (Aldrich and Bartok, 1994), can exceed 20,000 gallons per acre per day, with 10 to 50% of the applied water discharged as waste in traditional overhead hand or sprinkler irrigation. Although this seems wasteful, on a cost of production basis these inputs represent only a tiny fraction of the total costs, and so they have historically been used in excess. This has however, been changing over the last two decades as environmental rather than economic considerations have driven a re-evaluation of many common production practices.

Treatment and/or recycling of wastewater is mandatory for point source municipal and industrial water discharges in the United States (U.S. Congress, Public Laws 84-660, 1956; 92-500, 1972). In a number of states this includes greenhouse and nursery growers (California Statute 482:1052, 1969). Growers have developed elaborate, and effective, recirculating irrigation and wastewater treatment systems to meet these demands (Skimna, 1986). Other states' regulations are not yet as stringent. However greenhouses and nurseries have come under increased pressure to reduce wastewater discharge. Because conventional wastewater treatment techniques such as air stripping, chemical oxidation and carbon adsorption (Symons, 1981) are costly, and may produce additional environmental problems like sludge disposal, the industry has increasingly relied on water recycling and recirculating irrigation systems (Hamrick, 1987).

Constructed wetlands are thought to function as attached growth bioreactors which can effectively treat liquid wastes for Biological Oxygen Demand (BOD) and Total Suspended Solids (TSS) reduction. There are hundreds of outdoor treatment wetlands operating throughout the world (Reed and Brown, 1992; Conley et al., 1991). They are used to treat municipal, industrial, and agricultural wastewater, landfill leachate and acid mine drainage (Anderson, 1993; Hammer, 1993; Conley et al., 1991). The quality of effluent from conventional outdoor constructed wetlands is known to vary throughout the year primarily due to seasonal temperature effects.

Constructing treatment wetlands within a greenhouse environment can provide more optimal year-round environmental conditions for plants and microbes to produce a consistent, high-quality effluent from the wetland. Other advantages of housing a wastewater treatment wetland in a greenhouse environment include wetland process control, possible automation of wetland maintenance systems, and the production of a greenhouse crop. Disadvantages of enclosing a constructed wetland in a greenhouse include the capital costs of the greenhouse structure, maintenance and energy to heat the greenhouse.

In summary, NE-164 collaborative projects have made significant scientific contributions relative to the goals and objectives over the past five years (see Critical Review for additional details). However, in recent years the composition of the committee has shifted from a predominantly engineering group to a more balanced mix of horticulturists and agricultural engineers. Now as the focus begins to shift away from production systems design and toward decision-support for crop systems management and technology transfer, there will be an added emphasis on interdependent research, multi-site replication, and cooperative database development to achieve future goals.

OBJECTIVES:

1. To integrate environmentally acceptable and economically-profitable management models (decision-support) into controlled-environment plant-production systems.
2. To enhance commercial greenhouse design, water management, and environmental systems for cool and cloudy climates.

PROCEDURES:

Objective 1: This objective will have two components; (a) To develop decision-support tools based on plant growth and development models to enhance crop growth control and profitability (CT, MI, NH, PA, NY, NJ), and (b) To develop an integrated information database on CEA plant growth systems to facilitate analysis and to produce a decision-support tool. (NJ, NY, MI, PA, CT, NE, NH).

Obj. 1a: Systems and decision-support tools will be developed, to control the greenhouse environment based on models that ~~link~~ plant performance with environmental variables. Examples of systems include an automated misting system, a plant nutrition-based fertigation system (Fynn et. al., 1994), and CO_2 optimization linked with an environmental computer (Ehler and Karlsen, 1993). Decision-support tools include graphical-tracking curves (used to manage plant height) for crops such as Easter lily (Heins et. al, 1987), poinsettia (Fisher and Heins, 1995), chrysanthemum (Karlsson and Heins, 1994), and Oriental and Asi-florum lilies (Fisher et.al., 1998).

Knowledge-based systems can be used to ensure that recommendations based on the output from models are feasible. Knowledge-based systems of this type, also called expert systems, are computer programs that attempt to capture human problem-solving ability (Stock, 1987). Such knowledge-based systems include the "The Greenhouse CARE System" (Ehler et.al., 1997; Fisher and Heins, 1997; Fisher, et.al, 1997a & b), a program for height-control decision support of poinsettia and Easter lily. Using plant/environment models for greenhouse control potentially optimizes resource use, minimizes agrichemical applications, and increases crop quality.

Researchers at several states (MI, NH, NY, NJ) are modeling plant responses to the greenhouse environment. This involves quantifying temperature effects on stem elongation and development rates of potted and cut flowering plants. Work in control and decision support is very integrated with specific Objective 2 goals. For example, researchers (MI, CT, NH) are working on pH management of bedding plants grown in soilless media which can be part of the total plant-environment control package.

Development of decision-support systems based on plant models go beyond traditional environmental control of temperature, light, and relative humidity. UNH FloraTrack (NH), a new software program for greenhouse process control, allows users to graphically track the height of potted plants. Graphical tracking allows growers to compare the actual height of their crop against a target height-curve during development of the crop. Graphical tracking curves have been developed for pinched and single-stem poinsettia, chrysanthemum, Easter lily, Oriental lily, Asi-florum lily and geranium. The graphical tracking technique has been so useful to growers that it is now being used in the production of most poinsettias and Easter lilies in the United States. These efforts have been shared among NE-164 members which has enhanced the distribution of knowledge throughout the industry.

Additional decision-support tools will be added to the UNH FloraTrack program based on input from researchers at other stations. These will include additional height-control curves for flowering pot-plant and bedding-plant species, monitoring pest levels, predicting flowering variability in crops such as Easter lily, and nutrient test result tracking.

Obj. 1b: The integrated information database on CEA plant growth systems will include information on automation, plant culture, and environmental factors and the database and decision-support tool will be implemented as an interactive WebSite on the Internet. The WebSite will be maintained by NJ but specific informational modules will be developed through collaboration with CT, OH, NY, NH, PA, and MI.

The plant growth systems database will be developed based on the "Automation-Culture-Environment oriented Systems analysis" (ACE_SYS) concept developed by Ting and Giacomelli (Ting and Giacomelli, 1991; Ting and Giacomelli, 1992; Ting, 1994). The ACE_SYS concept was developed to facilitate structured analyses for plant based engineering systems where a system is defined as "a set of interrelated objects organized to achieve certain goals".

To implement the ACE_SYS methodology for analyzing plant growth systems, a communication platform will be constructed on the internet using the World Wide Web technology. The first step of developing ACE_SYS analysis tools is systems abstraction. Object-oriented analysis will be applied for extracting the classes and objects found in the information gathering process which includes face to face discussion sessions with plant growth systems researchers and a real-time information gathering mechanism running on the ACE_SYS web site.

All users will access this cyber environment to enter information, view information, execute related programs (i.e. applets), utilize resources, participate in discussion, and conduct systems analysis. The underlying concept of ACE_SYS methodology is currently being applied to the New Jersey NASA Specialized Center Of Research and Training (NJ_NSCORT) project (http://nj-nscort.rutgers.edu/acesys) and the details of the techniques are evolving satisfactorily (Chao et al, 1997; Rodriguez et al, 1997; Ting et al, 1997).

Object-oriented programming will be the programming paradigm used to code these software packages. Java (Sun Microsystems, Inc.) is an object-oriented programming language that delivers the most robust and architecture neutral software components in the distributed networked environment. Java applets will be developed for the ACE_SYS for its seamless connectivity to the WWW.

Objective 2: This objective will have three components; (1) to develop design and control recommendations for naturally ventilated greenhouses (OH, NY, PA, NJ), (2) to enhance technology transfer and research in artificial lighting (MI, NJ, NY, PA), and (3) to improve greenhouse wastewater treatment through the use of constructed wetlands, or phytoremediation (NE, NJ, NY, PA).

Obj. 2a: Progressive growers, both large and small, have a high interest in the relatively new naturally ventilated, double-poly, gutter connected greenhouses. The greenhouses are very popular since they tend to have uniform temperatures; they allow open doors in summer; they use no fans; and they are extremely pleasant (including quiet) for workers. These greenhouses can greatly improve labor efficiency, especially when compared to growing in numerous quonset style houses.

Cost cutting designs have resulted in numerous grower questions and choices that can have long term negative influences on the effectiveness of naturally ventilated greenhouses. Each vent, for instance, is a significant cost to the total structure (Short & Van Duyne, 1990; Short, 1994; Short and Kacira, 1996; Short et.al., 1997) such that growers and sales people often reduce costs by eliminating an important portion of the ventilation system. While such choices usually violate engineering design recommendations (ASAE, 1997), the consequences are seldom known in terms of air exchange rates and crop production and quality.

A computational fluid dynamics (CFD) program has been used in OH for studying natural ventilation rates of double-poly, gutter-connected greenhouses (Kacira, 1996; Kacira et al., 1997; Woodruff, 1997). Air exchanges were predicted with the CFD model and compared to an energy balance model. Very good agreement was achieved on sunny days with significant wind. There was generally poor agreement, however, on low wind, cloudy days as the CFD model was mainly influenced by wind speed and the energy balance model was mainly influenced by solar radiation.

A contrasting computer model for natural ventilation in greenhouses has been developed in NY, a model based on the concept of the neutral pressure level and resulting ventilation rates arising from thermal buoyancy and wind effects. The model has a limited background of testing, but appears to be fairly successful in predicting ventilation rates. However, the most severe restriction to using the model for design is to know how winds will generate pressures around the shell of a greenhouse, especially at vent openings.

The CFD work at OH provides a means to develop rules for estimating wind pressure coefficients, and that will be a central focus of this objective. The CFD program will be used to generate wind pressure coefficient predictions for a variety of greenhouse shapes, vent placements, and wind directions. Those results will then be used in the neutral pressure level model to calculate expected ventilation rates.

Finally, the predictions generated by these two approaches to greenhouse natural ventilation (OH and NY) will be compared and contrasted with the goal of identifying where they differ, why they differ, and what can be done to bring the predictions closer. Moreover, designs and resulting natural ventilation rates will be evaluated in commercial and research greenhouses in cooperating states, primarily OH and NY. Portable data loggers with temperature, humidity, solar radiation, wind and vent opening sensors will be installed and monitored via modems.

Ultimately, when the subtleties of natural ventilation are better understood, computer-based control programs can be developed to provide more consistent temperature control in naturally ventilated greenhouses, as well as more consistent temperature uniformity through optimized air distribution.

Obj. 2b: One aspect of the lighting work will be to evaluate effects of local electric utility rate structure variations, for each of the participating states. Hourly weather data from each station will be obtained (for one or more years of weather) and used, along with the local electric utility rate structures, to determine optimum lighting design and control strategies for each participating state, strategies to provide a consistent daily PAR target integral. States will develop a combined data base of electric rates structures and hourly weather data for our respective stations. This will be especially helpful in light of deregulation of the electric industry and will allow growers to compare cost structures among electrical service providers. A thorough study of the interactions of power rates and weather on different lighting control strategies will help in the understanding of real lighting costs. Heating needs, and timing and interactions of heating, ventilation and lighting are other algorithms of importance and will be part of the evaluation.

A second and very important contribution of the group effort on this project will be to select different crops and work toward developing recommendations (or at least data) for daily light integrals for best growth. For example, NY is accumulating a database on lettuce and spinach response to supplemental lighting, CT is collecting similar data on purslane and watercress, and NJ continues to study tomato. MI will study how the ratio of thermal energy (temperature) and radiant energy (light) (RRT) influences floral crop growth, development, and quality. This information will be developed into a decision-support tool for grower control of the greenhouse temperature and light environment. The emphasis will be on vegetable crops where consistent timing of production and quality is important for marketing advantage.

Obj. 2c: MI, NE, CT, and OH will continue to determine crop specific nutrient requirements under CEA conditions. MI, OH, NY, and NJ will implement and test nutrient delivery methods to further limit greenhouse wastewater effluent. These activities with all contribute to decision-support for nutrient management as per *Obj. 1b*. Facility constraints will limit research on phytoremediation using indoor treatment wetlands to PA and NJ.

Data obtained to date (PA) suggest that biological filtration using constructed wetlands is an alternative for treating greenhouse and nursery waste and irrigation water. Both planted and unplanted wetlands can effectively remove organic contaminants, reducing the potential for environmental contamination, chemical carry over from one crop to the next, or development of resistant pathogens from continuous exposure to low-level pesticide residuals (MacNeal, 1997; Berghage et al., 1998). Although planted systems appear to be more robust, in many cases removing contaminants more quickly, unplanted systems have the advantage of not taking up potentially productive greenhouse space. Provided that differences in effectiveness between planted and unplanted systems can be accommodated in either increased retention time or increased system size, unplanted biofilters may be a better choice. PA research will address this issue along with management options for environmental control for most effective wetland operation. Ideally, treatment wetlands for commercial greenhouse or nursery use should be simple, low cost, and easy to build and maintain.

Waste products from other agricultural enterprises, such as liquid manure from swine operations, can be processed in a greenhouse-based constructed wetland. Thus, the controlled environment housing the wetlands can be optimized to yield more predictable performance than outdoor-based wetlands that have fluctuating performance with the change of seasons. Wastewater nitrate-N, odorous compounds, and organic pesticide removal research is ongoing at three universities while other researchers are providing quantification of wetland use for heavy metal removal. Processes are similar despite the differences in wetland plants and wastewater composition so that more collaborative effort is desirable.

EXPECTED OUTCOME:

Obj.1a: The outcome of this objective will be decision-support tools usable by commercial greenhouse growers that will increase their ability to produce high-quality crops to market specification. These tools will assist growers with height-control, temperature/timing, pest control, and nutrient-control decisions. These tools will improve crop quality, increase grower profitability, and help eliminate over-application of pesticides and fertilizers.

Obj. 1b: The deliverables of ACE_SYS are a set of plant growth systems analysis tools running on an open information superhighway. Another major result of this study, will be the quantification of the effects of key factors affecting the performance of plant growth systems. This information will be valuable in helping plant growth system managers make decisions on whether and how to take advantage of available technologies; especially when the proper integration of automation, culture, and environment factors may become beneficial.

The data used in this project will be mainly contributed by NE-164 collaborators. The result will be carefully reviewed by the NE-164 collaborators and other experts in the particular fields. While it is extremely important to have up-to-date, accurate databases (informational modules), the emphasis is in the structure of databases in a technical sense. Efforts will be devoted to determining the key systems parameters and the compatibility among them. Therefore, a significant product of this research will be a methodology of interpreting information on automation, culture, and environment to facilitate the integration of plant growth systems. The successful completion of this proposed work will demonstrate an innovative and effective method for information integration, as well as deliver a powerful systems analysis tool and useful guidelines for plant production industry.

Obj. 2a: Outcomes will include;

- Design and control algorithms for natural ventilation.
- A natural ventilation module for the ACE_SYS database.
- Results of this work will also be disseminated at grower meetings, through newsletter publication, and in technical journal articles.

Obj. 2b: Outcomes will include;

- Electrical cost analysis for lighting control strategies under various climatic (weather) conditions.
- Crop recommendations for light levels and daily integrals for desirable growth.

Efficient use of lighting is critical. Each species of plant has different light requirements (photoperiod, intensity and daily integral) which must be quantified for successful production. Greenhouses use 'free' natural light and can be supplemented with artificial light when needed. The cost of electric power varies during the day providing motivation to use the cheapest power. Computer programs may be used to measure and apply the correct amount of light at the correct time to supplement natural light which varies from day to day. A new light standard is proposed using the daily integral not intensity. This is a new concept for CEA and offers a more meaningful value of light usefulness for plant growth. Crops at different research stations can be described by the integral method and results brought together through this project.

Obj. 2c: Outcomes will include;

- Crop specific nutrient requirements and effective delivery methods.
- Greenhouse wastewater cleaning recommendations: design and operation.
- Criteria for enhanced use of CEA for constructed wetlands in mitigating other agricultural and light industrial wastes, including swine waste for odor and nutrient reduction, organic pesticides, and

heavy metals

Wastewater from greenhouse runoff or from other agricultural sources can be remediated by a wetland plant and microbiological system. The construction of a bioremediation system in the greenhouse allows the system to be environmentally controlled and, therefore, used year round.

More research is needed on constructed wetland biological filters to verify their effectiveness with a variety of greenhouse chemicals and other agricultural and industrial wastes. Removal rates for target chemicals in planted and unplanted treatment wetlands are needed to determine design criteria to achieve desired treatment results. This will allow potential users to better compare costs and benefits associated with using planted or unplanted constructed wetland biofilters to clean irrigation and waste water.

ORGANIZATION:
A Technical Committee, comprised of agricultural engineers, horticulturists and economists will direct the project and project-related activities. Each participating agency will have one official member of the Technical Committee. A major committee function will be coordination of contributing projects to ensure adherence to regional project objectives. An executive committee composed of: the Administrative Advisor, the Chairman, the Past Chairman and the Secretary, is designated to conduct the activities of the regional project between annual Technical Committee meetings. Elections of Chairman and Secretary of the Executive Committee to one year terms will take place at the annual meeting.

The committee will meet annually at either a participating institution or at a conference that focuses on engineering of greenhouse and other plant production systems. The committee will sponsor seminars and workshops to increase the awareness of the subject matter.

RESPONSIBILITIES:
Obj. 1a & 1b: CT, MI, NH, NJ, and NY will develop data on crop specific growth responses under various environmental conditions. These data will be used to develop robust, crop specific decision-support models that will feed into the ACE_SYS interactive website. The interactive website will be a systems analysis cyber environment which holds information and information processing tools for real-time, wide area distribution of decision support resources. NJ will take the lead in developing the website. All participating states (CT, MI, NH, NJ, NY, PA, OH, and NE) will contribute to the development of automation, cultural, or environmental information modules and functional modules to be integrated into the ACE_SYS. It is a common belief that agriculture in the next century will be information technology driven. Compilation of information and the use of information require seamless cooperation of many disciplines from many climatic zones. The success of ACE_SYS is therefore dependent on the active "regional" effort as described in this proposal.

Obj. 2a: The proposed natural ventilation work is dependent on cooperation between OH and NY. OH has access to the FLUENT program and NY has the neutral pressure level program, cooperation will alleviate the need to duplicate expensive resources.

Obj. 2b: Each state will provide weather data and data regarding their local electric utility rate structures. NY will coordinate evaluations of the interactions of weather, rate structures and plant lighting needs through computer simulation. NY, NJ and MI will develop data on plant responses to daily target PAR integrals for several important greenhouse crops (vegetable and floral). This interactive collaboration will facilitate the development and testing of an this important new concept of greenhouse supplemental lighting control to a commercially usable stage much faster than if all the work were to be attempted by a single station.

Obj. 2c: MI, CT, NE, and OH will determine specific nutrient requirements for different crops; NJ and PA will evaluate the effectiveness of indoor constructed wetlands for phytoremediation of different greenhouse and industrial waste products.

SIGNATURES:

Regional Project Title: Controlled Environment and Facilities Engineering for Greenhouses.

[signature]

Administrative Advisor

May 27, 1998

Date

[signature]

Chairman, Regional Association Directors

July 29, 1998

Date

[signature]

Administrator, Cooperative State Research, Education and Extension Service

8/18/98

Date

COOPERATIVE STATE RESEARCH, EDUCATION, AND EXTENSION REFERENCES:

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Specialization: Greenhouse Crop Production

Michigan (MI)

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Specialization: Plant Modeling

Leader: Dr. John Birnbaum, Department of Horticulture
Specialization: Irrigation and Fertilization of Greenhouse Crops

Nebraska (NE)

Leader: Dr. George E. Meyer*, Department of Biological Systems Engineering
Specialization: Plant Modeling and Instrumentation

Leader: Dr. Michael Kocher, Department of Biological Systems Engineering
Specialization: Sensors and Controls

Co-operator: Dr. Jay B. Fitzgerald, Department of Horticulture
Specialization: Greenhouse Crops (Extension)

New Hampshire (NH)

Leader: Dr. Paul Fisher *, Department of Plant Science
Specialization: Horticultural Crop Physiology

New Jersey (NJ)

Leader: Dr. K.C. Ting*, Department of Bioresource Engineering
Specialization: Systems and Automation

Leader: Dr. G.A. Giacomelli, Department of Bioresource Engineering
Specialization: Integrated Plant Production Systems

Leader: Professor W.J. Roberts, Department of Bioresource Engineering
Specialization: Structures and Environment

Leader: Dr. D.R. Mears, Department of Bioresource Engineering
Specialization: Environmental Control

Leader: Dr. P.P. Ling, Department of Bioresource Engineering
Specialization: Machine Vision

Leader: Dr. Harry Janes, Department of Plant Science
Specialization: Plant Modeling

Leader: Dr. Robin Brunfield, Department of Agricultural Economics and Marketing
Specialization: Economics of Horticultural Production

Leader: Dr. George Wulster, Department of Plant Science
Specialization: Floriculture

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Leader: Dr. R.W. Langhans, Department of Floriculture and Ornamental Horticulture
Specialization: Greenhouse Management

Leader: Dr. G. White, Department of Agricultural Economics
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Leader: Dr. E. Jay Holcomb, Department of Horticulture
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Leader: Dr. Robert D. Berghage, Department of Horticulture
Specialization: Greenhouse crops, Phytoremediation

*Voting Member

RESOURCES:

Annual Input

Station	Scientist Years (SY)	Professional Years (PY)	Tech. Support Years (TY)
Connecticut	0.15	0.25	0.50
Michigan	0.60	0.75	---
Nebraska	---	---	---
New Hampshire	0.20	---	1.00
New Jersey	1.50	---	---
New York	0.75	3.50	1.00
Ohio	1.00	0.50	0.50
Pennsylvania	0.57	1.00	0.81
Total	4.77	6.00	3.81