# CHRYSANTHEMUM PRODUCTION PLANNING UNDER TIME-TO-HARVEST UNCERTAINTY*

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## INTRODUCTION

Planning a season's planting is a complex problem facing Florida's chrysanthemum producers. Planting must be carefully timed to assure adequate supplies of flowers during peak marketing periods. Also, widely varying labor requirements of the crop should be considered. Finally, even the best-laid plans may be ruined by crops coming in too soon or too late due to unexpected weather variations. In this paper, a dynamic linear program is developed as a planning aid for chrysantheum production. The model parameters are then estimated with sufficient accuracy to demonstrate the model's workability, and an application of the model is suggested.

Chrysanthemums (pompons) may be grown as either a single-stem or pinched crop. In single-stem production, a cutting is planted and harvested as a single stem of flowers that is sold in a bunch of six or seven stems. In pinched crop production, approximately three weeks after a cutting is planted the terminal bud is removed ("pinched"). This allows three stems of flowers to be harvested. Thus pinched crop production requires only one-third as many cuttings to produce a given number of bunches; however, the labor requirements for a pinched crop are considerably higher than for a single-stem crop. Another factor that enters into the single-stem vs. pinched decision is that a single-stem crop is usually harvested 14 weeks after planting while a pinched crop takes 16 weeks, since the pinching operation delays harvest. This allows a single-stem producer the possibility of harvesting more crops per acre in a growing season. Since a typical south Florida growing season is 42 weeks long (mid-August through late May), single-stem plantings cannot be made after week 29, nor pinched plantings after week 27, in order to allow enough time to harvest the flowers before the end of the growing season.

## THE MODEL

Dynamic linear programming was chosen as a means of analysis for this problem because timing, as well as magnitude, of input requirements and production levels is of critical importance to the success of a chrysanthemum farm.

### Objective Function

The objective function, specified below, is an indicator of profits at the farm level.

$$(1)\ \text{Maximize } \Pi = [p - f]Z - \sum_{i=1}^{3} c\ S_i - \sum_{i=1}^{3} c^*P_i - CH - F$$

where:

p is a 1 x 30 vector of per bunch market prices adjusted for wholesale commissions in weeks 13-42,

f is a 1 x 30 vector of per bunch freight rates in weeks 13-42,

Z is a 30 x 1 vector of bunches sold in weeks 13-42,

c is a 1 x 29 vector of the out-of-pocket costs other than labor to plant, disbud, and harvest for single stem-flowers planted in weeks 1-29,

$S_1$, $S_2$, and $S_3$ are 29 x 1 vectors of single stem-plantings that are planted in weeks 1-29 and harvested early, on time, and late, respectively,

c* is a 1 x 27 vector of out-of-pocket costs other than labor to plant, pinch, prune, disbud, and

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harvest pinched flowers planted in weeks 1-27,

$P_1$, $P_2$, and $P_3$ are 27 x 1 vectors of pinched plantings that are planted in weeks 1-27 and harvested early, late and on time, respectively,

C is a 1 x 42 vector of the weekly costs of one laborer employed in weeks 1-42,

H is a 42 x 1 vector of the number of workers hired in weeks 1-42 to plant, pinch, prune, disbud, and harvest both types of flowers, and

F is a scalar of all other farm costs, including fixed costs, cash overhead costs, and land costs.

Flower prices used were a series of weekly wholesale consignment prices on the New York market for the 1973-74 season. As shown in Table 1, prices are usually higher during and immediately preceding the holiday seasons of Thanksgiving

**Table 1. GROSS WEEKLY PER BUNCH FLOWER PRICES FOR NEW YORK WHOLESALE CONSIGNMENT MARKET, 1973-74 SEASON**

| Week | Price | Week | Price |
|---|---|---|---|
| | ($/bunch) | | ($/bunch) |
| 13 | 1.10 | 28 | 1.35 |
| 14 | 1.25 | 29 | 1.00 |
| 15 | 1.15 | 30 | .85 |
| 16 | .80 | 31 | .85 |
| 17 | .80 | 32 | .90 |
| 18 | 1.00 | 33 | 1.00 |
| 19 | 1.50 | 34 | 1.25 |
| 20 | 1.30 | 35 | 1.60 |
| 21 | 1.15 | 36 | 1.35 |
| 22 | .80 | 37 | 1.05 |
| 23 | .90 | 38 | 1.25 |
| 24 | 1.00 | 39 | 1.60 |
| 25 | 1.25 | 40 | 1.25 |
| 26 | 1.35 | 41 | 1.10 |
| 27 | 1.55 | 42 | 1.10 |

(week 15), Christmas (week 20), Valentine's Day (week 27), Easter (week 35), and Mother's Day (week 40). The sales commission in each week was taken to be 25 percent of the gross price. The freight rate in each was estimated at 18 cents per bunch.

Values for the c and c* vectors were assumed to be constant with respect to planting dates and time-to-harvest. Using estimates in [1], each element of c was taken to be $3,447 and each element of c* was taken to be $2,973. Each element of the C vector was estimated at $100 per 40-hour week. The value of F, which was also taken from [1], was $168,082 per year.

### Time-to-Harvest Uncertainty

Although single stem and pinched pompons normally are ready for harvest 14 and 16 weeks respectively, after planting, extreme weather often delays or hastens the time when flowers must be harvested to assure maximum product quality. For purposes of this study, it was assumed that weather would not affect the time to harvest by more than one week in either direction.

This uncertainty was incorporated into the model by introducing the following constraints:

(2) $\theta_i S = S_i \qquad i = 1, 2, 3 \qquad \sum_{i=1}^{3} \theta_i = \underline{1}$

(3) $\theta_i^* P = P_i \qquad i = 1, 2, 3 \qquad \sum_{i=1}^{3} \theta_i = \underline{1}^*$

where:

$\theta_1$, $\theta_2$, and $\theta_3$ are $1 \times 29$ vectors of probabilities that single-stem flowers planted in weeks 1-29 will be harvested early (in 13 weeks), on time (in 14 weeks), or later (in 15 weeks), respectively,

S is a 29 x 1 vector of acres planted to single-stem pompons in weeks 1-29,

$\theta_1^*$, $\theta_2^*$, and $\theta_3^*$ are $1 \times 27$ vectors of probabilities that pinched flowers planted in weeks 1-27 will be harvested early (in 15 weeks), on time (in 16 weeks), or late (in 17 weeks), respectively,

P is a 27 x 1 vector of acres planted to pinched pompons in weeks 1-27,

$\underline{1}$ and $\underline{1}^*$ are 1 x 29 and 1 x 27 vectors of 1's, respectively.

The effect of equations (2) and (3) is to spread the expected yield over a three-week period, even though in any particular year harvest will occur in only one of the three weeks.

Values for $\theta_i$ and $\theta_i^*$ were based on informal interviews with growers (see Table 2). It was felt that relying on their experience would provide more accurate information than that which could be obtained by working with weather data.

**Table 2. ESTIMATED PROBABILITIES OF FLOWERS HARVESTED IN A GIVEN MONTH COMING IN EARLY, ON SCHEDULE, AND LATE**

| Month of Harvest | Early | On Schedule | Late |
|---|---|---|---|
| November | 0.1 | 0.8 | 0.1 |
| December | 0.3 | 0.6 | 0.1 |
| January | 0.0 | 0.6 | 0.4 |
| February | 0.0 | 0.4 | 0.6 |
| March-May | 0.1 | 0.8 | 0.1 |
| Week 27 pinched planting | 0.1 | 0.9 | 0.0 |
| Week 29 single-stem planting | 0.1 | 0.9 | 0.0 |

Special probabilities for plantings in the last possible week are specified (Table 2) for computational convenience only. If the "late probabilities" were non-zero, harvest would occur outside the 42 week growing season.

### Land Use Constraints

In any given week, all available land must be accounted for by plantings of either flower type or by carrying the land into the following week.

(4) $S + P^* + Y = Y^* + R$

where:

- $P^*$ is a $29 \times 1$ vector, the first 27 elements of which are those of the P vector and the last two elements are zero,
- Y is a $29 \times 1$ vector, the $i^{th}$ element of which is the number of acres transferred from week i to week i + 1,
- $Y^*$ is a $29 \times 1$ vector, the $i^{th}$ element of which is the number of acres transferred from

i − 1 to week i, and

R is a 29 × 1 vector of the number of acres which have been previously planted to either flower type, harvested, and prepared for replanting.

To illustrate how elements of the R vector were formed, consider the case of an acre of land planted to single-stem flowers in week 2 and harvested 14 weeks later. This acre would be available for replanting in week 2 + 14 + 4 = 20, assuming four weeks to prepare the field for a new crop after a previous crop has been harvested. Therefore, the acre of land would appear as part of the 20th element of the R vector since it would be available for replanting in the 20th week.

The value of the first element of Y*, farm size, was taken to be 16 acres.

### Labor Constraints

Per acre labor requirements for both flower types were estimated from [1] and are shown in Table 3. The reader should not interpret Table 3 to mean that labor is not required except during the weeks shown. However, labor requirements in other weeks are relatively small and constant and are not major considerations in production planning. Cost for this portion of the labor is included in c and c* in equation (1).

**Table 3. HOURLY LABOR REQUIREMENTS FOR CHRYSANTHEMUMS PLANTED IN WEEK i AND HARVESTED j WEEKS LATER**

| Operation | Week of Operation | Labor Requirements | |
|---|---|---|---|
| | | Single-Stem | Pinched |
| | | (hours per acre) | |
| Plant | i | 112 | 70 |
| Pinch | i + 2 | - | 20 |
| Prune | i + 5 | - | 150 |
| Disbud | i + j - 3 | 100 | 100 |
| Harvest | i + j - 1 | 646 | 646 |

The labor constraints in the model are

$$(5) \quad \sum_{i=1}^{3} L_i S_i + \sum_{i=1}^{3} L_i^* P_i \leqslant 40 H$$

where:

$L_1$ is a 42 × 29 matrix, the ij[th] element of which is the week i labor requirement in hours per acre for planting, disbudding, and harvesting single-stem flowers which were planted in week j and harvested early. $L_2$ and $L_3$ are defined similarly for single-stem plants which were harvested on schedule and late, respectively. $L^{1*}$ is a 42 × 27 matrix, the ij[th] element of which is the week i labor requirement in hours per acre for planting, pinching, pruning, disbudding, and harvesting pinched flowers which were planted in week j and harvested early. $L_2^*$ and $L_3^*$ are defined similarly for pinched plantings which are harvested on schedule and late, respectively.

In passing, it should be noted that the $L_i$ and $L_i^*$ matrices will contain a large proportion of zero elements.

### Flower Selling Constraints

The total number of saleable bunches harvested in each week is:

$$(6) \quad Z = \sum_{i=1}^{3} X A_i + \sum_{i=1}^{3} X^* A^*$$

[1] A more precise specification of the definition of the R vector in equation (4) and the $A_i$ and $A_i^*$ vectors of equation (6) are available from the authors.

where:
$A_1$, $A_2$, and $A_3$ are $30 \times 1$ vectors of the number acres of early, on schedule, and late single-stem flowers harvested in weeks 13-42; $A_1^*$, $A_2^*$, and $A_3^*$ are $30 \times 1$ vectors of the number of acres of early, on schedule and late pinch flowers harvested in weeks 13-42, and X and X* are scalars representing the per acre yields of saleable bunches of single-stem and pinched flowers.

Determining elements of the A and A* vectors, although laborious, is simply a matter of arithmetic. For example, if one acre of pinched flowers is planted in week 3, (i.e., the third element of the $P_2$ vector is one) and harvested on schedule (16 weeks later), then the flowers are harvested in week $3 + 16 - 1 = 18$. Thus, that acre of flowers will become part of the sixth element of the $A_2^*$ vector.

For purposes of this study, it was assumed that $X = X^* = 21{,}940$ bunches per acre. There is an implicit assumption, in accord with the opinions of growers interviewed by the authors, that time-to-harvest and yields are independent. A further implicit assumption is that per acre yields of single-stem and pinched flowers are identical. Some growers feel that single-stem production requires less stems to make a marketable bunch and, hence, will provide a higher yield of bunches. Data are not presently available to either verify or estimate the magnitude of this effect. If sufficient data were available, the model could be improved by relaxing the implicit assumption that yields and the date of planting are independent.

One may wonder why a grower would plant single-stem flowers if the same yield could be achieved with pinched flowers, and growing costs for which are less. The reason is that pinched flowers take longer to grow, making more crops per season of single-stem flowers possible.

Most growers do not feel that marketing zero flowers in any given week is a feasible alternative, since they have certain regular customers whose orders must always be filled. Thus, the following constraints were specified

$$(7) \quad Z_k \geqslant M_k \quad k = 13, \ldots, 42$$

where:
$Z_k$ is the $k^{th}$ element of Z and $M_k$ is the minimum acceptable number of bunches sold in week k. In this study, it was somewhat arbitrarily assumed that $M_k = 7{,}500$ bunches for all k.

**Summary**

The dynamic linear program specified here is to maximize equation (1) subject to equations (2) — (7) and the usual non-negativity constraints.

## AN APPLICATION OF THE MODEL

Nonfarm competition for labor has become increasingly intense in Florida over the past several years. Nonfarm employment opportunities in general offer the worker a higher wage and steady employment. In this section, effects of production planning to provide steady employment, without wage increases, for all farm employees throughout the 42-week growing season will be examined. This is, of course, an extreme example since making farm employment more competitive with other opportunities will probably involve some combination of higher wages and steady employment for some, but not all, employees. Nonetheless, the example will serve both to demonstrate the model's capabilities and to point out some problems that may be associated with offering steady employment for a production activity in which the weekly labor demands are quite variable.

The model was first run as specified in the preceding discussion. It assumes that the farm manager has an infinite supply of labor which can be drawn upon to any extent subject to the \$100 per week wage rate. The model was then run with the further restriction that

$$(8) \quad H_j = h \qquad j = 1, \ldots, 42$$

where:
$H_i$ is the $j^{th}$ element of H and h is a constant number of workers determined by the model. For purposes of discussion, the two formulations will be referred to as the variable labor model and the constant labor model.

Results of the two model formulations are shown in Table 4. Total acres planted for both solutions were, for all practical purposes, the same, although weekly plantings were quite different for the two solutions.

It might be noted that the land turnover rate, i.e., the ratio of total acres planted to total acres on he farm is about 1.9 in both solutions. The turnover rate rarely exceeds 1.5 under actual conditions.

The addition of equation (8) to the model

**Table 4. OPTIMAL SOLUTIONS FOR THE VARIABLE LABOR MODEL AND THE CONSTANT LABOR MODEL**

| | Variable Labor Model | | | | Constant Labor Model | | |
|---|---|---|---|---|---|---|---|
| Week | Single-stem Flowers Planted | Pinched Flowers Planted | Flowers Sold | Laborers Hired | Single-stem Flowers Planted | Pinched Flowers Planted | Flowers Sold |
| | (acres) | (acres) | 1,000 (bunches) | | (acres) | (acres) | 1,000 (bunches) |
| 1 | 3.42 | .23 | | 10.0 | 3.42 | .43 | |
| 2 | | .53 | | .9 | | | |
| 3 | | | | .1 | | 1.43 | |
| 4 | | .96 | | 1.9 | | 2.80 | |
| 5 | | 7.68 | | 13.4 | | 1.96 | |
| 6 | | | | 1.3 | | 3.21 | |
| 7 | | .57 | | 6.8 | | .04 | |
| 8 | | .19 | | .3 | | .55 | |
| 9 | | .44 | | 4.7 | | | |
| 10 | | .27 | | 29.4 | | .43 | |
| 11 | | .58 | | 2.1 | .21 | .42 | |
| 12 | | .23 | | 9.5 | | .23 | |
| 13 | | .51 | 7.50 | 8.3 | | .51 | 7.50 |
| 14 | | | 60.00 | 46.8 | | | 60.00 |
| 15 | | .39 | 8.00 | 8.7 | | | 8.44 |
| 16 | | | 7.50 | 8.6 | | | 7.50 |
| 17 | | | 7.50 | 13.8 | .39 | | 10.35 |
| 18 | .34 | .01 | 7.50 | 20.1 | .34 | .01 | 37.23 |
| 19 | .34 | | 63.21 | 49.4 | .34 | | 52.84 |
| 20 | .38 | 2.38 | 103.20 | 83.5 | .38 | 2.40 | 53.00 |
| 21 | | | 16.85 | 13.3 | | | 46.49 |
| 22 | .65 | .03 | 7.50 | 9.5 | .81 | | 7.50 |
| 23 | | | 7.50 | 6.4 | 1.70 | | 7.50 |
| 24 | .40 | 2.83 | 7.50 | 23.5 | .05 | .76 | 7.50 |
| 25 | | | 7.50 | 15.6 | 1.31 | 2.70 | 7.50 |
| 26 | 5.47 | | 7.50 | 23.1 | 2.12 | | 7.50 |
| 27 | .30 | | 9.68 | 8.9 | .31 | .03 | 7.60 |
| 28 | .38 | | 7.50 | 7.5 | | | 7.50 |
| 29 | .34 | | 7.50 | 17.9 | .68 | | 7.50 |
| 30 | | | 7.50 | 6.4 | | | 7.50 |
| 31 | | | 7.50 | 6.4 | | | 7.50 |
| 32 | | | 7.50 | 6.4 | | | 7.50 |
| 33 | | | 7.50 | 11.6 | | | 7.50 |
| 34 | | | 7.50 | 6.4 | | | 7.90 |
| 35 | | | 53.24 | 40.0 | | | 60.16 |
| 36 | | | 7.59 | 7.8 | | | 36.95 |
| 37 | | | 7.50 | 22.2 | | | 7.50 |
| 38 | | | 19.15 | 16.9 | | | 29.41 |
| 39 | | | 146.33 | 108.6 | | | 60.05 |
| 40 | | | 24.30 | 18.8 | | | 59.12 |
| 41 | | | 7.50 | 6.0 | | | 7.50 |
| 42 | | | 7.59 | 5.6 | | | 14.17 |
| Total | 12.02 | 17.83 | 654.14 | 697.4 | 12.06 | 17.91 | 656.21 |

NOTES: 1. The constant labor production schedule employed 45.1 workers in each of 42 weeks.

2. Profits were $209,304 for variable labor schedule and $57,965 for the constant labor schedule.

proved to be quite costly. The objective function was optimized at $209,304 for the variable labor model and at $57,965 for the constant labor model. About $119,400 of the difference in $\pi$ values is due to the fact that the optimal solution of the constant labor model included 75,768 hours of labor used (45.1 workers each week), only 28,006 hours of which were used productively. The remaining difference is largely attributable to the fact that the variable labor model solution had a greater portion of flowers produced marketed in weeks when prices were at their peak. It should be pointed out that this model does not include external costs of hiring laborers. These costs, if included, would make the variable labor model less attractive with respect to the constant labor model.

Again, it is stressed that these two model formulations represent extremes. On the one hand, it is unlikely that a producer would sacrifice so much income in order to provide all workers with constant employment. On the other hand, it is equally unlikely that a producer could satisfy the widely varying labor demands of the variable labor model solution in today's market.

## DISCUSSION

Using producer judgement to specify probabilities for various occurences may be the strong point of this model. There are oftentimes insufficient data to formally evaluate probability functions, yet the researcher feels uneasy about ignoring uncertainty for this reason. It may be possible for models of this type to be used in other areas where uncertainty is also a major influence on decision makers. Some examples would be price and yield uncertainty.

The most serious drawback of the analysis is that the model as formulated assumes that market prices are independent of the number of bunches supplied each week by the producer. In practice, it is improbable that a producer could supply such a widely varying amount of flowers from week to week without affecting the market price. However, there is no reliable data from which to estimate even crude weekly demand functions, thus the problem seems largely unavoidable at this time.

In spite of rather gross abstractions in the model, the authors found it useful in analyzing individual problems of Florida chrysanthemum growers as part of a special project of the Florida Cooperative Extension Service.

## REFERENCES

[1] Walker, Charles and Richard A. Levins. *The Economic Effect of Alternative Production Systems for Chrysanthemums in Florida, 1973.* University of Florida, Economics Report 63, April 1974.