Engineering, Structures and Innovation

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High Tunnel Construction and Production: A Learning Experience

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Index Words: high tunnel design, season-extension

Significance to the Industry: High tunnel production is gaining popularity across the Southeast. Growers in Mississippi are becoming more aware of this production technique through programming provided by the MSU Extension Service (MSU-ES), a recent tour and grant program administered by the Mississippi Department of Agriculture and Commerce (MDAC), and research findings and field days provided through the Mississippi Agricultural and Forestry Experiment Station (MAFES). The USDA Natural Resources Conservation Service (NRCS) recently launched a 3-year high tunnel pilot project for farmers.

Nature of Work: Primarily used for season-extension, high tunnels allow growers to get their product to market early or continue to have product even into winter. The structures may also reduce pesticide use, increase yields, and maintain soil nutrition. High tunnels are basically unheated greenhouses. Ranging in height from 12-15 ft., crops are produced in the native soil, with or without mulch material.
In 2008, the first of 2 high tunnels was erected at the Beaumont Horticultural Research Unit in Perry County, Mississippi. This structure was purchased as a kit (ClearSpan TM) from Gothic Arch Greenhouses (Mobile, AL). The second structure was built to the station's specifications by a local greenhouse manufacturer (Tubular Structures, George Co., MS)

Results and Discussion: Early into the construction of the first structure, it was clear that many parts were not included in the kit. This posed a problem, since the station is remotely located and a trip to the nearest supply store requires a great deal of time. The cost of these extra parts also added to the expense of the structure, in addition to time and labor costs. Once the high tunnel was constructed, we became increasingly aware of changes to be made to a second structure.

There are many configurations of high tunnels commercially-available. Choosing the right one for a given operation requires planning. While the design of the "kit" structure was acceptable and adequate for the needs of this project, some changes were made to the design of the second structure. The changes in design relate primarily to ease-of-use, efficient use of space, and structural stability.

Relatively small changes in design may have a large impact on the integration of a high tunnel into a growing system . One important change was the height of the sidewalls. The “kit” house was designed with 4' sidewalls. While this is a standard height, 6' sidewalls provide greater efficiency of space by allowing equipment (especially tractors with implements) closer to the edges.

Because of the lack of snow-load requirements and as a cost-saving measure, a minimal number of purlins may be used for high tunnels in the Deep South. However, strong winds, particularly in coastal areas such as south Mississippi, can pose a threat to the stability of the structure. For this reason, additional purlins are recommended for growers in the region.

High tunnels are semi-permanent structures. They are intended to be erected and disassembled or moved between seasons. The original design specified the use of a treated lumber 2x4 to serve as the base along the sides. Not only does this provide minimal structural support, but it also makes transport of the intact structure nearly impossible.

Perhaps one of the simplest design improvements concerned the end walls . Both the side and end walls of high tunnels are designed to be opened or closed dependent on weather conditions. Side walls are rolled up either manually or with battery-operated mechanisms. A zipper closure was employed in the design of the “kit” high tunnel. While this method seemed user-friendly and inexpensive, it proved to be inadequate. After short-term use, the zipper apparatus was torn apart by strong winds. To keep the tunnel closed through the winter, grommets were inserted and the curtain was laced closed. An improved design element was the addition of roll-up end walls. These are actually easier to use and provide greater crop protection while still allowing access into the tunnel.
The two simple designs employed at the Beaumont Horticultural Unit are in no way indicative of the wide range of design options available. These recommendations are intended to be of use to growers who are new to this production system.

Current Mechanization Practices among Greenhouse Operations

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Index Words: greenhouse, greenhouse mechanization.

Significance to Industry: The nursery and greenhouse industry in the Gulf South region of the United States creates a significant economic impact to the economy within the region. Hall *et al*. (5) estimated that the annual economic impact of the industry in the seven states included in this paper amounted to $5.182 billion with Alabama, Mississippi, Louisiana, Florida, Tennessee, South Carolina and Georgia contributing $411 million, $55.6 million, $149.3 million, $3.006 billion, $548 million, $445.2 million, and $566.8 million, respectively. In addition, these states generated 59,903 jobs and an estimated $148 million of indirect business taxes throughout the region. As horticulture production in the northern Gulf of Mexico states increases in value, it is expected that nursery and greenhouse growers will desire to increase production capability and efficiency through adoption of mechanized/automated technologies, improved working conditions and workers' safety, and enhance the markets for horticulture products. A socioeconomic survey of nursery automation was conducted in the Gulf South as part of a research program undertaken by the Mississippi Agricultural and Forestry Experiment Station (MAFES) and the U.S. Department of Labor entitled 'Enhancing Labor Performance in the Green Industry'(9). The overall goal of this paper is to present the results of the analysis of the major tasks performed by workers manually among greenhouse only operations with little or no mechanization. Results of this analysis would provide guidance for horticulture research scientists to make recommendations as to which automation/mechanization systems could be most beneficial to the growers. In addition, growers could use this information to make more informed financial and personnel decisions.

Nature of work: The socioeconomic survey of wholesale nurseries and greenhouses in seven Gulf South States: Mississippi, Alabama, Louisiana, Florida, Tennessee, South Carolina and Georgia was conducted between Dec. 2003 and Sep. 2008. Official lists of certified nurseries were acquired from state regulatory agencies and green industry buyers' guides (2, 3, 4, 6, 7, 8, 10, and 11). Only wholesale growers operating throughout the seven states, except North Florida, were used in selection of survey participants. In Florida the selection was made from nurseries operating geographically in counties from Gainesville (Alachua County) and North. A random sample of 50 wholesale growers from each state was generated. The selected growers were contacted via mail and asked for their co-operation in survey participation. These growers were also asked to indicate their willingness to participate in the survey, by returning a postcard with their intentions indicated. The growers that indicated their willingness to participate were contacted by phone and interviews were scheduled. A total of 185 nursery automation surveys were completed through personal interviews with wholesale nurseries (56), greenhouses (48), and mixed nursery and greenhouse operations (71) in Mississippi (32), Louisiana (29), Alabama (26), Florida (27), Tennessee (17), South Carolina (30), and Georgia (24). Only the greenhouse operations and mixed nursery and greenhouse operations were considered for the purposes of this paper, for a total of 119 growers. SPSS version 17 (11) was used to analyze the survey data to determine the frequency distribution of each type of mechanization/automation within each task of greenhouse production as described within the survey instrument. Miriam-Webster defined mechanization as “to equip with machinery, especially to replace human or animal labor”, and automation as “automatically controlled operation of an apparatus, process, or system by mechanical or electronic devices that take the place of human labor” (13). This paper will examine the major tasks performed manually among greenhouse operations without mechanization/automation.

Results and Discussion: The ten nursery tasks included in this survey were Media preparation, Pot/tray filling, Cutting/seed collection, Cutting/seed preparation, Sticking cuttings/planting seed, Environmental control, harvesting and grading production, Greenhouse fertilizer application, Greenhouse pesticide application, and Irrigation management. Table 1 shows the numbers and percentages of growers which reported that the major tasks were performed by workers manually. Harvesting and grading were performed by workers manually. The tasks of cutting/seed collection were reported as zero mechanization by 99% of growers, and 96% reported no mechanization in cutting/seed preparation. Sticking cuttings/planting seeds was done manually by 87% of growers, while 85% reported that media preparation was not mechanized. Sixty percent of growers filled their pot and trays manually, and 53% had no mechanization in fertilizer application, as is 46% of pesticide application.

Two of the major tasks were performed by workers with substantial mechanization. Environmental control and irrigation management both were indicated by only 39% of growers as having no mechanization in these areas. The mechanization systems used in environmental control included: boilers and heaters; computerized greenhouse controls; fans; and roll up sides. Irrigation management included mechanization systems such as: drip; misters; injectors; timers; sprinklers; overhead; hoses and nozzles; or some combination of these.

The survey results indicated that there was a great deal of room for mechanization implementation among the participating greenhouse and mixed operations, particularly in the areas of harvesting and grading production, cutting/seed collection, cutting/seed preparation, sticking cuttings/planting seed, and media preparation.

Table 1. Number and percent of participating greenhouse operations which reported that the major tasks were performed by their workers manually

Nursery Task	Greenhouse Only (N=48)	Mixed Operations (N=71)	All Operations (N=119)	Percentage of all operations
Media Preparation	39	62	101	84.9
Pot/tray filling	24	47	71	59.7
Cutting/seed collection	48	70	118	99.2
Cutting/seed preparation	47	67	114	95.8
Sticking cuttings/planting seed	36	67	103	86.6
Environmental control	11	35	46	38.7
Harvesting and grading production	48	71	119	100
Greenhouse fertilizer application	22	41	63	52.9
Greenhouse pesticide application	20	35	55	46.2
Irrigation management	11	35	46	38.7

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A Specialty Crops Research Project: Using Wireless Sensor Networks and Crop Modeling for Precision Irrigation and Nutrient Management in Nursery, Greenhouse and Green Roof Systems

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Index Words: irrigation management, wireless control, radio-powered nodes, Ech$_2$0 sensors

Significance to Industry: The overarching objective of this proposal is to make better use of increasingly scarce water resources. Water is vital to the sustainability of nursery and greenhouse production systems, and water management has consistently been ranked as one of the top three issues by industry associations nationwide. Almost all growers have some issues with water management, but oftentimes the most basic question is – should I irrigate today? While this question could seem trivial, plant water requirements vary by species, season and microclimate, and depend upon any number of environmental and plant developmental factors that need to be integrated on a day-to-day basis. Add to these factors the number of species grown in a 'typical' operation and the length of crop cycles which can range from a few months to several years, it quickly becomes obvious why precision irrigation scheduling in nurseries is extremely difficult. If done well, daily irrigation decisions take a lot of time and the irrigation manager often faces complex decisions about scheduling that requires the integration of knowledge at many levels. Irrigation management is therefore probably one of the most complicated tasks in a nursery operation, particularly when water is limiting.

Nature of the Work: This research project brings together a national group of engineers, plant scientists, economists and extension specialists from five universities and two commercial companies, to develop the next generation of precision irrigation management tools, using networks of sensors in the field that can instantaneously relay that information back to a grower's computer (or iPhone™), so that the grower can monitor and control irrigation management decisions using real-time data (Lea-Cox, Ristvey et al., 2008). These tools will allow growers to precisely monitor plant water use to allow better control of irrigation water and nutrient applications, and increase the profitability and efficiency of commercial plant producers.

Sensor Networks. The project participants are using networks of sensor nodes. Each sensor network consists of a system of radio-powered "nodes" that are deployed in a plant production area, to which a number of environmental sensors are connected (Zhang et al, 2004). Any combination of soil moisture and electrical conductivity sensors, soil and air temperature, relative humidity, tipping rain gauge and light (photosynthetically-active radiation) sensors can be connected to the radio nodes, according to the specific sensing requirements of the grower. The nodes sense data on a per minute basis, and log the average data every 5 minutes, to conserve battery life and memory. The accumulated data is then transmitted at 900 MHz using a battery operated radio card to a 'base station' which is then connected to a computer. The grower uses software (a "graphical user interface") to plot and display the information from each of the nodes. This software can display multiple networks, enabling the grower to monitoring the data in real time. The advantages of these networks are obvious – they provide information at the "micro-scale" which can be expanded to any resolution for a specific operation, for specific needs. Precision irrigation and plant growth management will benefit greenhouse and nursery producers, while a better understanding of the water dynamics of green roofs will provide stormwater and energy performance metrics for LEED Green Buildings. The result will be a commercially available product for irrigation water management that is specifically designed for diverse and intensive production environments, but that also has broad applications for all high-value specialty crops, including ornamental, fruit and vegetable production.

Project Objectives. The global objectives of this five-year project are to: (1) Further develop and commercialize wireless sensor networks and advanced customizable software that specifically meets the monitoring and control requirements at the species level for field (soil-based), container- (soilless) production and green roof systems; (2) Determine the performance and utility of moisture and electrical conductivity sensors for precision irrigation and nutrient management in soil and soilless substrates. Additionally, we will integrate other sensors into networks (e.g., temperature, relative humidity, solar radiation , tipping rain gauges for rain and irrigation), to model daily plant evapotranspiration; (3) Determine spatial and temporal variability of soil/substrate moisture and electrical conductivity, to minimize the numbers of sensors required in diverse root environments at various scales; (4) Provide micro-scale (root environment) data and integrate it with macro-scale (atmospheric environment) models so we can *predict* (i.e. forecast) water use for indicator plant species; (5) Develop best management practices for the use of sensors for irrigation and nutrient management, working with specialty crop partners to capture needs-based issues during on-farm system development; (6) Quantify improvements in water and nutrient management, nutrient runoff, plant quality, and yield; (7) Evaluate the private and public economic and environmental impacts of precision sensor-controlled practices; identify barriers to adoption and implementation of these practices and (8) Engage growers and the industry on the operation, benefits and current limitations of this sensor / modeling approach to irrigation management.

Grower Partners. The research is tightly integrated with the deployment of sensor networks on a number of commercial nurseries and greenhouses throughout the US, including Raemelton Farm (Lea-Cox, Black, Ross and Ristvey, 2008), Waverly Farm and Bauers Greenhouses in Maryland, Willoway Nurseries in Ohio, McCorkle Nurseries and Evergreen Nursery in Georgia and Hales and Hines Nursery in Tennessee. The integration of commercial partners into this project is critical for its success: it assures that the software and hardware that will be developed meets the needs of the industry, rather than the researcher's perception of those needs. The project is structured in such a way that the research scientists, engineers and economists can engage the industry collaborators on a day-to-day basis. An economic, environmental and social analysis will identify cost and benefits to the industry and society as well as barriers to adoption of this new technology.

Data Management Tools. This data is important to make informed decisions about nutrient management, which has particular importance in implementing sustainable management practices. One of the key goals of this project is to use scientific methods to interpret, analyze, and integrate the information gathered from a large number of sensors, and to present summarized information in a graphical format that will allow farmers to quickly and intuitively make decisions regarding their irrigation and fertilizer management. Equally important, the project intends to develop a number of plant-specific software modules for predictive management of water use, based upon plant and environmental models developed by the scientific teams.

Results and Discussion: A better knowledge of real-time environmental conditions will also aid integrated pest and disease management decisions, as well as assessing crop development over time, which has large impacts on labor costs, productivity and the profitability of farms. In addition to these private benefits, there also are public benefits: reductions in water use and runoff from these facilities will result in environmental benefits for the public at large, which the macro-economic team will be researching. All of this information will be made available over the internet, by developing new modules for an online water and nutrient management knowledge center (Lea-Cox, Zhao et al., 2008). Full details about the university team members, the commercial partners and detailed project goals and information can be found at http://www.smart-farms.net.

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Water and Nutrient Modeling in Nursery and Greenhouse Operations in Maryland

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Index words: Nitrogen, phosphorus, greenhouse, container, field, decision tools

Significance to Industry: Many researchers have looked at various aspects of plant growth, nutrient requirements, and operational efficiency of nursery and greenhouse operations over the years, but few studies have looked at the water and nutrient efficiency of whole production systems. Most studies have focused on a specific practice, to increase efficiency. We are developing multivariate production system decision tools, to provide insight into how changing one practice may have multiple outcomes, both positive and negative, on enterprise profitability and environmental impacts. This approach will help both growers and researchers identify ways to best change practice, which will help achieve the most efficient and profitable outcome.

Nature of Work: The Chesapeake Bay watershed has been negatively impacted by human activity, and is currently the target of a long-term multi-state cleanup effort. In 2008, the bay's health was rated at 28/100, with a score of 40 required to remove the bay from the impaired waters list by 2010, and avoid additional regulations (1). Nutrient pollution is considered the largest threat to the bay, with nonpoint sources contributing approximately two-thirds of the nitrogen (N) and one-quarter of the phosphorus (P) (2). Much of the research on nutrient addition to the bay has focused on N and P inputs from point sources and agronomic crops, with minimal research on quantifying N and P inputs from the nursery and greenhouse industry (3,4).

Nursery and greenhouse production areas can range from extensive, field operations with low N and P input rates to highly intensive container-nursery and greenhouse operations, which can contribute varying quantities of N and P to the surrounding environment, if appropriate management and water-control structures are not in place. All wholesale greenhouse, field and container-nursery operations in Maryland are required to develop and implement an N and P-based nutrient management plan which incorporates nutrient, irrigation, and surface water runoff risk assessment components (5). The goals of this research project are to gain a deeper understanding of grower practices in Maryland, and develop decision tools that can aid this industry in increasing efficiency, and reducing N and P runoff into the Chesapeake Bay.

Materials and Methods

Data collection: Site visits were conducted for 50 volunteer nursery and greenhouse operations in Maryland, combining detailed information from grower interviews with more general data submitted in state water and nutrient management plans (6). Collected data were entered into a database, and summary statistics were derived from the database as model inputs (see model development below). This information allows us to determine ranges of key variables, such as nutrient and water application rates, to get a better understanding of the efficiency of these practices and identify those points in the process which are key to production efficiency. We also intend to use it to identify gaps in our current knowledge, to target future research areas.

***Model Development*:** The Stella modeling program (7) has been used to develop three separate models (greenhouse, container-nursery, and field nursery); only the container model is discussed in this paper, as an example. Each model incorporates major variables affecting plant growth, water and nutrient runoff, as well as the unique management and operational factors associated with each production system (Figure 1).

Following model development, each model was calibrated by entering the inputs from appropriate published datasets and adjusting model variables to approximate those of the published dataset outputs (e.g. 8). After calibration, additional published datasets will be used to further verify the model outputs, to increase the confidence of the model assumptions. After this verification process has been completed, data (i.e. low, median, and high values) obtained from site visits to growing operations will be used to run a number of “what-if” scenarios, to help determine the impact of current practices on nutrient and water runoff. Models could be run for a normal production cycle (e.g. outputs in Figs. 2 and 3 are for a 20-week growing cycle) or for extended periods of time, for forecasting / learning purposes. For example, by looking at the range of fertilizer amounts in 1 gallon containers for low nutrient use species, the minimum, maximum, and average values can be input into the model, keeping all other variables constant, to ascertain at the effect of different fertilizer rates on nutrient leaching and denitrification rates.

Results and Discussion: A total of 15 field, 24 container nursery, and 21 greenhouse operations were included in the database, with a total of 32, 130, and 119 management units respectively representing 1351 acres of land. Nutrient application rates varied widely for all three production system, which can be seen in Table 1. Field operations were found to have the lowest average inputs, then greenhouse, with container nursery operations having the highest average inputs. By understanding not only rate, but also specific management practices (i.e. plant density, irrigation practices, fertilizer rate) we can begin to identify practices that have the highest impact in reducing nutrient runoff. There are a variety of N and P rates in published literature, recommended by fertilizer companies, and applied by the grower. Numerous articles have shown that increasing fertilizer rates increases plant growth up to a point, but nutrient uptake efficiency typically decreases with increasing rates (9,10). It is important to understand the balance between nutrient application rate, plant growth, irrigation application, and nutrient uptake efficiency, to achieve the fastest growth with the least amount of inputs and losses.

Conclusions and Future Developments: We are developing specific models for nursery and greenhouse production systems as tools to target water and nutrient efficiency. The database that has been developed for this project provides real-world nutrient and irrigation information, while the models will help determine the impact of those management decisions not only on the plants, but also the environment. These models will be useful for growers, researchers, and extension educators to provide a better understanding of system water and nutrient efficiency, using a range of realistic resource inputs. With a greater understanding of the problem, we can be more effective at educating growers and implementing better nutrient reduction practices. This should lead to greater efficiencies, lower costs, and enhanced profitability for growers, which are usually the most important incentives for changing practices. These models also have the potential of being used in other states and countries to increase resource use efficiency in similar production systems.

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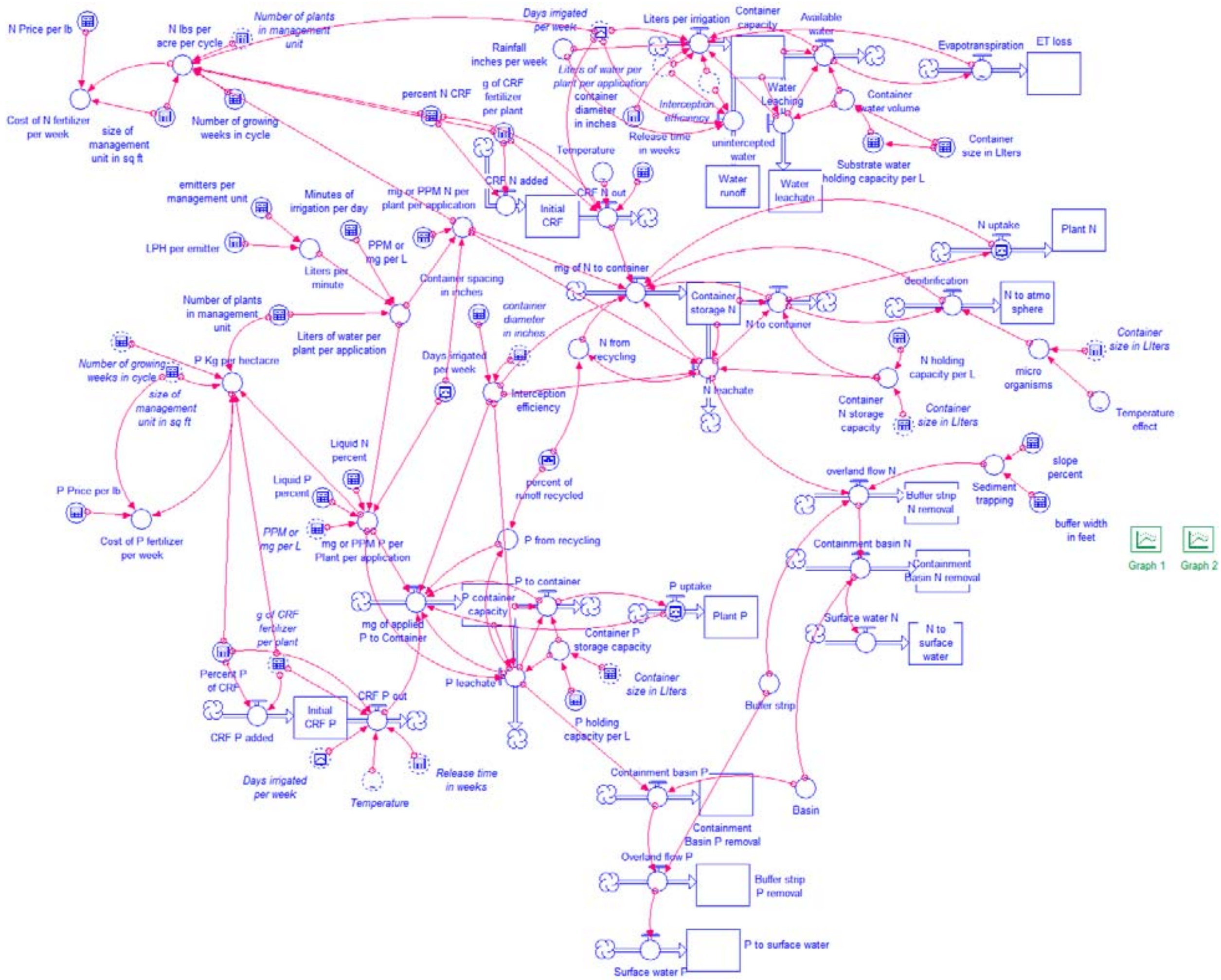

Figure 1. Graphical representation of the preliminary container-nursery model. Users can input site-specific variables such as container size, plant density (plants/ft^2), fertilizer type (soluble vs. slow-release), application rate and timing, irrigation practices, etc. After the various inputs are entered, the user can run the model to determine the allocation of applied N, P, and water over the production cycle, based on the specific variables. Non site-specific variables are obtained from published literature.

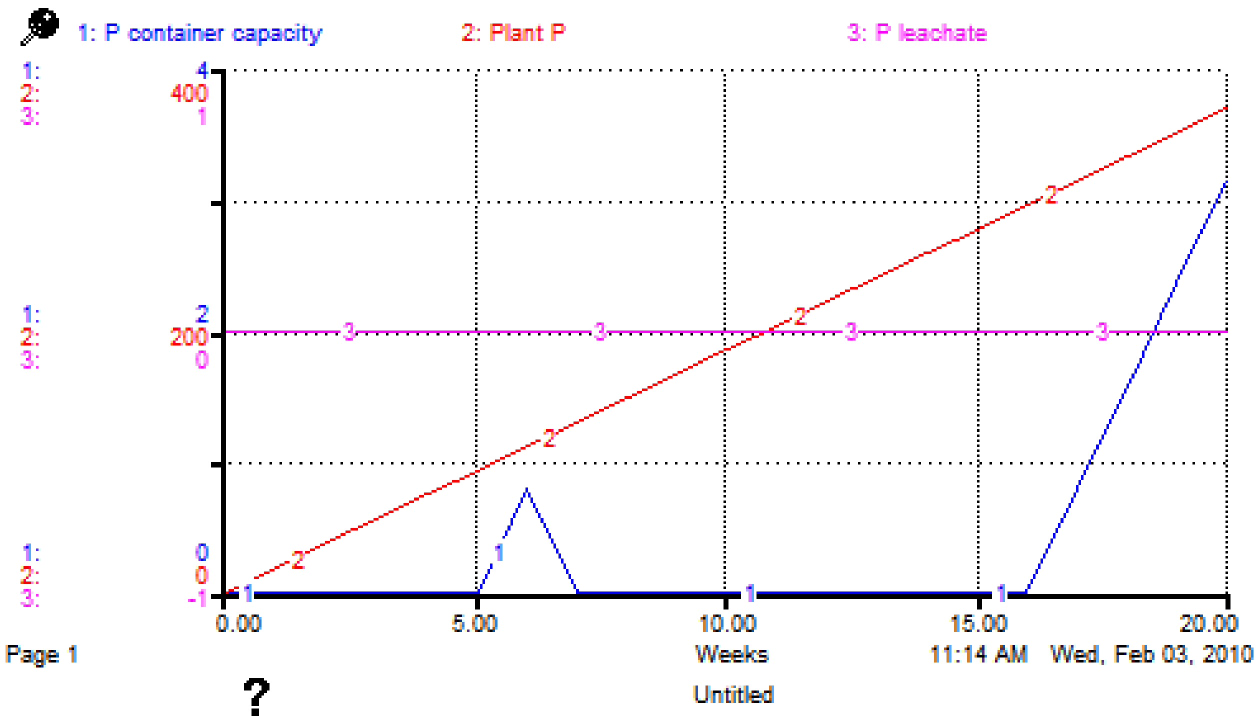

Figure 2: Hypothetical Stella container model output of phosporus allocations over a 20-week growing cycle. Line 1 represents mg P stored in the container substrate, by week; line 2 represents the mg P stored in the plant per week, and line 3 is the P leached per week. (Note different values on Y axis). Note that models are still being developed; graphical outputs are given only for visualization.

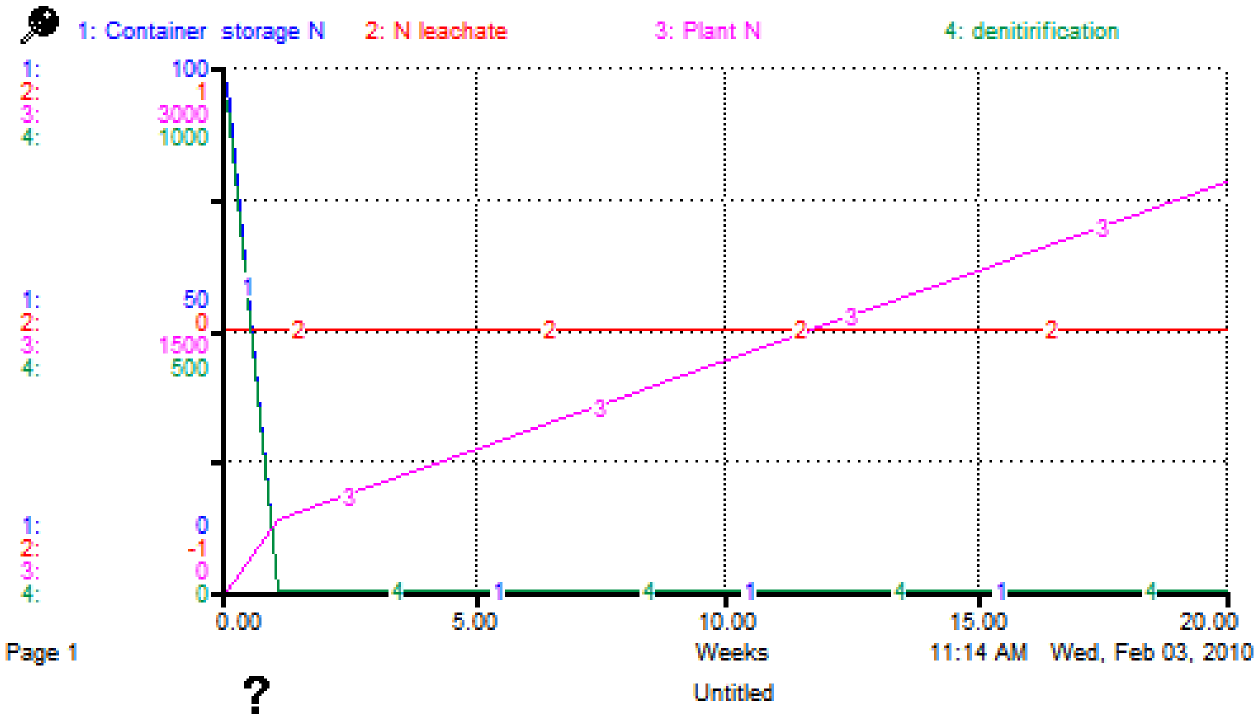

Figure 3: Hypothetical Stella container model output of nitrogen allocations over a 20-week growing cycle. Line 1 represents mg N stored in the container substrate, by week; line 2 represents the mg N leached each week; line 3 is the N taken up by the plant, and line 4 is N removed from the container by denitrification. (Note different values on Y axis). Note that models are still being developed; graphical outputs are given only for visualization.

Table 1. Low, median and high levels of N and P applied per acre per year to greenhouse, container and field operations in Maryland. Numbers are based on calculations from grower interviews at 50 operations in Maryland that were site visited during February-April, 2009.

	Greenhouse		Container		Field	
	lb of N /acre/yr	lb of P2O5 /acre/yr	lb of N /acre/yr	lb of P2O5 /acre/yr	lb of N /acre/yr	lb of P2O5 /acre/yr
Low	10	5	4	6	1	1
Median	63	29	482	284	34	27
High	1712	2019	2649	1091	182	272