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Decision Support System for single truss tomato production

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Abstract

Engineering and horticultural research efforts aimed at developing an innovative, controlled environment, plant production system have been completed. In this production system, tomato plants are made transportable and each plant is allowed to produce only one truss of fruit. The main objective of this production system is to secure uninterrupted and predictable quantities of uniform quality tomatoes and make efficient use of resources. This single truss tomato production system (STTPS) is a highly integrated and technology intensive system. A computerized decision support system has been developed to aid the production planning of STTPS. The capabilities of this decision support system include:

- calculate/estimate daily photosynthetically active radiation available to plants;
- establish the production schedule based on the specified annual number of plantings;
- calculate the number of plants per crop based on the greenhouse space constraint;
- calculate the size of seedling area;
- display the production area layout and crop placement;
- determine yearly greenhouse space utilization efficiency;
- estimate labour requirement;
- provide a task and time table for the entire production year;
- predict the yield;
- estimate the revenue.

Key words: controlled environment plant production systems, tomato plant factory, computer aided production planning

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1 Introduction

Traditionally, within a greenhouse, tomato plants are grown at fixed locations and multiple clusters of fruit are harvested from each plant during a production season. Strings are normally used to hang plant canopies from overhead structures in the greenhouse. An annual two-crop production schedule, one in spring and the other one in the fall, is usually practiced in the United States. In many European countries, an eleven-month schedule, with harvests beginning in March and ending in November, is quite common. These production systems are relatively simple in concept and straight forward in operation. However, they each show weaknesses when evaluated against the following desirable features:

- efficient greenhouse space utilization and material handling;
- efficient use of natural and supplemental light;
- predictable production schedule, particularly November through March;
- potential for automation/mechanization;
- high labour efficiency;
- possibility of continuous year round production.

Engineers and horticulturists at Rutgers University have developed an innovative greenhouse tomato production system which possesses all of the above features (McAvoy, 1984; McAvoy et al., 1988 & 1989; Giniger et al., 1988; Ting et al., 1989; Giacomelli et al., 1988; Kabala & Giacomelli, 1992; Fischer et al., 1990; Ling et al., 1990; Luxhoj & Giacomelli, 1990). In this production system, tomato plants are made transportable and each plant is allowed to produce only one truss of fruit. The main objective of this continuous-batch production system is to produce uninterrupted and predictable quantities of uniform quality tomatoes with efficient resource utilization. One added advantage of this system is its short growth and production cycle for each 'batch' of plants (i.e. crop). This single truss tomato production system (STTPS) integrates many aspects of automation, plant culture, and environmental control (Ting & Giacomelli, 1991).

1.1 Tomato plants

Plant growth is terminated above the first truss of flowers. After harvest of one truss of fruit, the plant is discarded and immediately replaced. There are a number of production blocks, each consisting of a crop of plants of the same physiological age, in the greenhouse at the same time. The number of days required to produce each crop can be predicted on the basis of the available photosynthetically active radiation (PAR), The available PAR is also used to estimate the total fruit weight produced by each plant. Crops are seeded at predetermined schedule times corresponding to the harvest schedule and the estimated available future light. The harvest window of each crop is less than two weeks. It is possible to schedule up to 52 crops per year. The production cycle of each crop consists of four developmental stages delineated by five distinct events: sowing, transplanting 1, spacing, flowering (also called transplanting2), and final harvest. A change in plant spacing is required between any two consecutive stages and thus access to and transportation of the crop must be efficient and rapid. Stages 1 through 3, from sowing to flowering, are vegetative growth stages and Stage 4, from flowering to final harvest, is the fruiting stage. Since uniformity is of great importance in maintaining production schedule, plant screening is normally done at an early stage.

1.2 Production environment

A sufficient amount of PAR is needed for proper plant growth and fruit development. If all other environmental conditions are not limiting, light can be effectively used to control plant productivity. Therefore, supplemental photosynthetic lights are operated for the period of low natural light levels. To complement the enhanced lighting, the atmosphere of the production area is enriched with co_2. Different air temperature set-points are used during day and night.

1.3 Growing system

Tomato plants are grown on transportable benches at a high population density to maintain near closed plant canopy conditions. They are transported for spacing as overcrowding develops. A uniform, continuous crop canopy assures maximum use of both natural and supplemental light. Containers filled with soil mix and rockwool have been successfully used as growth substrates. The method of nutrient solution supply to the plants can be trickle irrigation, ebb-flood, or nutrient film technique (NFT).However, a means of distributing and recollect the nutrient solution, so as not to hinder plant access or transportation, is a design requirement. Another important design consideration in the growing system is plant support. The design of plant support may affect the fruit quality, plant mobility, labour efficiency, system costs, and flexibility for future modification.

1.4 Layout and flow of materials

The ultimate form of an operational single truss tomato production system will parallel a manufacturing factory. The layout and flow of materials of this plant factory need to be carefully organized. The layout designates where the crop and raw materials are required for each days operation. The components included in the greenhouse layout are plants at various stages, plant culture support systems, environmental control systems, transport devices, machines, work stations, storage, and other personnel and physical support facilities. A layout plan will inevitably affect the way materials flow, and the work flow procedures allowed subsequently; however, it is likely that there are many workable (although sub-optimal) internal transport methods within a given layout. Every transport system requires a certain level of labour coordination, transport devices and machinery. The types of internal transport system could range from very labour intensive to highly automated, and from rigidly controlled to flexible.

1.5 Management

The major managerial concern of this production system is the use of predictive planning and the application of real-time adjustment to keep on schedule. A production schedule needs to be established and precisely executed. During the operation stage, situations may deviate from the desired predicted states. Possible influencing factors include weather conditions, labour availability, system performance, and markets. Automatic data collection and analysis systems accompanied by computer models with predictive power will be invaluable to the management.

Systems integration work is underway to develop a commercially viable greenhouse system for producing single truss tomatoes. A part of this effort is the development of a decision support software package for the various tasks the greenhouse manager has to carry out. This paper describes the utilities of this software package.

2 Software development

The goal of this project was to develop a software package for those who design, manage, and operate single truss tomato production systems. The software would be a user-friendly, menu-driven, self-contained package executable on DOS-based personal computers.

A software package 'TOMATO' has been developed to provide information for assisting the operation of single truss production systems. The capabilities of this software package include:

- calculate/estimate daily photosynthetically active radiation available to plants;
- establish the production schedule based on the specified annual number of crops;
- calculate the number of plants per crop based on the greenhouse space constraint;

- calculate the size of seedling area;
- display the production area layout and crop placement;
- determine yearly greenhouse space utilization efficiency;
- provide a task and time table for the entire production year;
- estimate labour requirement;
- predict the yield;
- estimate the revenue.

Each of these functions will be described in the following section.

3 Results and discussion

3.1 Daily available PAR

The cumulative amount of PAR available to plants is used for two purposes:

- to determine the required number of days between sowing and flowering, which indirectly provides harvest date;
- the weight of fruit that each plant can produce.

Both solar radiation and supplemental light are combined in the calculation. Solar energy data on a daily basis and the overall transmission of greenhouse glazing may be entered to the software. A formula is incorporated to calculate the amount of PAR on the basis of total solar energy. The intensity within the PAR wave band, power requirement, and operating schedule of supplemental lights may be specified by the user. A file containing the estimated daily PAR at the plant level is created. This file also contains information about the power consumption and utility cost of the supplemental lights.

3.2 Production schedule

This tomato production system allows up to two weeks as the harvest window of each crop. Since multiple crops will be grown annually, it is desirable to distribute the final harvest days of all crops evenly throughout the year. The duration of a crop, between sowing and final harvest, varies from 101 days to 115 days. Stages 1, 2, and 4 are considered to have fixed lengths of time, and they are 14, 14, and 56 days, respectively. Stage 3 has a variable time length depending on PAR availability (Giniger et al., 1988). Estimation of the cycle time of a particular crop is carried out, with reference to its specified final harvest, by back-calculation based on the data of available PAR. This software is capable of generating a complete annual schedule containing specific timing of all stages for all crops grown within a year.

3.3 Number of plants per crop

Tomato plants in different stages are allocated different plant densities. Several crops, each in its own production stage, may co-exist in the same greenhouse. Once the size of the available greenhouse production area is known and the decision is made on the number of crops to grow per year, it is possible to determine the maximum allowable number of plants in each crop. Normally, it is assumed that all the crops will have the same number of plants. Growing each crop with a number of plants not exceeding the maximum allowable number ensures that the space requirement will be kept within the size of the greenhouse throughout the entire production year.

3.4 Size of seedling area

The space requirement for Stages 1 and 2 (i.e. seedling stages) are much smaller than that for Stages 3 and 4. It is possible to dedicate an entire greenhouse production area only to the plants in Stages 3 and 4 and place the plants in seedling stages elsewhere. The software will calculate the required size of the seedling area needed for this.

3.5 Greenhouse layout and crop placement

The single truss tomato production system is essentially a plant factory. Plants are expected to be regularly transported and manipulated (for example, pruning, pinching and harvesting). Since there will be multiple crops in different stages co-existing within a production area, the physical location of each crop and the routes of its transportation could potentially affect space utilization and labour efficiency. Based on the shapes and sizes of production area and benches specified by the user, the software traces the placement of each stage of each crop over time.

3.6 Space utilization

The production area within a greenhouse will be maximized; however, it is not expected to be fully occupied by the plants all the time. A summary of annual space utilization efficiency is given by the software. The software calculates the daily space requirements and add them up to determine the annual space requirement. The comparison of this space requirement and the available production space gives the efficiency of space utilization.

3.7 Task and time table

The manipulation of plants, including plant transport and cultural practices, can normally be described by tasks. Some examples of tasks are sowing, transplanting, pruning, and harvest. Each task requires a predetermined amount of labour time. Once the required tasks and their frequencies are established for each crop, the software will generate a table listing daily task requirements for the entire year.

3.8 Labour requirement

The information contained in the task and time table is also used to produce a annual profile of daily labour requirement. This enables the manager to plan labour allocation and estimate labour costs.

3.9 Yield prediction

The average weight of fruit produced by each plant in a crop was found to correlate well with the amount of PAR available to the plants during Stage 4. This relationship was presented as a regression equation by Giniger et al., (1988). Based on this equation and the number of plants in the crop, the yield of a particular crop is calculated.

3.10 Revenue estimation

The economic return of a production system relies not only on its productivity but also on its capability of delivering its products when the market value is high. Tomato market price is known to fluctuate over time. Therefore, knowing the yield alone will not necessarily provide correct assessment of the economic potential of a tomato production system. It is more important to know the market value that the tomatoes can potentially bring. This software allows the user to enter monthly tomato market prices, both wholesale and retail. The revenue is then estimated by summing up the twelve monthly products of yield and market price. In a study by Ting et al. (1989), it was found that the revenue is the most significant factor affecting the return on investment of an STTPS.

4 Conclusions

The single truss tomato production system is a tomato plant factory of the future. It is a technology and capital intensive system. However, its operational advantages and economic potential may very well justify the investment necessary. Many new concepts and technologies are crucial to the success of its operation. The software 'TOMATO' integrates the essential knowledge base with the means of making use of this knowledge. It may be used as an information source, a training tool, and/or a decision support system. It is felt that, by having this software system available, the likelihood of a successful commercial STTPS in the near future is substantially increased.

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