Environmental Control of a Single-cluster Greenhouse Tomato Crop

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Summary. In this paper we review our research of light effects on tomato production. It was demonstrated that, during the production of greenhouse tomatoes, the total fruit yield, as well as time of harvest, was related to light. The date of harvest was inversely correlated with the amount of light the crop received during the seedling phase of growth, while fruit weight was positively correlated with light during the production phase. Additionally, we present information that shows that light was most effective in promoting fruit development between 15 and 45 days after flowering. Some of these relationships were quantified and used to develop a predictive model to help a grower plan a tomato crop to meet market demand. The concept of the Single-cluster Tomato Production System was developed, and the rewards of using our understanding of plant-environment interactions to control plant growth and, therefore maxim& profits were shown. Furthermore, the need to create a more dynamic model and the methods for doing so were discussed.

Greenhouses enable tomato growers to produce fruit beyond the period permitted by local weather conditions for field production. An extended production season in conjunction with the superior level ofenvironmental control afforded by the greenhouse results in higher fruit quality and higher rates of production per unit area.

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Environmental control in the greenhouse, however, is energy-intensive. The cost of environmental inputs (heat, light, nutrients, and carbon dioxide) can be minimized by using them as judiciously as possible without sacrificing productivity or quality. The most efficient and effective use of expensive environmental inputs will result only from a greater understanding of plant response to single or interactive environmental stimuli at each stage of development (e.g., vegetative vs. reproductive). The advantage of precise climate control in the greenhouse can be enhanced greatly when computer-monitoring and control systems are added. However, this advantage can be realized fully only when adequate scientific information relating plant response to greenhouse climatic conditions is readily programmable into environmental control computers. Gradually, this type of informational database is being developed.

In the production of greenhouse tomatoes, predictability and continuity of yield are difficult to accomplish (Cooper, 1961a). However, market demands place a premium on the dependability and continuity of supply, which is important for retaining a competitive edge, Additionally, the winter-produced commodity commands a high price.

In the northeastern United States, greenhouse tomato production traditionally has been a seasonal occupation limited to spring and autumn. While summer field production is responsible for the summer hiatus, the limiting factor for winter production is low light quantities, i.e., short days with low intensities (Cooper, 1961b; Craig, 1959). This is due primarily to the fact that, under low light conditions, tomato plants will not set fruit but will grow vegetatively (Kinet, 1977; Kinet et al., 1978; Marr and Hilklyer, 1967). Therefore, even if heat is provided during midwinter, production will be low. Supplementing the naturally available light with additional light from an artificial source will alleviate some of the problems encountered during winter tomato production (Boivin et al., 1987; McAvoy and Janes, 1988; Rodriquez and Lambeth, 1975). Supplementary lighting is costly, and using this resource to achieve the maximum benefit with a minimum investment is an important economic consideration. If supplemental lighting is employed, production strategies that were most often used commercially under natural light conditions may not be appropriate for exploiting the beneficial effect of light. For this reason, different greenhouse production strategies were evaluated, both with and without supplemental lighting.

In our experiments, tomatoes (*Lycopersicon esculentum* cv. Dombito) were grown in a peat-vermiculite mix in 5-gal white plastic bags as described by McAvoy et al. (1989). Supplemental light was provided from. a high-pressure sodium (HPS) light source at an intensity of ≈ 540 footcandles (80 $\mu mol \cdot m^{-2} \cdot s^{-1}$) for 18 h/day.

Shown in Fig. 1 are the four cropping strategies used in our first experiment. The one-crop-per-year and two-crops-per-year production strategies represent the strategies most often employed commercially. For these production strategies, a plant population density of about one plant/3 ft^2 (3.6 plants/m^2) was used. Two alternative production strategies also were investigated: a) the three-cluster, three-crops-per-year and b) the single-cluster, five-crops-per-year strategies. The plant density for the three-cluster, three-crops-per-year strategy was about one plant/2 ft^2 (5.4 plants/m^2); the plant density for single-cluster, five-crops-per-year was about one plant/ft^2 (10.8 plants/m^2). The experiment ran from 15 Sept. to 15 July.

We found previously (McAvoy and Janes, 1988) that similar total yields were obtained under the different cropping strategies, but in all cases yields were significantly higher with the application of supplemental light. Factors other than yield, such as light distribution, labor, and crop automation and management, must be considered when different cropping strategies are compared. Vertically oriented crops (e.g., multi-cluster, one and two crops per year) present a special problem with regard to supplemental lighting. Uniformity in the lighting pattern is difficult to maintain because of the distance required between the light fixtures and the crop. As a result, the uneven plant growth becomes difficult to manage. Another problem with the vertical crop is the amount of mechanical damage that results from constantly lowering the vines. In large-scale operations, this damage results in a high rate of attrition, decreased productivity, and a need to interplant with replacements throughout the year.

The potential for mechanization with a vertical crop is limited to tasks that can be performed on the crop at a fixed position in the greenhouse. The single-cluster crop resembles a bench crop and can be transported with relative ease. This can be an advantage from the standpoint of a) labor management, b) use of space in the greenhouse, and c) robotics applications in the greenhouse. For these reasons, the high-density (43,000 plants/acre) single-cluster cropping strategy was chosen for further study.

The potential advantages of single-cluster tomato crop production have long been recognized (Cooper, 1964; Morgan, 1968). Canham (1967) used fluorescent lighting with single-cluster plants to increase yields. These early attempts at single-cluster cropping lacked automation, and the bulky fluorescent light fixtures needed to be within inches of the crop in order to stimulate yield; thus, access to the crop was greatly resticted. As a result of these shortcomings, this high-density cropping technique eventually evolved into a crop produced in tubes suspended on A-frames called the "Archway Concept" (Morgan, 1972; Morgan 1976-77; Morgan and Hussey, 1972). The system used determinate plants that produced four clusters per plant and high population densities. Nonetheless, mechanization, lighting, efficient use of space, and precise crop timing remained a problem, and single-cluster technology was relegated to use as a convenient study system (Bangerth and Ho, 1984; Fisher, 1975; Hand and Postlethwaite, 1971; Hurewitz and Janes, 1987; Lake, 1967). with advances in pot-crop automation, such as moveable benches, mechanical transplanters, compact

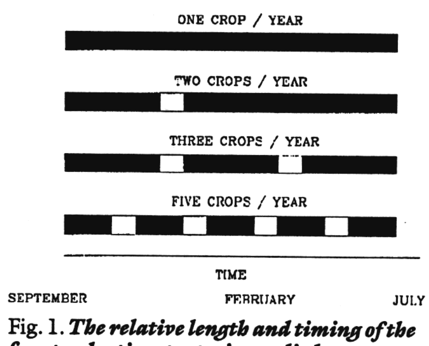

Fig. 1. ***The relative length and timing of the four production strategies studied, represented by solid lines.***

high-intensity light sources (HPS), and computer control systems, single-cluster crop production became a technology of renewed interest.

Our research goal was to develop a growing system capable of producing a continuous yield oftomatoes. To accomplish this goal with the single-cluster crop, it was necessary to schedule and produce a sequence of successive crops. This required knowing when a crop started at any given time of year would flower and produce fruit. It also was necessary to determine how light, the most limiting environmental factor, could be manipulated to control plant growth.

To quantify the effect of light on production of single-cluster plants throughout the growing season, a technique commonly used to develop plant response databases for simple models was employed. A series of 20 single-cluster crops was planted at 2-week intervals throughout the growing season, with plant growth and development as well as light and temperature being monitored. We divided the single-cluster crop growth into two parts: 1) the seedling phase (i.e., from germination to 5 days before predicted flowering), and 2) the production phase (i.e., 5 days before predicted flowering to final harvest). Light level changes during the course of the growing season and how the addition of small amounts ofsupplemental light could significantly alter the amount of light a plant received in a day are shown in Fig. 2. The actual production of our 20 crops over the year are depicted in Fig. 3. It is seen that by using HPS lighting to supplement the natural radiation, a significant (0.01% level, ANOVA F test) increase in yield resulted. It is quite clear that a good correlation (r = 0.947) exists between yield and light received in the production phase (Fig. 4). Light during the seedling phase of growth was correlated closely, but negatively (r = -0.867), with the date ofharvest (Fig. 5). From these data it is clear that by controlling the amount of light a single-cluster crop receives during the seedling and production phases, we should be able to predict the timing and amount of yield.

Based on this information, it was possible to build a simple planning model. This model used the relationship between plant response and light to predict future responses. Simple models have proven to be accurate tools for timing and predicting yields. Wolf et al. (1986) developed a simple model for predicting the harvest dates of processing tomatoes in Israel based on temperature, the dominant environmental factor during seasonal field production. We developed a predictive model for single-cluster tomato production (Giniger et al., 1988). The model makes a prediction of the expected amount of solar light energy available to the plant canopy during the time period encompassed by each crop block. This predicted light value in our study is based on historical weather data for our location in central New Jersey. In addition to this natural light, a grower may have a certain amount of light from the HPS source. Therefore, by using expected light inputs, expected plant responses, and a desired production starting date, we should be able to schedule a series of overlapping crops that will provide nearly continuous production during the growing season, with an expected yield for each crop. Since the time from initial flowering to first harvest is fairly constant within a certain temperature range (McAvoy et al., 1989b), we are able to generate a cropping schedule for continuous production (Table 1). Table 1 also indicates when

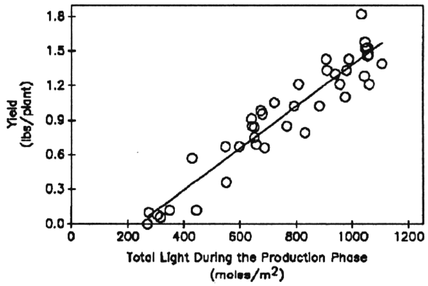

Fig. 4. ***Comparison between yield and the total light received during the 60-day production cycle. The data represent yields obtained both with and without HPS light for all 20 crops.***

certain tasks need to be done. For example, transplanting from the seedling section to the production section should occur ≈ 5 days before the predicted date of flowering.

Experiments were conducted to validate the model's predictions (McAvoy et al., 1989a). yield data for the scheduled crops is shown in Fig. 6. We achieved a very high correlation between expected and actual production. Crops 16, 17, and 18, which were growing as we moved into the warm part of the year, deviated more from the expected yield than the others, indicating that a temperature factor needs to be added to the model. The length of the harvest window for each crop is reported in Fig. 7. The length of the lines represents the amount of time the grower would spend harvesting each crop. The dotted lines are similar in length and indicate our predicted harvest period. For continuous production we would like to harvest the crops sequentially with little down-time between crops. The solid lines represent our actual harvest periods for 24 successive crops. Some overlap and down-time is apparent. The model predicted red tit to be available during 93.6% of the study

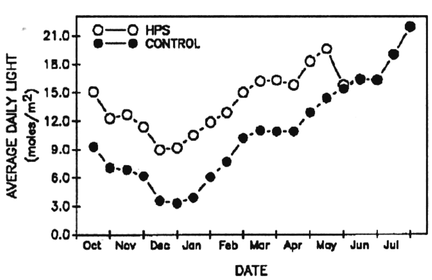

Fig. 2. ***Seasonal change in natural radiation levels over the year compared with that received when supplementary HPS lighting was used, as expressed in average daily light for semi-monthly periods, are plotted over time.***

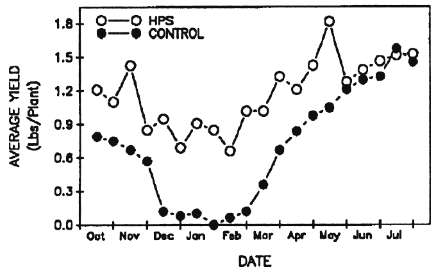

Fig. 3. ***Comparison of the production of tomato plants grown with and without supplementary light.***

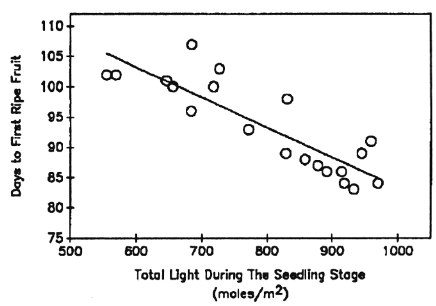

Fig. 5. ***Relationship between the total light received during the seedling stage (emergence to anthesis) and the onset of red fruit production.***

Table 1. ***Schedule for 24 successive crops designed to produce a continuous fruit harvest. The dates predicted by the model include the date 1) to sow seed for each successive crop, 2) of first anthesis, and 3) of first harvest.***

	Predicted date of event[a]		
Crop no.	Seed sowing	First anthesis	First harvest
1	31 July	11 Sept.	27 Oct.
2	13 Aug.	26 Sept.	11 Nov.
3	26 Aug.	11 Oct.	26 Nov.
4	9 Sept.	26 Oct.	11 Dec.
5	22 Sept.	10 Nov.	25 Dec.
6	5 Oct.	26 Nov.	10 Jan.
7	18 Oct.	10 Dec.	25 Jan.
8	30 Oct.	25 Dec.	9 Feb.
9	12 Nov.	9 Jan.	24 Feb.
10	27 Nov.	24 Jan.	11 Mar.
11	12 Dec.	8 Feb.	26 Mar.
12	29 Dec.	24 Feb.	10 Apr.
13	16 Jan.	10 Mar.	25 Apr.
14	2 Feb.	25 Mar.	10 May
15	20 Feb.	9 Apr.	27 May
16	9 Mar.	24 Apr.	9 June
17	26 Mar.	9 May	24 June
18	13 Apr.	24 May	9 July
19	28 Apr.	8 June	24 July
20	13 May	23 June	8 Aug.
21	28 May	8 July	23 Aug.
22	12 June	23 July	7 Sept.
23	27 June	7 Aug.	22 Sept.
24	12 July	22 Aug.	7 Oct.

[a]*Dates were predicted based on crop model equations (Giniger et al., 1988) and anticipated seasonal light availability.*

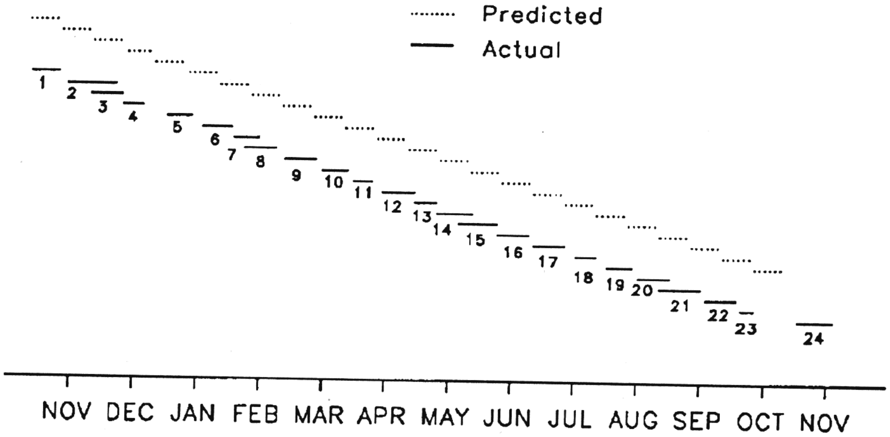

Fig. 7. ***Length of the harvest window for each crop. The dotted lines indicate the predicted harvest window, while the solid lines present the actual harvest period. Numerals associated with horizontal bars represent crop number. Tick marks represent the first day of each month.***

period; fruit were actually available during 89% of the period. In most cases we were able to achieve our goal of continuous production. Such a schedule would allow a grower to market the crop more effectively.

It would be advantageous for a grower to be able to monitor the environment on a continuous basis and then make dynamic adjustments to maximize the crop response. These adjustments will be based on crop growth stage, the desired crop response, and economic factors such as electrical costs and crop value. To begin to realize this goal, an experiment was conducted to determine if there is a critical time period during the fruit set and development stage of growth when yield is most affected by light.

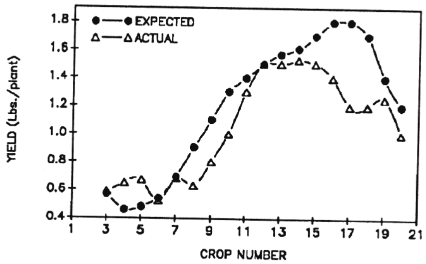

Fig. 6. ***Comparison of the expected and the actual yields obtained during the period Fall 1986 to Summer 1987. Expected values were generated by the planning model. The actual data represent the experimental observations.***

HPS supplemental light was applied to a crop for 0,15,45, or 70 days following flowering (McAvoy and Janes, 1989). In Fig. 8, the total quantity of light received by the crop under each light treatment is listed. Plants received natural light (control) or natural light in addition to 1) supplemental light during flowering (15 days), 2) supplemental light from flowering to mature-green fruit development (45 days), and 3) supplemental light from flowering through final harvest (70 days). The average weight of individual fruit on plants exposed to each of these treatments appears in Fig. 9. Supplemental light between days 15 and 45 was highly effective. By incorporating such new information into our calculations, the grower will be able to balance the use of supplemental light with the yield increase and cost of electricity. We are moving slowly closer to the goal of not just maximizing yield, but maximizing profits.

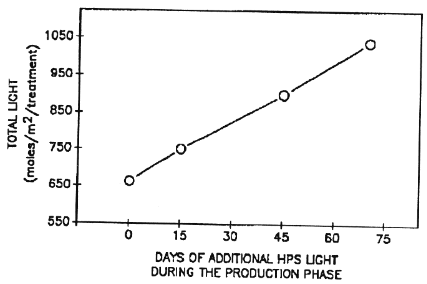

Fig. 8. ***The total light available at leaf canopy level during the development period flowering to final harvest.***

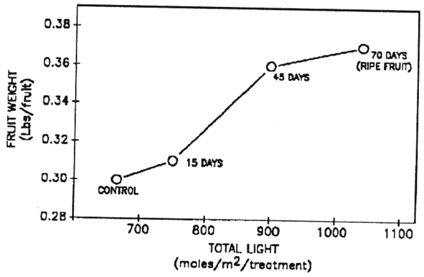

Fig. 9. ***Average fruit weight attained by groups of plants receiving supplemental light as shown in Fig. 8.***

It is evident that the single-cluster production system has many advantages with regard to productivity, automation and control. Perhaps the most exciting aspect of the system is the potential for further improvement. Certainly from a mechanization standpoint, many existing pot plant technologies and robotic handling processes can be incorporated. However, being a simplified production system also means that more in-depth study of plant-environment interaction will allow the predictive planning model to become more dynamic.

Literature Cited

Bangerth, F. and L.C. Ho. 1984. Fruit position and fruit set sequence in a truss as factors determining final size of tomato fruits. Ann. Bot. 53:315-319.

Boivin, C., A. Gosselin, and M.J. Trudel. 1987. Effect of supplementary lighting on transplant growth and yield of greenhouse tomato. HortScience 22:1266-1268.

Canham, A.E. 1967. Single truss tomatoes in a growing room. Electric Res. Sta., Shinfield Prog. Rpts., 10 Jan. and 11 Aug. 1967.

Cooper, A.J. 1961a. Observations on flowering in glasshouse tomato plants considered in relation to light duration and plant age. J. Hort. Sci. 36:102-115.

Cooper, A.J. 1961b. Observations on the seasonal trends in the growth of the leaves and fruit of glasshouse tomato plants, considered in relation to light duration and plant age. J. Hort. Sci. 36:55-69.

Cooper, A.J. 1964. Single-truss tomato production, Rpt. Glasshouse Crops Res. Inst. p. 106-107.

Craig, P.L. 1959. Response of greenhouse crops to supplementary illumination during the winter months in Nova Scotia. Can. J. Plant Biol. 39:135-140.

Fisher, K.J. 1975. Effect of the amount and position of leaftissue on the yield of single-truss tomatoes. Scientia Hort. 3:303-308.

Giniger, M.S., R.J. McAvoy, G.A. Giacomelli, and H.W. Janes. 1988. Computer simulation of a single truss tomato cropping system. Trans. Amer. Soc. Agr. Eng. 31:1176-1179.

Hand, D. W. and J.D. Postlethwaite. 1971. The response to CO_2 enrichment of capillary-watered single-truss tomatoes at different plant densities and seasons. J. Hort. Sci. 46:461-470.

Hurewitz, J. and H. W. Janes. 1987. The relationship between activity and the activation state of RUBP carboxylase and carbon exchange rate as affected by sink and developmental changes. Photosyn. Res. 12:105-117.

Kinet, J.M. 1977 Effect of light conditions on the development of the inflorescence in tomato. Scientia Hort. 6:15-26.

Kinet, J.M., D. Hurdebise, A. Parmentier, and R. Stainer. 1978. Promotion of inflorescence development by growth substance treatments to tomato plants grown in insufficient light conditions. J. Amer. Soc. Hort. Sci. 103:724-729.

Lake, J.V. 1967. The temperature response ofsingle-truss tomatoes. J. Hort. Sci. 42:1-12.

Marr, C. and I.G. Hillyer. 1967. Effect of light intensity on pollination and fertilization of field and greenhouse tomatoes. J. Amer. Soc. Hort. Sci. 92:526-530.

McAvoy, R. and H.W. Janes., 1988. Alternative production strategies for greenhouse tomatoes using supplemental lighting. Scientia Hort. 35:161-166.

McAvoy, R.J. and H.W. Janes. 1989. Tomato plant photosynthetic activity as related to canopy age and tomato development. J. Amer. Soc. Hort. Sci. 114:478-482.

McAvoy, R.J., H. W. Janes, G. Giacomelli, and M.S. Ginger. 1989a. Validation of a computer model for a single-truss tomato cropping system. J. Amer. Soc. Hort. Sci. 114:746-750.

McAvoy, R.J., H.W. Janes, B.L. Godfriaux, M. Secks, D. Duchai, and W.K. Wittman. 1989b. The effect of total available photosynthetic photon flux on single truss tomato growth and production. J. Hort. Sci. 64:331-338.

Morgan, J.V. 1968. The upright trough system of tomato growing. Proc. 4th Natl. Greenhouse Conf., Dublin. p. 39-44.

Morgan, J.V. 1972. Perlite as a growing medium in high density tomato and cucumber culture. Acta Hort. 26:149-154.

Morgan, J.V. 1976-77. The archway system of high-density crop production. Fac. Gen. Agr., Univ. College, Dublin. Res. Rpt. (1976/77).

Morgan, J.V. and M.J., Hussey. 1972a. Advances in high density cropping techniques. Proc. 8th Natl. Glasshouse Conf., Dublin. p. 25-34.

Morgan, J.V. and M.J. Hussey. 1972b. Advances in high density cropping techniques. Proc. 8th Natl. Glasshouse Conf., Dublin. p. 25-34.

Rodriguez, B.P. and V.N. Lambeth. 1975. Artificial lighting and spacing as photosynthetic and yield factors in winter greenhouse tomato culture. J. Amer. Soc. Hort. Sci. 100:694-697.

Wolf, S., J Rudich, A. Marani, and V. Rekah. 1986. Predicting harvesting date of processing tomatoes by a simulation model. J. Amer. Soc. Hort. Sci. 111:11-16.