Space Allocation in Foliage Production Greenhouses[1]

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Abstract

A profit-maximizing linear programming model of a typical Rio Grande Valley foliage plant operation was developed to allocate finish-house space among alternative combinations of plants. This model accounted for seasonal changes in both market prices and growth rates of foliage plants. It was written to permit solution by microcomputer. The model may also aid foliage producers in making marketing and capital budgeting decisions by providing marginal revenue and cost estimates under varying crop rotations and product mixes.

Index words: linear programming, profit maximization, space allocation, foliage plant production

Introduction

Greenhouse space can be a critical short-run limiting input in foliage plant operations. Economically efficient utilization and allocation of this space is an important concern of foliage plant growers. Plant producers using greenhouses may have one of the most difficult space allocation problems in agriculture. Many foliage producers grow a diverse selection of plants which may take from 40 days to several years to reach a saleable size. Most plants do not grow at a uniform rate throughout the year because of seasonal variations in light and temperature. In addition, sales of potted plants are highly seasonal.

Based on a 1984 survey, nearly 6,000,000 ft^2 of greenhouse area were used for foliage plant production in the Rio Grande Valley of Texas (3). Although this was only 2.5% of the national area devoted to foliage production, it included 81% of the foliage production area in Texas.

The purpose of this study was to use Rio Grande Valley greenhouses as a model system to develop a linear program which would maximize the economic efficiency of greenhouse space, allow the program and pre-processor to be operational on standard microcomputer equipment, and apply it to a representative firm.

Materials and Methods

The greenhouse space allocation problem was formulated as a profit-maximizing linear programming (LP) model (1). Linear programming is a widely used mathematical technique that identifies optimal allocations of limited resources. It searches for the maximum (or minimum) point on a linear objective function which is restricted from approaching infinity or zero by a set of linear constraints. The approach is similar to that followed by Basham and Hanan (2) in their greenhouse space optimization study. They maximized profit from the greenhouse subject to production volume constraints (or restrictions) dictated by the market and management preferences. In this study, different seasonal growth rates were also taken into account in the formation of alternative plant sequences (decision variables) from which the LP model selected the optimal combination. The LP model considered as decision variables all possible combinations of several popular foliage plants that could be grown in the Rio Grande Valley during a one-year period. Constraints were applied for limits on available greenhouse space each month, the maximum number of each plant the grower expected to be able to sell each month at specified prices, and the minimum number of each plant which had to be available for sale during the month to satisfy either contractual obligations or the minimum product mix consistent with the grower's marketing strategy.

The objective was to maximize the expected annual revenue minus the direct expenses of putting each plant into the greenhouse. These direct expenses included the container, medium, plant material (either purchase price or the cost of maintaining stock plants), labor for potting and placement in the greenhouse, and all other direct costs. These variable expenses were reflected in the objective function and were not treated as constraints. Costs and/or constraints for other labor and for materials such as water, fertilizer, and other chemicals used during the growing process were not included in the objective function because (a) total net profit from operations was not being calculated and (b) most Rio Grande Valley growers responding to the survey (3) indicated that such inputs were used almost equally per unit of space and growing time of each crop.[1] Since the objective of the LP was to maximize net returns per unit of space and growing time, expenses that do not vary among plant species per unit of space and time required in the greenhouse do not affect the choice of plant combination. Growers also indicated that water, fertilizer, chemicals, and growing period labor were not normally binding constraints. Thus, including costs and/or constraints for these inputs would only increase computational burden without affecting the profit-maximizing allocation decision.

Monthly constraints for available plant assignment space were based on total greenhouse space. The space available

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[1]For application of this model in other areas where additional resources may limit foliage plant production, these resources can be conveniently considered by including the appropriate constraints.

for assignment each month was the total greenhouse space minus the area occupied by plants carried over from the previous month. Plants carried over comprised the initial greenhouse inventory (i.e., plants already growing before the simulation began plus space freed by plant sales less space occupied by new or growing plants in each previous month of the simulation).

Alternative 12-month sequences of plants were the model decision variables from which the producer could choose to occupy available greenhouse space. Using 12-month sequences rather than individual plants permitted both a reduction in the number of model activities and proper accounting for seasonal differences in market prices and growth rates. The former is an important issue when using microcomputers to solve the LP model, while the latter is an important empirical fact affecting any plant grower.

Valley survey estimates (3) suggested that plants grown during the coldest months, November–February, take about 30 percent longer to finish than when grown in other parts of the year. Thus, the length of time it takes for a plant to reach a saleable size is very dependent on which month it is started in the greenhouse. An LP model which internally accounted for these changing growth rates on a monthly basis for every plant grown by a particular nursery would be immense and beyond the practical capabilities of most microcomputers. Instead, the more simplistic approach of generating plant sequences by means of a pre-processing program was taken in this research which still provides a workable solution.

The pre-processing program was written in BASIC language (3) and generates all possible sequences (including combinations) of up to 30 alternative plants specified by the user that can be grown over a 12-month period starting in a specified month. When a sequence does not take exactly 12 months, the space it occupies can either be left vacant or expenses and receipts prorated by initiating a repeat of the sequence. It was these sequences which became the LP model decision variables. To account for greenhouse space initially occupied at the beginning of the model period, sequences were computed starting in each month. The total length of each sequence was specified to be the same, so a semi-dynamic (long-term) analysis of greenhouse space allocation could be conducted using an LP model of only a year's duration. The sequence was presumed to be repeated once a steady state (or equilibrium) condition was achieved or until prices or other conditions changed. Thus, the LP solution was regarded as a snapshot of a 1-year production pattern during the steady state.

The computer models were applied for demonstration purposes to the allocation of greenhouse space among the six most popular foliage plants (actually plant/pot combinations) by a typical Valley producer. Space requirements, growing time, direct expenses, and expected market prices were based on the 1984 survey (3) and are summarized in Table 1. The plant options (up to 30) can be easily changed by the user along with space, time, expense and price information to accomodate any unique situation. Only a knowledge of BASIC and some familiarity with LP software are needed.

Upper and lower limits on monthly plant sales and available greenhouse space used in the demonstration analysis were based on the survey (3) and are presented in Table 2. Lower limits on sales of *Epipremnum aureum* (golden pothos) were specified in every month to assure that this plant was always available for sale. The greenhouse allocation was not constrained by upper limits on the sale of this plant. In the demonstration, it was expected that all 10.1 cm containers of this plant could be marketed for \$.90 apiece from January through July and \$.80 apiece thereafter. For all other plants, upper limits on expected monthly sales were specified at the noted prices to reflect reasonable marketing expectations. Only in selected months were lower limits for any of these plants imposed to assure an adequate product mix.

The computer code for the pre-processing program, detailed LP model structure, and additional profit-maximizing greenhouse results can be obtained from the authors. The LP model was written to use readily available commercial software. The PC version of LINDO (4) requiring 512K RAM was the software used to solve the LP problem. This

Table 1. Plant data collected on 6 plant products from a survey of Rio Grande Valley greenhouse operations in summer 1984.

Plant[z]	Space (m² per plant)	Cost to set on bench—direct expenses[y]	Selling price[x] Jan.–July	Selling price[x] Aug.–Dec.	Growing time[w] (days)
A	.023	\$ .13	\$ .90	\$ .80	90
B	.047	.85	3.00	2.50	120
C	.326	2.50	13.50	12.00	280
D	.093	1.40	5.50	4.50	150
E	.047	.60	2.50	2.00	100
F	.047	.90	3.00	2.50	140

[z]Plant codes are as follows:

A—*Epipremnum aureum* (golden pothos) grown in a 10.1 cm pot.

B—*Epipremnum aureum* (golden pothos) grown as a 15.2 cm totem.

C—*Ficus lyrata* (fiddle leaf fig) grown in a 30.4 cm pot.

D—*Philodendron* 'Red Emerald' grown as an 20.3 cm totem.

E—*Syngonium podophyllum* 'White Butterfly' grown in a 15.2 cm pot.

F—*Syngonium podophyllum* 'White Butterfly' grown as a 15.2 cm totem.

[y]Direct expenses include the pot, soil, labor, and plant material necessary to start a plant in the greenhouse.

[x]Selling price based on typical 1984 prices.

[w]Between March and October. Add 30 percent to days in the greenhouse between November and February.

Table 2. Limits on monthly plant sales and available greenhouse space.

Month	A	B	C	D	E	F	Initial space available (m^2)
	Number of plants in product mix[z]						
January							93
Upper		1500	300	1000	3000	1000	
Lower	1000						
February							465
Upper		5000	300	3000	5000	3000	
Lower	1000	1000	100	500	1000	500	
March							279
Upper		5000	300	3000	5000	3000	
Lower	1000	1000		500		500	
April							372
Upper		5000	300	3000	5000	3000	
Lower	1000	1000			1300		
May							186
Upper		5000	300	3000	5000	3000	
Lower	1000	1000					
June							93
Upper		1500	300	2000	5000	2000	
Lower	1000	300		300	300	300	
July							0
Upper		1500	300	2000	5000	2000	
Lower	1000						
August							279
Upper		5000	300	3000	5000	3000	
Lower	1000	1000		500	500	500	
September							279
Upper		1500	300	2500	3000	2500	
Lower	1000						
October							93
Upper		1500	300	1500	3000	1500	
Lower	1000		100				
November							0
Upper		1500	300	1000	3000	1000	
Lower	1000						
December							0
Upper		1500	300	1000	3000	1000	
Lower							
					Total greenhouse space		2140

[z]See Table 1 for plant varieties.

software was judged to be adequate for the demonstration problem, efficient, and convenient to use. Other LP software packages are available and would be equally suitable.

Results and Discussion

The six plants in Table 1 created 44 alternatives for production sequences begun in January. Up to 59 alternatives were available for production sequences begun in other months. Net returns were computed for each plant sequence per unit of total greenhouse space (including walkways) per year. For example, based on the information in Table 1, the pre-processing program determined that the sequence A-E-B begun in January and completed in November gave expected annual net revenue of $110/m^2 ($10.18/ft^2). By beginning the sequence again in December, the prorated annual net revenue exceeded $118/m^2 ($11.00/ft^2).

The profit-maximizing LP solution for this typical producer allocated greenhouse space to 33 selected plant sequences, which were optimally chosen from among the much larger number of possible sequences. All available space in January was allocated. A small portion of the space in February and March was left vacant and then all available space was again filled in April. The reason some space was temporarily left vacant was that some plant sequences starting in April permitted monthly sales within the upper and lower limits that provided a higher net revenue after direct expenses (even with one or two fewer growing months) than possible from sequences begun in February and March. Some space also was left vacant in May for a similar reason. However, leaving any space open in June would have been very costly to this producer by reducing annual net returns by an estimated $124/m^2 ($11.56/ft^2).

In addition to identifying the profit-maximizing allocation of greenhouse space, the LP solution also determined the value of relaxing each of the constraints (i.e., increasing initial space, reducing upper and raising lower monthly sales limits). The most costly restrictions were the minimum sales requirements in February and October for plant C. If these constraints could be removed without hindrance to other marketing activities, they would have increased net returns about $85/m^2 ($8/ft^2) of space made available for other plants. The minimum sales requirements on plants D and F in March, June, and August were also costly [as much as $20/m^2 ($2/ft^2)]. Consequently, one implication of this analysis is that the producer should carefully consider the impact on total marketing activities if these plants were not produced for sale in those particular months.

The profit-maximizing solution suggested relative space allocations among plants B, C, D and F that were similar to current practice. Plants A and E, however, should be grown in substantially larger quantities if profits were to be maximized under these circumstances. In some months sales of these plants would have more than doubled if those quantities could have been sold at the stated prices. Net revenues from all operations could have doubled by converting greenhouse space from current utilization patterns to those prescribed by the model. Consequently, potential gains were sufficient to warrant careful consideration by the producer of the market feasibility of this plan.

In the profit-maximizing plan, plants C, D, and F were grown primarily to meet minimum sales requirements. Enough space was devoted to plant B so that there was a crop finishing almost every month, but upper sales limits were rarely reached. The bulk of available space was devoted to plants A and E, plants with relatively higher net returns per growing time and space. Most plant combinations which were close economic alternatives to chosen variables (i.e., would reduce net returns the least if chosen) were variations on plant combinations containing plants A and E. For instance, beginning in February, 23 m^2 (250 ft^2) were devoted to the sequence D-A-A, but the sequences D-E-A and D-E-E were close economic alternatives. Also beginning in February, 14 m^2 (150 ft^2) were committed to the sequence F-A-E. Close economic alternatives included F-A-A, F-E-A, and F-E-E. The availability of several close alternatives gave the producer considerable freedom to switch among these two plants if propagation material was in short supply or if market conditions changed.

These results have three major implications for the Valley foliage industry. First, for nurseries which have market outlets and do not feel the need for a large product mix to draw customers, greater specialization in production should be more profitable. Nurseries following this schedule would grow only those plants that would yield the highest net return per growing time and space. With the advent of plant brokerage businesses in the Valley, this might be a feasible alternative. It would not necessarily lead to all producers growing the same plants, however. Because of managerial experience and other firm-specific resources, it is possible that different producers may have comparative economic advantage in the production of different plants. This could lead to greater regional-level than firm-level diversification.

Second, nurseries can grow a combination of plants with similar net revenues per growing time and space. This allows flexibility in scheduling and quick adjustments as market conditions change among product lines.

Third, less production of plants in large containers appears advisable which would make them relatively more scarce unless the market responds with increased prices. Only nurseries with a great deal of space which could not be allocated to other products would grow plants in large containers.

Significance to the Nursery Industry

The linear program (LP) model and accompanying computer software reported in this paper were developed specifically for foliage plant growers in the Rio Grande Valley of Texas who do not grow plants in highly regulated environments and, therefore, must plan around seasonal variations in climatic conditions. User modifications could make the model directly applicable to any greenhouse operation which deals in plants that grow and finish in less than one year.

In addition to allocating greenhouse space, this firm-specific model can aid firms in making marketing and capital budgeting decisions by providing incremental net revenue estimates under different scenarios. Managers can experiment with different product mixes or greenhouse sizes in a systematic way before expenditures are actually made. The computer code for the pre-processing program, detailed LP model structure and additional greenhouse results can be obtained by contacting C. Richard Shumway, Department of Agricultural Economics, Texas A&M University, College Station, TX 77843-2124. A nominal fee will be charged to cover the cost of diskette, copying, and handling.

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