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Linear programming applied to the flower sector: a Gladiolus bulb production case study

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Abstract

Mathematical modeling structure was developed to support representative Brazilian bulb growing and trading company's decision making process, during the Gladiolus production planning activity. The pertinent LP model was focused on client's bulb requests to be attended and showed interesting results (e.g., profit maximization and suggestions for optimal combinations of types of bulblet and spacing to be planted).

Keywords: Linear programming; Flower industry; Bulb production

1. Introduction

The Gladiolus production is inserted in a global market in which Holland and Brazil are the main bulb exporters. According to the U.S. Netherlands Flower Bulb Information Center (2000), Holland exports a total of more than three-quarters-of-a-billion dollars worth of bulbs to the world each year. America is now the world's leading bulb market, buying just over $130

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million worth (wholesale value) in 1994/95. The Americans are followed by the Germans who imported \$117 million worth, and the Japanese who imported \$110 million worth in 1993/94.

Bulb has commonly come to mean a herbaceous plant with an underground storage organ, which is a reserve of carbohydrates, nutrients, and water. Bulbs fall generally into two groups: spring-flowering (which are planted in the fall) and summer-flowering (which are planted in the spring). Gladiolus is one of the most popular summer-flowering bulbs, people use them either for the garden or as a cut flower in the summer months.

According to González et al. (1998), bulb flowers such as Gladiolus, Iris, Narcissus and Tulip, among others, make up a substantial proportion of the cut flower trade, with Gladiolus being prized by florists for their showy flowering stems and by growers for their relative ease of production.

The Gladiolus trading and production chain involve various actors, such as: final consumers of cut flowers, final consumers of garden bulbs, flower retailers, flower wholesalers, flower growers, bulb retailers, bulb wholesalers, importers, exporters, bulb growers and plant breeders.

The complete bulb production cycle takes two years. In the first year bulblets are produced from offshoots (cormels) and, in the second year, bulbs are produced from the bulblets (see Fig. 1).

Final consumers on the demand side and bulb growers on the supply side are the main actors. The final consumers define the quality parameters to be followed by the flowers (stem length, color, flower size, sanity, appearance, durability and price) and the bulbs (size, sanity, appearance, pureness and price). On the other side, the efficiency of the bulb growers influences directly all chain links. The other actors, except for the plant breeders, are merely brokers. The main challenge for growers and brokers is to identify in detail the final consumers requests, to attend them with products and services of good quality.

Based on that, this paper has as its main objective the formulation of a linear programming model, focusing on the second year of the bulb production cycle, to help in the calculation of bulblet quantities to be planted per variety, size and spacing, based on the quantities sold, sale prices, bulblet stock, return stock, return curves, available area, cost parameters and expected gross margin. The resulting modeling structure was tested by a representative bulb grower within his production planning activity, so that he could attend in the best manner his client requests and maximize his own gross economic result (an approximation of profit).

2. Mathematical model

There is no tradition in developing optimization models for the flower industry. Some examples come from Schumacher and Weston (1984), who developed an LP application for a Carnation production/sales system, as well from Chao et al. (1998a, 1998b) who designed, implemented and evaluated a knowledge-based control system for single stem rose production. Applications focused on bulb production are still more rarely documented by the specialized literature. For instance, Rossing et al. (1997) developed an interactive multiple goal linear programming to help designing farming systems that meet environmental objectives in addition to economic objectives.

There are also some other technical studies, not necessarily focused on modeling or dealing with the main aspects that affect bulb production rates. For instance, Rees et al. (1973) investigated the effects of planting density, arrangement, bulb type and cropping duration on flower and bulb production of Narcissus, in England; Rees and Briggs (1974) analyzed the effects of bulb size, planting density, leaf area, plant height and senescence on bulb yield of Tulips; Schumacher and Weston (1984), in a modeling exercise, considered the following factors for a Carnation production/sales system: planting dates and their effect on flowering dates, year round sales and holiday peak requirements, seasonal price fluctuations, short versus long term storage capabilities; Dhua et al. (1987) studied the effects of bulb size, storage and treatment with chemicals on growth and flower production in Tuberose, a very important flower crop of India.

The mathematical structure of the linear programming model developed in this paper follows the main characteristics of optimization models, where an objective function, represented by what was called "gross economic result" (an approximation of the profit) has to be maximized, subject to a set of constraints. Also, some of the factors taken into consideration in the technical studies mentioned above are incorporated into the model.

The general structure of this model is presented as follows, where the main variables to be calculated are regarding the quantities of bulblets to be planted and number of bulbs of a given size to be harvested.

2.1. Objective function

$$\mathrm{RBRU} = \mathrm{RECTOT} - \mathrm{CUS} \tag{1}$$

being considered as endogenous variables:

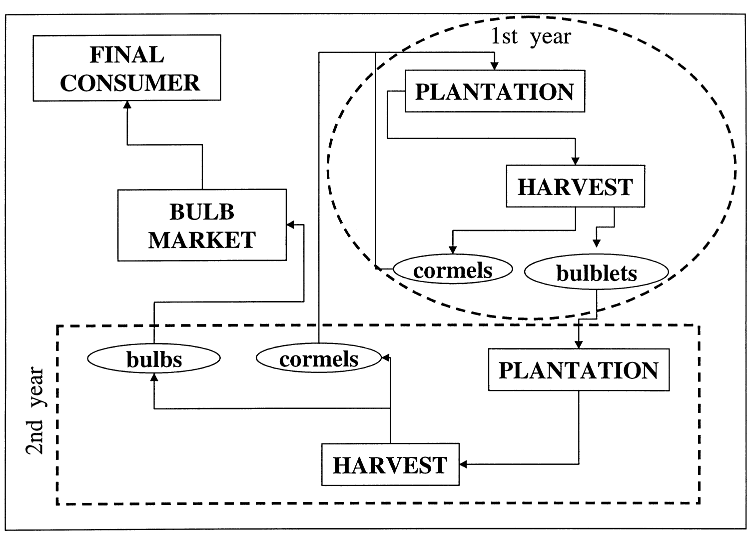

Fig. 1. Flower bulb production cycle.

- RBRU = gross economic result ($);
- RECTOT = total revenue ($);
- CUS = total cost ($);

where:

$$\text{RECTOT} = \sum_k \text{PRO}_k \times \text{PRECO}_k \tag{2}$$

$$\text{PRO}_k = \sum_i \sum_j \text{RET}_{ijk} \times X_{ij} \tag{3}$$

$$\text{CUS} = \text{AP} \times \text{CUSTOHA} \tag{4}$$

$$\text{AP} = \sum_i \sum_j \text{BPM}_j \times X_{ij} \tag{5}$$

being also considered as endogenous variables:

- PRO_k = number of bulbs of size k to be produced;
- X_{ij} = number of bulblets of size i to be planted at spacing j;
- AP = planted area (ha);

and the following parameters as given data:

- PRECO_k = price of the bulb of size k ($);
- RET_{ijk} = rate of harvested bulbs of a given size k in function of the size i and spacing j of the bulblet planted;
- CUSTOHA = unit cost ($/ha);
- BPM_j = used area by bulblets planted at spacing j.

2.2. Constraints

$$\sum_j X_{ij} \leq \text{BBI}_i \tag{6}$$

$$\text{PEDMIN}_k \leq \text{PRO}_k \leq \text{PEDMAX}_k \tag{7}$$

$$\text{AP} \leq \text{AD} \tag{8}$$

$$\frac{\text{RECTOT}}{\text{CUS}} \geq \text{MARGIN} \tag{9}$$

where:

- BBI_i = available stock of bulblets of size i (units);
- PEDMIN_k = minimum request of bulbs of size k to be considered (units);
- PEDMAX_k = maximum request of bulbs of size k to be considered (units);
- AD = available area (ha);
- MARGIN = minimum gross margin.

3. Case study

To illustrate an application of the model, a case study was simulated for a representative Brazilian grower of the Gladiolus variety named White Friendship. The data utilized are presented as follows, being the model processed through the optimization language GAMS (Brooke et al., 1992).

3.1. Quantities to be sold

The bulbs are sold as per variety and size. The variety determines the flower's characteristics. The size, given by the bulb's circumference measured in centimeters, may be 6/8, 8/10, 10/12, 12/14 and 14/+. The size 10/12, for instance, has a circumference of more than 10 and less than 12 cm. The minimum values for each size (PEDMIN_k) are presented in Table 1.

3.2. Sales prices

Prices of bulbs according to size are crucial parameters whose variations are likely to influence the outcome of the model. van Dalen and Thurik (1998), analyzing the pricing behavior of flower exporters in Holland, detected that firms serving large buyers, such as foreign distributors (which can be applied to the role exerted by the representative bulb grower

Table 1
Minimum quantities to be sold (PEDMIN_k)[a]

Size (k)	Quantity (thousand units)
6/8	0
8/10	0
10/12	1220
12/14	2020
14/+	700

[a] Source: field data.

Table 2
Average sale prices ($PRECO_k$)[a]

Size (k)	Price ($ per 1000 bulbs)
10/12	37.94
12/14	46.42
14/16	51.89

[a] Source: field data.

treated in this case study) and mass retailers, as well as firms operating in nearby European markets, reveal a tendency towards sales maximizing strategies.

Therefore, price information can be considered as a main input for the "gross economic result" maximization behavior incorporated into the modeling structure. The average sale prices for a given size k of a bulb, used in the model, are presented in Table 2.

3.3. Bulblet stock

As observed from Fig. 1, in the second year, bulbs are produced from the bulblets. For this case study, the stock of bulblets, classified in the sizes G, 2/3, 3/4, 4/5, 5/6, 6/7 and 7/8, is presented in Table 3.

3.4. Spacing

The spacing between lines is settled by the planting machine, in the case 4 lines on 1.5 m. The spacing between bulblets is variable, depending on the desired production. The greater the number of plants per hectare, the smaller the number of bulbs harvested, and vice-versa.

Three types of spacing between bulblets were considered: 55, 45 and 40 bulblets per linear meter. The pertinent data are presented in Table 4.

Table 3
Bulblet stock (BBI_i)[a]

Size (i)	Quantity (thousand units)
G	0
2/3	8370
3/4	8679
4/5	5450
5/6	4846
6/7	842
7/8	2095

[a] Source: field data.

Table 4
Used area (ha) by each type of spacing between bulblets (BPM_j)[a]

Spacing between bulblets (j)	Area (ha/1000 bulblets)
55	6.8×10^{-4}
45	8.3×10^{-4}
40	9.4×10^{-4}

[a] Source: field data.

3.5. Return curves

Those curves, which present as their main points the ones illustrated in Table 5, indicate the rate of harvested bulbs from a given size per 100 planted bulblets, according to the variety, planted bulblet size and spacing.

It was also considered an available area of 20 ha (AD), a unit cost per ha (CUSTOHA) of $21,000.00 and a minimum gross margin (MARGIN) of 10%.

4. Discussion of the results

The optimal solution found was related to the recommendation of the plantation of an area of 7.63 ha, with 5450 thousand bulblets of size 4/5, and a density of 45 bulblets per meter, and 3742.366 thousand bulblets of size 5/6, with a density of 45 bulblets per meter. The expected production of bulbs, taking into consideration these results, is presented in Table 6.

The values of revenue, cost and gross economic result, also calculated into the model, were, respectively, $176,378.20, $160,222.94 and $16,155.26.

The production of bulbs of size 12/14 was equal to the minimum established quantity of 2020 thousand bulbs sold. For each 1000 additional bulb request from this size, the gross economic result would be altered in $36.03. The production of the remaining sizes was larger than the quantities to be sold, resulting in surpluses and indicating those individual variations

Table 5
Available data on return curves (RET_{ijk})[a]

Bulblet Size (i)	Spacing (j)	Return curves				
		6/8	8/10	10/12	12/14	14/+
2/3	55	10.32	16.21	16.79	6.40	1.67
3/4	55	12.12	15.56	22.57	12.26	4.06
4/5	45	2.80	13.20	25.49	22.55	10.30
5/6	45	2.62	15.70	33.17	21.14	8.65
6/7	40	0	7.45	29.62	18.86	5.87

[a] Source: field data.

Table 6
Quantities to be sold, production and surpluses observed[a]

Bulb size (k)	Quantities (thousand units)		
	Sale	Production	Surplus
6/8	0	250.688	250.688
8/10	0	1294.667	1294.667
10/12	1220	2630.626	1410.626
12/14	2020	2020.000	0
14/+	700	885.189	185.189
Total	3940	7081.170	3141.170

[a] Source: model results.

and within certain limits in the quantities sold, would not imply changes in the gross economic result.

With respect to the stock of bulblets, it can be seen from Table 7 that 5450 thousand 4/5 size bulblet stock was totally used for planting. For each 1000 additional bulblet from this size, the gross economic result would change in \$1.16. The stock from other sizes was not totally used, indicating that individual variation and within certain limits in the available quantities, would not alter the gross economic result.

The constraints associated with the maximum limit of 20 ha of area and minimum of 10% of gross margin were not binding (the corresponding results were, respectively, 7.63 ha and 10.083%).

5. Concluding remarks

The modeling structure developed can be used to support decision-making process during

Table 7
Bulblet stock and planting[a]

Bulblet size (i)	Quantities (thousand units)	
	Stock	Planting
G	0	0
2/3	8370	0
3/4	8679	0
4/5	5450	5450.000
5/6	4846	3742.366
6/7	842	0
7/8	2095	0

[a] Source: model results.

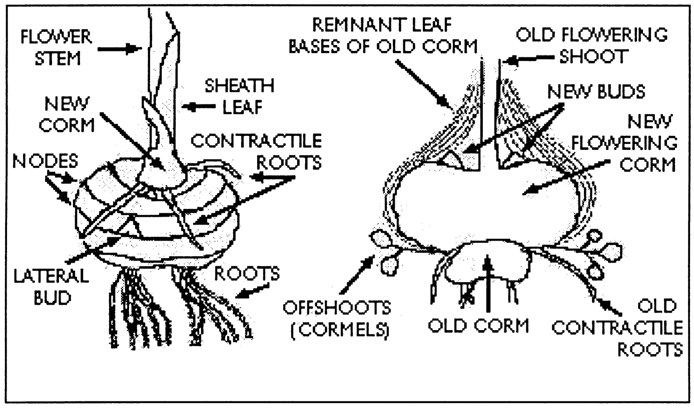

Fig. 2. Basic scheme of a Gladiolus plant. (Source: de Hertogh and le Nard, 1993).

Gladiolus planning activities, through suggestions of optimal combinations of planting. The greater the number of possible combinations between planting sizes and spacing, the greater the size of the model and more useful is the information obtained.

However, even considering that the implementation of this optimization model by the representative bulb grower already represented a 15% gain in the gross economic result in the first year, it must be remembered that the data to be used have to be reliable, once "garbage in, garbage out'. For instance, experiments to determine the return curves must be expanded and for scenarios which result infeasible solutions, the pertinent constraints have to be relaxed, to make possible the evaluation of the quality of the new results.

The solution, in terms of gross economic result for the grower, may be improved if sale limits can be adjusted to the production. Therefore, it is important that these involved in the bulb sale process take also part in the production planning activity.

Finally, as Hanks (1996) already pointed out, it seems clear that a good understanding of the factors involved in the bulb and flower production could lead to the modification of cultural practices and the development of precision growing systems.

Appendix A. Gladiolus bulb description

Like a true bulb, the corm is a modified stem with a basal plate, but the primary storage tissue is the stem tissue itself, rather than leaf tissue; so, corms are frequently described as "solid bulbs". These organs may also be tunicated or non-tunicated, and they have nodes from which meristems originate. Gladiolus (see Fig. 2), freesia, crocus, and ixia are some examples.

Appendix B. Example of matrix with the technical coefficients, based on output from GAMS (Brooke et al., 1992)

("R" stands for "Row" and "C" stands for "Column")

Maximize:
R0: C117

Constraints:
R1: $C105 >= 0$
R2: $C106 >= 0$
R3: $C107 >= 1220$
R4: $C108 >= 2020$
R5: $C109 >= 700$
R6: $C0 + C5 + C10 <= 0$
R7: $C15 + C20 + C25 <= 8370$
R8: $C30 + C35 + C40 <= 8679$
R9: $C45 + C50 + C55 <= 5450$
R10: $C60 + C65 + C70 <= 4846$
R11: $C75 + C80 + C85 <= 842$
R12: $C90 + C95 + C100 <= 2095$
R13: $C116 <= 20$
R14: $C118 - 1.1C119 >= 0$
R15: $-0.103171C15 - 0.1211574C30 - 0.02802618C50 - 0.02617216C65 + C105 = 0$
R16: $-0.1620525C16 - 0.1556407C31 - 0.1297233C51 - 0.157033C66 - 0.07445695C86 + C106 = 0$
R17: $-0.1678585C17 - 0.2257389C32 - 0.2549119C52 - 0.3317037C67 - 0.2961595C87 + C107 = 0$
R18: $-0.0639681C18 - 0.1225554C33 - 0.2254732C53 - 0.2114093C68 - 0.1885831C88 + C108 = 0$
R19: $-0.01674988C19 - 0.0406077C34 - 0.1030352C54 - 0.08648192C69 - 0.0587005C89 + C109 = 0$
R20: $-C105 + C110 = 0$
R21: $-C106 + C111 = 0$
R22: $-C107 + C112 = -1220$
R23: $-C108 + C113 = -2020$
R24: $-C109 + C114 = -700$
R25: $-C110 - C111 - C112 - C113 - C114 + C115 = 0$
R26: $-0.00068C0 - 0.00083C5 - 0.00094C10 - 0.00068C15 - 0.00083C20 - 0.00094C25 - 0.00068C30 - 0.00083C35 - 0.00094C40 - 0.00068C45 - 0.00083C50 - 0.00094C55 - 0.00068C60 - 0.00083C65 - 0.00094C70 - 0.00068C75 - 0.00083C80 - 0.00094C85 - 0.00068C90 - 0.00083C95 - 0.00094C100 + C116 = 0$
R27: $C118 = 176378$
R28: $-21000C116 + C119 = 0$
R29: $C117 - C118 + C119 = 0$
R30: $C0 - C1 = 0$
R31: $C1 - C2 = 0$
R32: $C2 - C3 = 0$
R33: $C3 - C4 = 0$

R34: $C5 - C6 = 0$
R35: $C6 - C7 = 0$
R36: $C7 - C8 = 0$
R37: $C8 - C9 = 0$
R38: $C10 - C11 = 0$
R39: $C11 - C12 = 0$
R40: $C12 - C13 = 0$
R41: $C13 - C14 = 0$
R42: $C15 - C16 = 0$
R43: $C16 - C17 = 0$
R44: $C17 - C18 = 0$
R45: $C18 - C19 = 0$
R46: $C20 - C21 = 0$
R47: $C21 - C22 = 0$
R48: $C22 - C23 = 0$
R49: $C23 - C24 = 0$
R50: $C25 - C26 = 0$
R51: $C26 - C27 = 0$
R52: $C27 - C28 = 0$
R53: $C28 - C29 = 0$
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R107: $C96 - C97 = 0$
R108: $C97 - C98 = 0$
R109: $C98 - C99 = 0$
R110: $C100 - C101 = 0$
R111: $C101 - C102 = 0$
R112: $C102 - C103 = 0$
R113: $C103 - C104 = 0$

C105 = FREE| C106 = FREE| C107 = FREE| C108 = FREE| C109 = FREE|
C110 = FREE| C111 = FREE| C112 = FREE| C113 = FREE| C114 = FREE|
C115 = FREE| C116 = FREE| C117 = FREE| C118 = FREE| C119 = FREE|

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