tion or have become fully committed. The near future promises many interesting possibilities.

CONCLUSION

On reviewing the new technologies and their potential economic impact it becomes evident that any economic assessment of the importance of biotechnology to agriculture is still very speculative. It is difficult to place a value on products which do not yet exist. Those that are in the marketplace or on the threshold of commercialization offer exciting prospects. The clear objective is that biotechnology will be applied in ways which will reduce costs to farmers, increase production efficiency, broaden genetic diversity, and enhance biological and economic stability.

LITERATURE CITED

1. Sluis, C. J. and K. A. Walker. 1985. Commercialization of plant tissue culture propagation. *Inter. Assoc. Plant Tissue Culture Newsletter.* 47:2–11.
2. Walker, K. A. 1986. Automating *in vitro* plant propagation: has its time finally arrived? *Genetic Engineering News* 6 (7):52.

CROP MODELING AND PRODUCTION COSTS

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A crop model is a mathematical representation of how a crop grows and develops. Although not much modeling has been done on horticultural crops, there are a number of agronomic modeling projects. Over the last few years many of these have developed to the stage where it is now possible to develop management tools from the results.

Only recently have research dollars been allocated for modeling horticultural crops. This is probably due to the realization that benefits are possible for the horticulture industry. The greenhouse industry has, for example, discovered that a crucial step in the area of automated environmental control is to be able to provide the control computer with some representation of how the plant responds to modifications in the environment. Those interested in production can benefit by having a lot of crop-specific information placed into a package which mimics the crop's response to changes in cultural practices. With such a model it is possible to develop cultivars (through breeding programs) which are more efficient in ways only apparent through a modeling analysis.

This paper gives a brief overview of crop modeling and then focuses on two ways in which crop models can be used to optimize horticultural production. The first is in selecting for plants which will be, in some way, less expensive to produce. The second involves reducing costs while increasing productivity through automated environmental control.

WHAT IS A MATHEMATICAL MODEL

A model is an abstract representation of something real. A mathematical model is one consisting entirely of mathematical equations. For example, the formula:

$$P = P_0(1 + r)^n \qquad (1)$$

is a mathematical model of the value (P) of some invested amount (P_0) of money at interest rate r per period of time for n such periods. Similarly, plant growth can be described with variables (such as P, P_0 and n above) by selecting a measurable characteristic of the plant (such as height or weight) and developing formulae which simulate (predict) the values of these variables over time in response to prevailing environmental factors (such as light intensity, air temperature, and carbon dioxide concentration).

It is generally not possible to describe the growth and development of a crop with one equation if it is to represent the process of plant growth and its response to many environmental factors and cultural practices. Plant growth can be conceptualized as consisting of a number of processes such as photosynthesis, respiration, distribution of accumulated photosynthates, leaf expansion, leaf and flower initiation, etc. Each of these processes is affected to a different degree by the environment and, in turn, affects the growth process as a whole in different ways. Thus a number of equations are required for each process, with an additional set of equations being needed to tie them all together into one model for the crop.

The science of developing these involves five stages of research and development: 1) identification of the problem and scope, 2) analysis of processes involved in crop growth and development, 3) constructing mathematical relationships which validly and quantitatively represent these processes, 4) combining these components (called submodels) into a dynamic system which models the plant, and 5) validating that the devised model actually represents the plant.

APPLICATION OF CROP MODELS

Using Modeling in Breeding. Mathematical models can be used in breeding to develop selection criteria. Selection can be based on directly observable characteristics such as: plant height, internode length, and flower color, or traits which, although not directly observable, are easily assessed. Examples of the latter would be drought tolerance, pathogen resistance, herbicide resistance, etc. Dealing with these types of breeding problems is fairly straightforward.

Models can provide a tool in cases where desired traits are not directly observable. The basic approach is to develop a model to represent how the plant grows and develops using parameters which quantify the desired traits. For example, a cultivar of a foliage plant with a high light utilization efficiency, a high maximum rate of photosynthesis, and a low temperature at which this maximum occurs, would have more resources for growth. Each of these characteristics could be a parameter of the model.

In this case data would be collected to develop a model involving all these parameters. Ideally this would entail development of a three dimensional model (photosynthetic rate versus light and temperature). Photosynthesis rates would be measured at a wide range of light and temperature values. The model is then fit to this data by using a statistical regression program to determine the parameter values which minimize the difference between the model and the data. These values are then used in breeding in the same way as measures of observable traits.

An illustration of this is part of a study being carried out by Dr. Aage Andersen at the Royal Veterinary and Agricultural University in Copenhagen, Denmark. A large number of different clones of *Ficus benjamina*, obtained from a variety of sources, are being grown. The objective of the study is to find which clone would minimize production costs while maintaining a high market value. To accomplish this it is desirable to select the clones with the maximum net photosynthetic rate at a relatively low temperature while the rate at this temperature is high. This would assure that the members of the resulting population would be capable of high photosynthetic rates at conditions which are inexpensive to maintain in Denmark's climate. Figure 1 illustrates the response of the photosynthetic rate (mg CO_2 per second per square meter of leaf area) to temperature at a fixed light level. A quadratic model can be used to describe this data:

$$PSYN = B - C\,(TEMP\text{-}A)^2 \quad (2)$$

where B is the maximum value, A is the temperature where this maximum occurs, and C is a scale factor which determines how "flat" the peak is. TEMP is temperature (°C) while PSYN is net photosynthetic rate. The smaller the value of C the "flatter" the peak. Fitting the above equation to the data from each clone resulted in the five curves in Figure 2. The corresponding parameter values (Table 1) provide the numbers which would then be used in the selection process. In considering the maximum rate, clone M is a clear favorite. However, it is not significantly better than any of the others when looking only at the temperature at which this maximum occurs. In fact, Dr. Andersen has found that this parameter seems to be the same for all *Ficus benjamina* plants he has measured. Yet, it may be possible, by always selecting clones with lower values for A, that a significant difference might show itself after a number of generations.

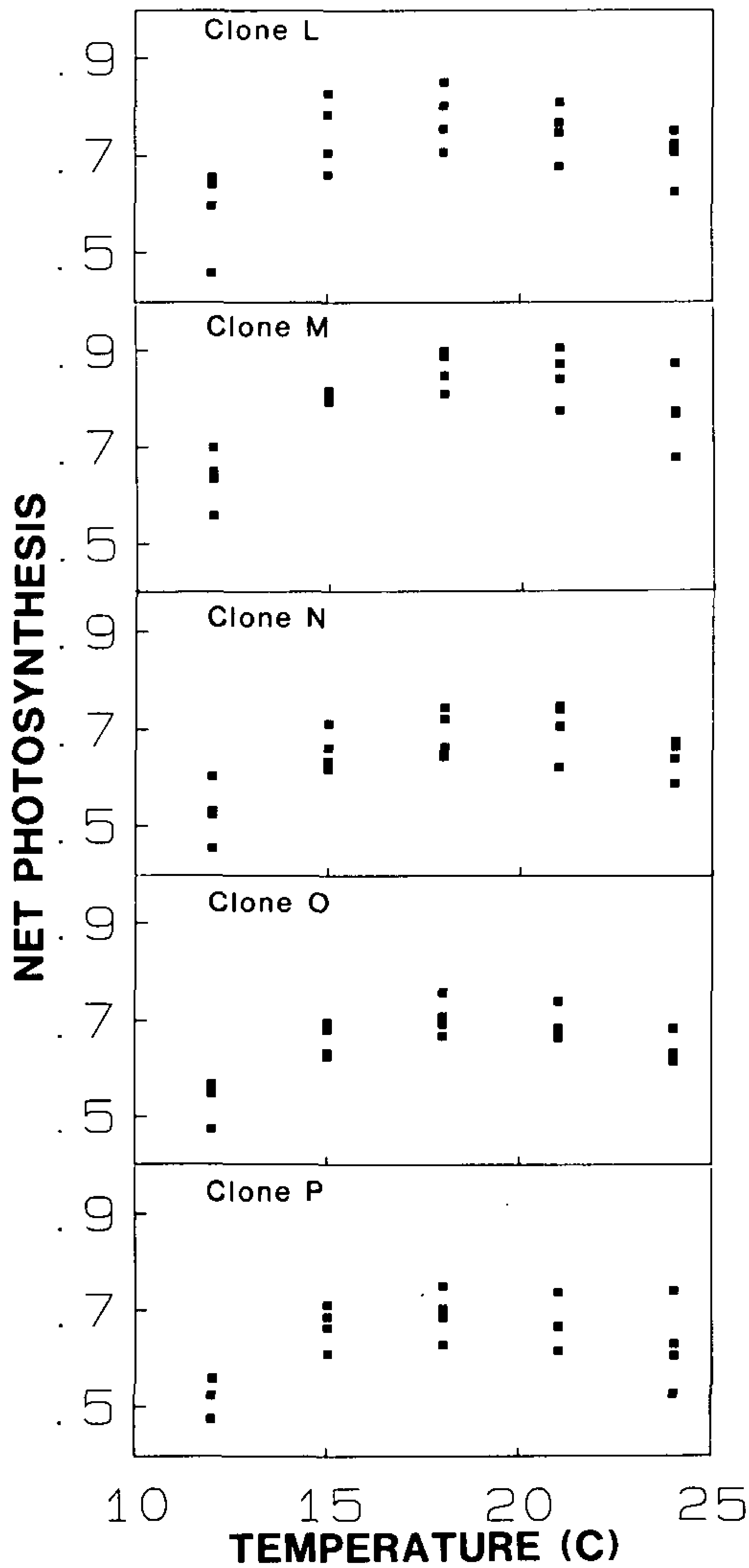

Figure 1. Net photosynthesis (mg CO_2 s^{-1} m^{-2}) data for five clones of *Ficus benjamina*.

Using C as a selection criterion might also be useful. The smaller this number, the flatter the curve. A flatter curve would indicate that the plant would operate near the maximum rate over a wider range of temperatures.

Table 1. Parameter values of the best least squares fit of equation (2) to the photosynthesis data of each clone. The units for the parameters are: A, °C; B, mg CO_2 s^{-1} m^{-2}leaf area; and C, mg CO_2 s^{-1} m^{-2} $°C^{-2}$.

	Parameter		
Clone	Temperature of Photosynthetic Maximum (A)	Maximum Net Photosynthetic Rate (B)	C
L	19.0	0.784	0.00376
M	19.2	0.869	0.00444
N	19.4	0.711	0.00325
O	19.2	0.711	0.00324
P	19.0	0.699	0.00330

Using Models in the Optimization of Production Costs. Physiologically based crop models can, in principle, be developed into management tools. For example, crop growth models based on environmental variables including water availability and nutrient dynamics can usually be converted into irrigation scheduling tools. Furthermore, since models provide a way of representing the plant to electronic equipment controlling the environment, it may be possible to convert this irrigation scheduling tool so that it can be linked directly to electronic equipment to automatically control when and how much water is applied.

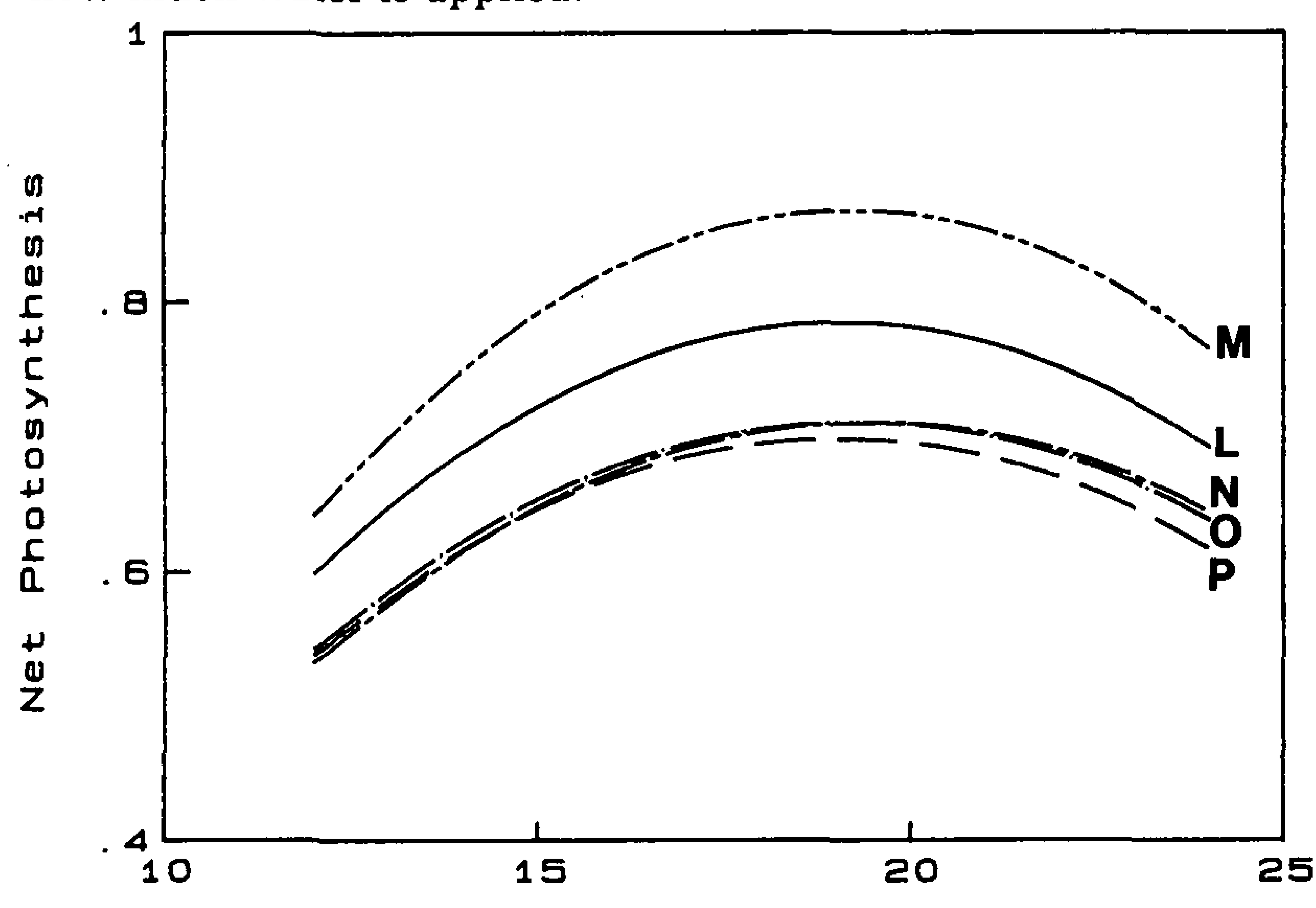

Figure 2. Polynomial least square fits of equation (2) to the data in Figure 1.

Many modeling projects which have succeeded in developing models for particular crops, are now converting these into management tools. For example, there are a number of modeling projects involving cotton. Some of these projects have been active for more than a decade. In that time, complex, large scale, physiologically based models for the growth of cotton have been developed. These respond to many environmental parameters such as temperature, light, fertilizer level, water, and pests, and can be used to forecast how cotton grows under field conditions.

One such project, SIRITAC, is a cotton model being developed in Australia. The model has evolved into a management tool operated by a cooperative of cotton growers (1). The model is capable of accepting and using data of the current growing season to forecast how, if future weather conditions are characterized by historical data, the crop will develop. Various possible management strategies can then be tested to see which yield will maximize profit. Another cotton model, GOSSYM, developed by USDA scientists, is currently being incorporated in a system of computer programs designed to accept information from the user and make management suggestions such as fertilizer and watering recommendations (2).

At the present time I am developing models which can find application in the ornamental floriculture industry. One of these is a model which simulates the growth and development of potted Easter lily. This crop is a particularly energy intensive crop since it is grown in warm greenhouses in the winter months. This means that a lot of energy is exerted to get this crop to grow and flower in time for Easter. If, for some reason, the crop falls behind schedule, the grower catches up by raising the temperature to speed up the plant processes. It would be useful to have a model which allows the grower to test various strategies for making his crop catch up. He might, for example, find that he will inevitably have to supply additional heat but that, rather than having to do it in February, he can delay this until March when the differential between the inside and outside temperatures is smaller. Consequently less energy is required. At this point it is unknown whether this would work.

Linking models to electronic environmental control equipment is likely to provide a very powerful tool for growers. Many growers are currently installing (or have installed) computers to control the environment in their greenhouses. At present this equipment is used like a thermostat since an operator still has to set the levels which he feels are best for the crop. The main benefit, at this time, is that he has more control over more variables such as temperature, relative humidity, CO_2 concentration, and light levels. In all cases, however, no system is, as yet, able to automatically select the levels which are optimal for crop growth. A mathematical crop model representing how the plant responds to its environment, can theoretically be used to either automatically set optimal conditions or to inform the operator of the optimal levels.

LITERATURE CITED

1. Hearn A. B., P. M. Ives, P. M. Room, N. J. Thompson, and L. T. Wilson, 1981. Computer-based cotton pest management in Australia. *Field Crops Research*, 4:321–332.

2. Lemmon, H. E., 1986. A crop management expert system—COMAX. Program and Abstracts: 9th Workshop on Crop Simulation, March 10–12, 1986, Manhattan, Kansas.

THE USE OF COMPUTERS IN NURSERY CROP PRODUCTION

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Computers at Oki Nursery are not a new sight. We obtained an IBM 403 Card Sorting System about 1960. Programming the machine required actual rewiring of a program board. Later, we graduated to an IBM System 3 and in 1980 to our current computer, an IBM System 38. With this computer, we have linked our Portland branch to our main office in Sacramento. There are more than 12 terminals distributed through the main office in Sacramento and between 20 to 30 people a day use the computer to utilize its processing capabilities or to access information which is held in its memory. Lately we have been networking personal computers to the System 38 to increase our capabilities. Our major applications are order entry, order picking, inventory, truck dispatching, accounting, payroll, credit, and accounts receivable, accounts payable, crop planning, and a variety of management reports.

Now, let me tell you about my personal experiences with a computer because I am not an expert with it. I want to assure you that it does not take a genius to figure out how to use them—because I am not one. A computer is just a machine—a tool. Just like you use a forklift to help move material or a soil machine to fill flats, you can use a computer to help with your business. But as with all tools, you can utilize a computer to its maximum potential or you can waste it if you are afraid to use it or do not learn to use it properly. You cannot be afraid of it and you have to make a commitment to yourself that it will work.

If you've decided that a computer can be part of your business, the next decision to make is not what kind of computer to buy, but what do you want to do. Do you want to use it to do accounting? Do