# Optimizing Resource Allocation for Greenhouse Potted Plant Production

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## Abstract

A procedure for studying the profitability of greenhouse potted plant production systems subject to resource constraints was developed. The constrained condition and resources were the crop production schedule, greenhouse space, labor, and budget. A database containing the information for determining the required resources and operating costs for growing various crops was established. The database also provides the estimated revenue from sales of the crops, on a per pot basis. An algorithm was developed to determine first the feasibility of a given production plan and then determine the quantities of crops to be grown in order to yield an optimum profit. The result of this algorithm may serve to optimize allocation of resources for year-round production. The algorithm along with the crop database was incorporated into a user-friendly micro-computer program.

**Keywords.** Optimization, Resource allocation, Greenhouse, Production planning.

## Introduction

A greenhouse system is an integration of components, such as controlled environment, crops, equipment, material supplies, and workers, which requires coordination to achieve successful plant production. Greenhouse systems must yield a much higher production per unit area as compared to the field operations, since a higher investment is needed. In order to have high productivity, all the components must be managed effectively.

Production planning is an important greenhouse management process which determines a year-round production schedule. Bio-economic models for planning the greenhouse production process were developed by Lentz (1987) and by Håkansson (1987). Both models require specialized crop growth models of which few have been successfully proven. Another model considering both production planning and production control was developed by Buchwald (1987). This model was based on the functions for plant growth energy input, labor and materials. Only a few of these functions are available, thus limiting the adaptability of the Buchwald's model.

In the process of preparing a year-round plan for greenhouse production, the objective function and the constraints must be quantified. However, for systems as dynamic as greenhouse production, the algorithm must be developed with considerable flexibility. For greenhouse production, a reasonable objective function is maximizing the profit from the sale of the products; the constraints are the production schedule of the crop(s) and the available production space, labor, and budget.

The type of crops grown in a greenhouse may be diverse and may change from year to year. The crop selection significantly influences the required cultural practice and affects the required space, labor, and budget. The technology level applied and the experience of the grower also affect the risk and the efficiency of the production. Due to the degree of diversity involved, the development of a crop database to store all the necessary information is considered more adaptable than the development of growth models or functions for crops. Therefore, in developing the optimization strategy, a crop database was built and was separated from the module program which seeks optimum solutions. The modular approach in organizing the crop database and the optimization mechanism allows a large variety of cases to be investigated without the need of altering the software. Furthermore, the crop database can be easily modified and/or appended when new information becomes available. The optimization software developed has a user-friendly, menu-driven front-end. The compiled version of the software allows the users to run the programs without the need for having other software packages.

### Objectives

The objectives of this study were to:

1. Develop an optimization algorithm and link it with a crop database to provide the decision support system for a year-round greenhouse crop production planning.
2. Develop a user-friendly, menu-driven micro-computer program to facilitate the use of the algorithm and the crop database.

## The Optimization Scheme

### Crop Module Program and Database

The crop database provides information, for various crops; material and energy costs in production, space and labor requirements at different stages, and predicted revenue. Information for the database was from catalogs, literature and marketing research results in the Netherlands (Kwantitatieve informatie voor de glastuinbouw, 1988).

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The database initially contained 34 types of potted plants. Information on cultural practices, and production costs such as fuel, container, media, cuttings, etc., were all included for each crop. With the inclusion of the predicted market prices, the database contained the information necessary for calculating the gross margin, excluding the labor costs, for each of the crops. In order to ease the database management task and to facilitate the software communication with other computer programs, such as the optimization program, a crop module program was developed. This module program performs the following tasks:

1. Allows the user to access (add, delete, edit, view, search) the crop-related databases.
2. Calculates the space, time, and labor requirement at each stage for each crop and performs the gross margin calculations.
3. Prepares data files containing production schedules for future use within the optimization routines.

Figures 1 through 4 show the example contents of the database. There are three pages for each crop record. The first line of figure 1-a shows the current page number and record number. It also indicates that there are a total of 34 crop records in the database and page 1 of crop 1 is currently displayed. Note that the information in this database is all on a per 1000 delivered plants (pots) basis as shown on the second line of figure 1-a. The two lines at the bottom of this figure show a list of commands to be selected by the user for manipulating the contents of the database.

The 'potting period' and 'sale period' categories are both 'year-round'. This means that the crop can be potted and sold any season (week) of the year. However, some other crops, because of environmental, biological or social factors, need to be potted and sold in some particular seasons, in which case the input under these categories should be the week number (1-52).

Figure 1-b shows page 2 of crop 1 . It contains 13 different operating costs for producing this particular crop. There are two columns under the 'AMOUNT' heading. The column on the right lists the values calculated by multiplying the values in the 'QUANTITY' and 'PRICE' columns, while the values in the column on the left are directly entered by the users. The 'TOTAL OPERATING COST' is the sum of all the values under the column 'AMOUNT'. Also shown in this figure are the return and the balance for producing this crop. The return is obtained by the subtracting the total operating cost from the revenue (shown in fig. 1-a). The balance is the ratio between the return and the parameter "week-m$^2$", which gives an indication of the production time and greenhouse space requirements for growing the crop. The term "balance" and "gross margin" are used interchangeably in this database. As noted in figure 1-a, the balance contained in this database does not include the effect of labor cost. Therefore, it can be used only for preliminary estimation of the crop profitability. The operating labor cost is considered during the optimization process.

In figure 1-c, the values in the first four columns are to be entered by the user. The fifth column is generated by dividing the values in column 3 by the values in column 4, and the sixth column is the product of the values in columns 2 and 5.

Figure 2 shows a summary of the crop database for easy viewing of the overall contents. The selection of interested crops to be considered in a year-round production plan is possible by marking them with a toggle switch "T". The labor requirements may also be viewed/edited by entering the letter "G" followed by a crop number and a desired week number. For instance, figure 3 shows crop number 28 is the selected crop and the desired week number is week 2 out of 17 weeks of crop turnover period. Basically, for each crop, this database gives the weekly accounts of production area and labor time requirements. Multiple-page displays are used for the crops requiring a turnover period longer

```
page 1/3   current Record number:   1/  34

BALANCE ESTIMATE  : per 1000 delivered plants (excl. LABOR COST)

CROP  :  AECHMEA FASCITATA (URN PLANT)
POTTING PERIOD  :  YEARROUND
SALE    PERIOD  :  YEARROUND

          POTS          PRICE              REVENUE
          ------        -------            --------
          1000          3.375              3375.00




TOTAL (A)  :                               3375.00

   B)ACK, N)EXT, D)elete, E)dit, P)rint, S)earch, ?) HELP
   Q)uit, L)AST, F)IRST, J)UMP or <RETURN> to next PAGE
```

(a) Page 1, crop record 1.

```
AECHMEA FASCITATA (URN PLANT)   : page 2/3 of Record    1/  34

RELATED COSTS---------------- QUANTITY----------PRICE  (/UNIT)------AMOUNT------
Plants                        1060              0.11                      116.60
Fuel (gas)                    4838    M3        0.11     / M3             532.18
Fertilization+Pl. protection                                              532.18
Sterilization (gas)
  9 / 14  cm  ES Container    1060    / 1030    0.025    / 0.095          124.35
Potting soil                  1.492   M3        47.5     / M3              70.87
Lighting (electricity costs)
Other materials                                                  1.87
Work done by others
Transport + rental                                               97.87
Packaging materials           1000              0.0625                      62.50
Levy + auction costs  6 %                                        202.50
Rate circulating capital                                         33.75
--------------------------------------------------------------------------------
TOTAL OPERATING COST, LABOR EXCLUDED (B) :                     1774.67
RETURN per 1000 delivered plants (A-B) :                       1600.33
BALANCE per WEEK-M2 at 100 % utilization (=net M2) :              0.45

      B)ACK, N)EXT, E)dit, P)rint, ?) HELP
      Q)uit, L)AST, F)IRST, J)UMP or <RETURN> to next PAGE
```

(b) Page 2, crop record 1.

```
AECHMEA FASCITATA (URN PLANT)   : page 3/3 of Record    1/  34

CROP STAGE-----------WEEKS/STAGE---PLANTS---PLANTS/NET M2-AREA (M2)--WEEK M2----

1. Potting-Repotting     13        1060       110         9.64         125.32
2. Repotting-Spacing1    20        1030       40          25.75        515.00
3. Spacing1-Spacing2     20        1020       25          40.80        816.00
4. Spacing2-Delivery     25        1010       12          84.17        2104.25
5.

TOTAL                                                                  3560.57

Misc. :   total loss  :  6 %
          3 % in stage 1
          1 % in stage 2
          1 % in stage 3
          1 % in stage 4

      B)ACK, N)EXT, E)dit, P)rint, ?) HELP
      Q)uit, L)AST, F)IRST, J)UMP or <RETURN> to next PAGE
```

(c) Page 3, crop record 1.

**Figure 1–An example of the contents of the crop database.**

This cultural efficiency was appropriately incorporated in the calculations (See fig. 1-c, column 3 - "PLANTS" and contents under "Misc."). The material supplies necessary for plant production were assumed as always available, as long as there was sufficient budget to cover the costs. The crop database contains the information which can be used to calculate the resource requirements for selected crops.

There exists a desirable space requirement for a particular potted plant during a given growing stage. At any given time, the total space required for all the crops being grown may not exceed the total available production area. This space constraint was imposed by checking the weekly space requirement against the available production area. The algorithm did not require detailed cash flow information; however, the user was allowed to set an overall limit on the available operating budget for the yearly material, energy and labor costs. This budget constraint allowed the user to investigate the effect of working capital on the scale of the greenhouse production.

The labor constraint is closely related to two factors: 1) the time required to complete the various cultural practices, and 2) the available work force. Similar to the space requirement, the labor requirement was based on a weekly time period. For the purpose of calculating the required number and salary cost of the work force, the following assumptions were made:

1. A regular employee will be able to work for a pre-determined number of regular working hours (RWH, 40 hours for instance) plus a fixed number of overtime working hours (OWH, 26 hours for instance) per week.
2. Every regular employee is paid a minimum of RWH worth of his/her time per week.
3. If the labor constraint is not imposed, the work force must be expanded by adding temporary employees, should the weekly operation require more time than the total time (RWH + OWH) that the regular employees can provide.
4. The hourly costs for paying regular, overtime and temporary working hours may be different.

The formula for calculating the annual labor cost for a given production plan is as follows:

$$LC = WAGE_r \, RWH \sum_{j=1}^{52} n(j) + WAGE_o \, WF_o + WAGE_t \, WF_t \qquad (2)$$

where

- $LC$ = annual labor cost, $,
- $n(j)$ = the number of regular workers in week j,
- $WAGE_r$ = cost of regular working hours, $/h,
- $WAGE_o$ = cost of overtime working hours, $/h,
- $WAGE_t$ = cost of temporary working hours, $/h,
- $WF_o$ = required overtime working hours for an entire year, h,
- $WF_t$ = required temporary working hours for an entire year, h.

### Solving the Optimization Problems

The knowledge for solving optimization problems has been well developed. Some commercial packages, such as micro-computer based LINDO (Schrage, 1986) and mainframe based MPSX (IBM Corp., 1979), are available for solving the linear programming (LP) and integer linear programming (ILP) problems. However, computer codes were developed to solve LP and ILP problems in this study, so that the resulting software could be used independently.

An ILP problem normally involves significantly more calculations to reach a solution as compared to a similar sized LP problem. There is a possibility that an ILP problem may not be solved in a reasonable time. The cutting planes method was applied as the primary method for solving ILP problems (Gomory, 1958). To avoid excessive computer run time, a maximum allowable number of cutting planes was assigned. If no solution is found within the limit, the program will stop the calculation and suggest the user to apply an enumerative method. Using this algorithm, the program will solve the ILP model as an LP model first, then search within the user assigned range for each unknown parameter based on the non-integer optimum solution. Since there are a finite number of possible solutions within the range, the optimum solution will be obtained in a reasonable time. However, the solution may be only a local optimum. Other ranges may be tried to approach a global optimum.

## Results and Discussion

Figure 5 shows the organization chart of the crop database and the module program. This crop module program was written in dBASE III Plus (Ashton-Tate, Inc.,

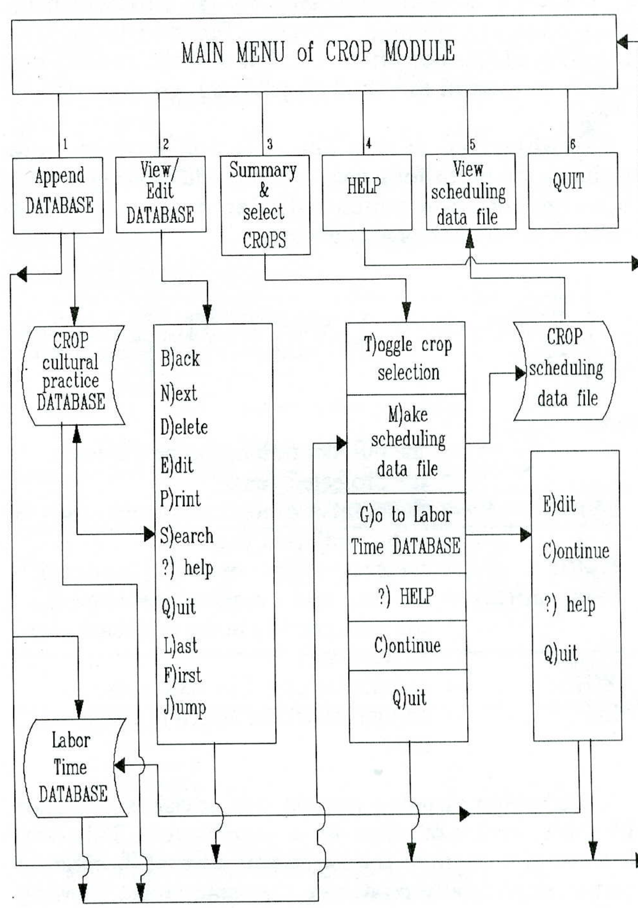


**Figure 5–The organization chart of the crop module program.**

| mark No. | CROP NAME | POT.-SALE PERIOD (WEEKS) | TURN-OVER (WEEKS) | BALANCE per Week-m2 |
|---|---|---|---|---|
| 27 | POINSETTIA | WEEK 33 - WEEK 51 | 19 | 0.63 |
| 28 @ | POINSETTIA | WEEK 34 - WEEK 50 | 17 | 1.28 |
| 29 | SAINTPAULIA (african | YEAR ROUND | 12 | 0.86 |
| 30 @ | SCHEFFLERA 'COMPACTA' | YEAR ROUND | 18 | 0.75 |
| 31 | SCINDAPSUS PICTUS 'ARG | YEAR ROUND | 24 | 0.70 |
| 32 | SPATHIPHILUM (white s | YEAR ROUND | 46 | 0.51 |
| 33 | VRIESEA SPLENDENS (fl | YEAR ROUND | 68 | 0.55 |
| 34 | YUCCA 45 CM STEM (yucc | YEAR ROUND | 25 | 2.00 |

SUMMARY OF CROPS' CULTURAL PRACTICE DATABASE

<T>oggle the selected crop, <M>ake scheduling data file
<G>o to labor time database, <?>help, <C>ontinue <Q>uit

**Figure 2–A display showing the summary of the crop database.**

View/Edit RELATED LABOR TIME in CULTURAL PRACTICE

CROP NAME : POINSETTIA — 17 weeks
No of PLANTs REQUIRED :1026 — OPERATING COST <$/1000 pots> : 1846.61
RETURN <$/1000 pots> :1453.39 — GROSS MARGINS <$/WEEK-M2> : 1.28

| WEEK.no | CROP.STAGE | AREA,m2 | LABOR TIME,hrs | LABOR TYPE |
|---|---|---|---|---|
| 001 | Potting-Spacing 1 | 26.24 | 2.72 | 14 28 |
| 002 | Potting-Spacing 1 | 26.24 | [illegible] | 25 |
| 003 | Potting-Spacing 1 | 26.24 | 1.56 | 25 21 12 |
| 004 | Potting-Spacing 1 | 26.24 | 0.46 | 25 21 |
| 005 | Potting-Spacing 1 | 26.24 | 0.46 | 25 21 |
| 006 | Spacing-Delivery | 84.03 | 2.25 | 25 21 20 |
| 007 | Spacing-Delivery | 84.03 | 0.96 | 25 21 29 |
| 008 | Spacing-Delivery | 84.03 | 0.96 | 25 21 29 |
| 009 | Spacing-Delivery | 84.03 | 0.86 | 25 |
| 010 | Spacing-Delivery | 84.03 | 0.36 | 25 21 |
| 011 | Spacing-Delivery | 84.03 | 0.66 | 25 |

INPUT: <E>dit labor time data and related labor CODE,
Select which week <0 to exit EDIT mode> ? 2

**Figure 3–A display of the crop labor requirement.**

than 11 weeks. The entries in the column labeled "LABOR TYPE" are the codes representing the cultural tasks to be performed. A list of the labor type codes and their corresponding cultural tasks is shown in figure 4.

## Optimization Module Program

The major functions of this program were: 1) to perform a case study, i.e., to determine the feasibility of a proposed production plan; and 2) to solve optimization problems, i.e., to determine the quantity of crops to be produced in order to maximize profit. The plan's feasibility was evaluated by testing whether the proposed conditions satisfied the imposed constraints. The optimization algorithm was developed to seek out the workable plan, which gave the optimum objective function value. The definition of the objective function and the constrained conditions used in this module program are presented as follows:

The objective of this optimization process is to maximize the profit for a year-round production cycle. The objective function which calculated the profit of a workable production plan is given as:

$$\left\{ \sum_{i=1}^{n} X(i) \left[ GM(i) \sum_{j=1}^{k(i)} Week\_m^2 (i,j) \right] \right\} - LC \quad (1)$$

where

n = the number of crops to be grown in the projected year,
k(i) = the number of replications for crop i in the projected year,
GM(i) = the gross margin of crop i, \$/week-m$^2$,
Week_m$^2$(i,j) = the time-space required for crop i in the time period j in the projected year in week-m$^2$,
X(i) = quantity of crop i in 1000 pots,
LC = annual labor cost which is discussed later.

A production planning process was envisioned to start with the selection of crops for a yearly cycle. This crop selection process may follow one of several production patterns: sequentially producing the same crops; growing several crops simultaneously; rotating crops on a year-round basis; or a combination of the above. After the timing and types of crops to be grown in a given year are known, the next task is to determine the quantity of each crop to be produced. Two possible approaches may be taken to determine crop quantity. One is to set the crop quantities based on the greenhouse manager's own judgment. Another way is to reach a solution by solving a constrained optimization problem. Each requires that resource limitations be taken into consideration. The micro-computer software developed in this study may be used as a decision support system in both cases.

The following major categories of resources for greenhouse potted plant production were considered for planning purposes:

1. The space requirement for the crops on a weekly basis,
2. The labor requirement for the crops on a weekly basis,
3. The available budget to cover operating costs on a yearly basis,
4. The projected plant survival rate at different crop stages,
5. The availability of supplies for plant production.

In this study, the plant survival rate was considered as the cultural efficiency of production, which was dependent on the cultural system and the experience of the operator.

related labor CODE in GREENHOUSE operation

| | |
|---|---|
| 01 : Cleaning | 16 : Relocation |
| 02 : Cultivate soil | 17 : Repotting |
| 03 : Disbudding | 18 : Stake and tie |
| 04 : Dusting | 19 : Seeding |
| 05 : Fertilization | 20 : Spacing |
| 06 : Fumigating | 21 : Spraying |
| 07 : Grafting | 22 : Sterlizing |
| 08 : Grading | 23 : Transplanting |
| 09 : Harvesting | 24 : Transport |
| 10 : Mixing soil | 25 : Water and syringe |
| 11 : Multch | 26 : Weeding |
| 12 : Pinching | 27 : MISC. |
| 13 : Pruning | |
| 14 : Potting | |
| 15 : Propagation | |

From W.W. Grimmer, 1975 and G.A. Giacomelli, 1987

Press any key to continue...

**Figure 4–A list of the labor-type codes and their descriptions.**

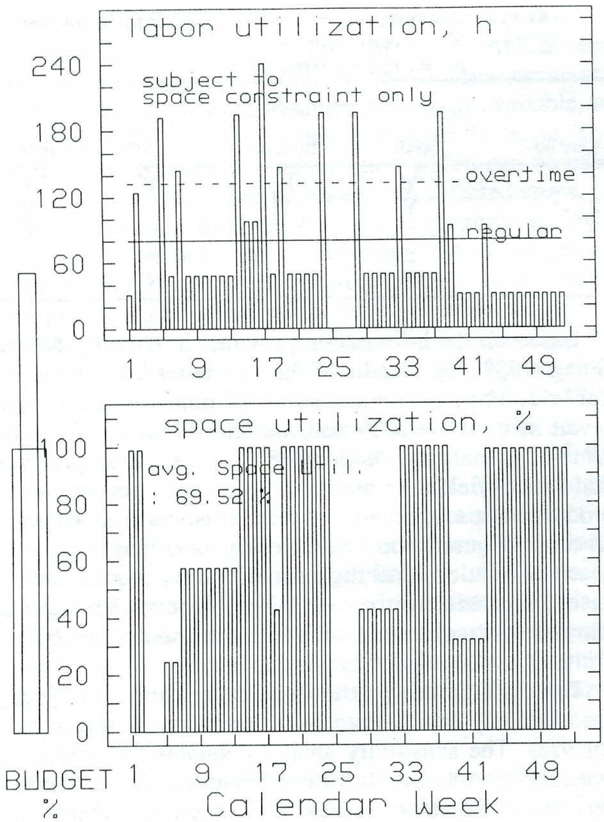


**Figure 7–The year-round weekly resource utilization for case 5 (Table 1) which is subject only to a space constraint.**

prepares data files to be used by the optimization module program. The optimization program solves the optimization problems, covering a wide range of constrained conditions. The objective of the optimization is to maximize the annual profit of a production plan. The constrained resources are the production space, the labor, and the operating budget. The optimized variables are the quantities of the crops to be grown for a one-year cycle. The modular organization of the crop database and the optimization program provides the system flexibility for future modification and expansion of crop information. It can become a valuable tool for greenhouse managers to aid their ever challenging task of production planning. It is especially useful for the managers when performing relative comparisons among alternatives. The accuracy of the program output may be improved by updating the crop database with more reliable information obtained in the future research.

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1986) programming language and compiled by using CLIPPER (Nantucket Corp., 1987).

The organization chart of the optimization module program is shown in figure 6. This program was written and compiled using QuickBASIC (Microsoft Corp., 1987). If the case study option is selected, the program evaluates the user's production plan for its feasibility. When the optimization scheme is employed, the outcome of this program is the number of pots to be produced for each of the selected crops. Specifically, the results of the program include:

1. The feasibility of a given crop production schedule,
2. The number of potted plants to be produced for each selected crop,
3. The initial number of cuttings or seedlings required for each crop,
4. Weekly and annual space utilization,
5. Weekly labor requirement and annual labor cost,
6. Annual budget requirement,
7. Annual profit.

The following example will demonstrate the utility of this optimization program. Five crops (with their time period for production) are selected to be grown for a one-year production cycle in a 0.4 ha (1 acre) greenhouse. They are: (1) hybrid rhododendron, weeks 1-5; (2) chrysanthemum, weeks 5-17; (3) rieger begonia, weeks 14-24; (4) rieger begonia, weeks 28-38; and (5) rieger begonia, weeks 01-02 (crop started in the previous year) and 39-52 (crop finished in the following year). In addition to the space constraint, different combinations of labor and budget constraints are imposed to establish the five different cases listed in Table 1.

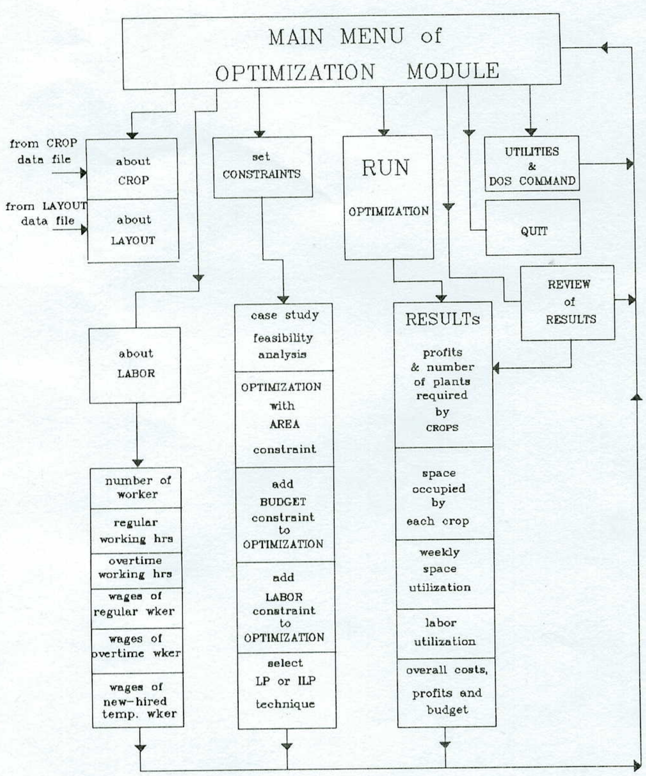


**Figure 6–The organization chart of the optimization module program.**

**TABLE 1. The constrained conditions for five different cases**
**Y = constrained**
**N = non-constrained**

| Case no. | Space | Budget | Labor: Overtime | Labor: Temporary |
|---|---|---|---|---|
| 1 | Y | N | Y | Y |
| 2 | Y | Y | N | Y |
| 3 | Y | Y | N | N |
| 4 | Y | N | N | Y |
| 5 | Y | N | N | N |

Based on the information provided in the crop database (Fang, 1989), the results of the five cases are presented in Table 2. The optimum number of pots for each crop is given in units of 1000 and the annual profit is given in $/m^2$ of greenhouse production area. This example shows that case 5 yields the highest annual profit per unit area of production space, because it is the least constrained among all cases. Figure 7 shows the weekly situations of labor and space utilization, and the annual budget requirement for case 5. In this figure, the labor force and budget are allowed to exceed the limit while the space availability is limited.

The parameters in the constraints and/or objective function may be changed in order to perform sensitivity analyses. The sensitivity analysis enables the greenhouse manager to study the shift of optimum conditions based on changes of parameter values. The parameter values which can be changed include: the size of the production area, the amount of budget, the status of work force, the number of workers in different periods of the year, and also any items related to the change of the gross margin of a selected crop.

## Summary and Conclusions

Micro-computer software was developed to provide greenhouse managers a decision support system for resource allocation. The software consists of a crop database, a crop module program, and an optimization module program. The crop database contains the information necessary to calculate crop-specific parameters to be used in the objective function and the constraints. The crop module program manipulates the crop database and

**TABLE 2. The optimum number of potted plants (in 1000 pots) to be produced and the annual profit (in $/m$^2$) for five different cases**

| Crop no.* | Case 1 | Case 2 | Case 3 | Case 4 | Case 5 |
|---|---|---|---|---|---|
| 1 | 28 | 0 | 0 | 0 | 0 |
| 2 | 40 | 66 | 98 | 66 | 98 |
| 3 | 40 | 42 | 11 | 66 | 98 |
| 4 | 33 | 62 | 62 | 62 | 62 |
| 5 | 12 | 1 | 0 | 49 | 96 |
| Profit | 10.93 | 15.09 | 15.47 | 17.73 | 23.19 |

* The name and duration time for each crop are as follows:
(1) Hybrid rhododendron, weeks 1-5,
(2) Chrysanthemum, weeks 5-17,
(3) Rieger begonia, weeks 14-24,
(4) Rieger begonia, weeks 28-38, and
(5) Rieger begonia, weeks 01-02 (crop started in the previous year) and 39-52 (crop finished in the following year).