Engineering Economy of Controlled Environment for Greenhouse Production

K. C. Ting, J. Dijkstra, W. Fang, M. Giniger
MEMBER ASAE, ASSOC. MEMBER ASAE, ASSOC. MEMBER ASAE

ABSTRACT

User-friendly, menu-driven, screen-editing microcomputer software was developed to evaluate the economic feasibility of a greenhouse operation employing the single truss tomato cropping system. A variety of scenarios were investigated to determine the cost-effectiveness of supplemental lighting. The software, written in BASIC, has a generic greenhouse engineering economic analysis algorithm plus a number of supporting subprograms for calculations of costs and revenues associated with specific design/operation conditions.

INTRODUCTION

Greenhouse production requires a higher investment per unit area than does traditional open-field agricultural production systems. However, the revenues generated as a result of the additional costs are expected to be higher. A method is needed to analyze the potential return on investment in order to justify the undertaking of a new project. The project may be a proposed new venture or an addition to an existing operation. The expenses and revenues of an operation will occur at different times during its lifetime. Engineering economy is a field of study, which provides an algorithm for adding cash amounts occurring at different times (Fleischer, 1984).

Many factors need to be considered in analyzing the economical viability of an investment. Although the principles are relatively simple, the calculations are complex and time consuming. A user-friendly, menu-driven economic analysis computer program is an extremely helpful managerial decision-making tool. Furthermore, it is even more convenient if the software is specific to greenhouse applications and can be executed on most computers with minimum requirements of additional supporting hardware and software.

One major purpose of investment in commercial greenhouses is to incorporate state-of-the-art technologies into a plant production system within a controlled environment. The return on investment is heavily dependent on the revenues resulting from the input of costs. The effect of supplemental lighting on the plant growth within a greenhouse is a good example (McAvoy and Janes, 1984). In this case, the cost of supplemental lighting is the input factor and the increased plant production is the corresponding output. Pena (1985) conducted an economic study on greenhouse vegetable production, with the focus on tomatoes. His analysis was based on the data collected from an intensive survey of over 60 growers in the United States. A 9.1 m x 29.3 m greenhouse was the base unit. He indicated that the economic competitiveness of each situation needed to be evaluated separately. He also recommended that a manager should maintain an awareness of economic advantages of new technologies.

The potential uses of engineering economic analysis applied to greenhouse operations, especially in the forms of a user-friendly software, can be listed as follows:

- Conduct case studies of an existing or proposed projects.
- Perform sensitivity analyses for alternative design/operations.
- Conduct parametric studies to cover ranges of input variables.
- Facilitate investment risk analyses.
- Incorporate the economic analysis program with other technical models, such as crop production, controlled environment, greenhouse automation/mechanization, etc.
- Provide a means of evaluating quantitative values of an objective function in a systems optimization process.

A greenhouse tomato production system which "can be managed to produce continuous yield on a predictable schedule throughout the year" has been under development at Cook College, Rutgers University (McAvoy and Giacomelli, 1985). The system employs a single truss tomato cropping scheme assisted by supplemental lighting. The economic feasibility of this production system was investigated using the software developed in this study.

Objectives

The objectives of this study were:

1. To develop a generic computer program for greenhouse engineering economic analysis.
2. To incorporate the program with other technical computer models into a software package which has an option of conducting economic analysis for specific types of greenhouse design and operations.
3. To perform engineering economic analysis on a greenhouse operation which employs the single truss tomato cropping system.

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The authors are: K. C. TING, Assistant Professor, J. DIJKSTRA, Visiting Scholar, W. FANG, Graduate Assistant and M. GINIGER, Research Associate, Biological and Agricultural Engineering Dept., New Jersey Agricultural Experiment Station, Rutgers University-Cook College, New Brunswick, NJ.

ENGINEERING ECONOMY

The worth of money is two dimensional: the dollar amount, and the occurring time. The time value is most affected by interest rates and inflation rates. Therefore, to compare the worth of amounts of money occurring at different times, the following conversions have to be made to standardize all amounts on a common time base:

$$W_p = W_f / (1+i)^n \quad \ldots\ldots\ldots\ldots\ldots\ldots [1]$$

$$A = W_p \, [i\,(1+i)^n / \{(1+i)^n - 1\}] \quad \ldots\ldots\ldots\ldots [2]$$

where

W_p = present worth (at time zero)

W_f = future worth at the time n periods after W_p

i = inflation rate or rate of return on investment per period (eq. [1]), or interest rate of a loan per period (eq. [2])

A = regular payment for a loan of W_p

n = number of periods between the times of occurrence of W_p and W_f (equation [1]), or number of payments (equation [2]).

Table 1 lists the costs and revenues considered in this study. Note that the initial cost is the investment of a project, and the direction "+" stands for income, and "−" for expense. All the items can be further divided into more detailed listings. Also shown in Table 1 are the concepts of Capital Basis and Equity Basis. The difference is how their initial costs (i.e. investments) and subsequent items are calculated. The initial cost for Equity Basis is the initial cost for Capital Basis less the bank loan. Consequently, the bank loan payments are considered as operating costs only in the Equity Basis analysis.

Two indices of a given investment are of special interest in this type of analysis. They are the expected return on investment (ROI) and its corresponding cumulative present worth equivalence (CPW). Their relationship, after N years of operation, is given by

$$CPW = -\text{(initial cost)} + \sum_{j=1}^{N} [(\text{return of year } j)/(1+ROI)^j] \quad \ldots\ldots\ldots [3]$$

where "return" is equal to "annual income" - "annual expense" and ROI is in decimal form.

In equation [3], CPW represents the overall cumulative present worth of an investment for a given ROI, when N is equal to the lifetime of the project. Obviously, when ROI changes, CPW will change accordingly. And, the ROI which makes overall CPW equal to zero is the lifetime overall return on investment.

Another important index is the break-even period of an investment for an expected ROI. The break-even period indicates the required number of years of operation in order to achieve a desired level of ROI. Therefore, the break-even period may be calculated, for a given ROI, using equation [3] by setting CPW equal to zero and solving for N.

TABLE 1. Timing and Direction of Relevant Revenues and Costs for Engineering Economic Analysis on Capital Basis and Equity Basis

		Direction*	
Item	Occurring Time	Capital Basis	Equity Basis
Initial cost	Time 0	−	−
Revenue	End of each year	+	+
Operating cost	End of each year	−	−
Loan payment	End of each year		−
Replacement cost	End of equipment life	−	−
Salvage value	End of equipment life	+	+
Income tax†	End of each year	− or 0	− or 0

*Direction: "+" = income; "−" = expense.

†Income tax = (Tax rate) x (Taxable income)
where, Taxable income = (Revenue − Operating cost − Interest on loan‡ - Depreciation)
and, Taxable income = 0 if it has a negative value.

‡Interest on loan is only applicable to equity basis analysis.

SINGLE TRUSS TOMATO CROPPING SYSTEM

Cropping System

Giniger et al. (1988) presented a supplemental lighting assisted greenhouse tomato growing system which had the potential for year round continuous production. The high density single truss plants grown on transportable benches facilitated sequential planting of crop blocks and their potential automation/mechanization. They developed a production model, based on their experimental results, for crop scheduling and yield prediction. The independent variable in their model was the available photosynthetically active radiation (PAR).

Some utility companies are offering demonstration grants and lower rates to growers who use supplemental lights (Brumfield and Ford, 1987). Therefore, it is important to know the economic benefit of supplemental lighting in greenhouse production. The model by Giniger et al. makes it possible to study the economic effects of supplemental lighting on greenhouse operations which employ the single truss tomato cropping system.

Economic Analysis

In this study, a 4047 m^2 (1 acre) air-inflated double polyethylene greenhouse located in New Brunswick, New Jersey was used as a base module. The base line information on the bank loan, initial costs, and operating costs was presented in detail by Ting et al. (1987). The operating cost for supplemental lighting and the corresponding monthly revenues were calculated using the model by Giniger et al. along with the combinations of the values listed in Table 2. The reference harvest date refers to the expected day fruit harvest will be completed for the first crop block. The remaining harvest dates are then equally spaced throughout the year according to the number of crops grown per year. Note that more than one crop may be grown at different stages at the same time in a greenhouse.

RESULTS AND DISCUSSION

Application Software

Figure 1 shows the structure of the greenhouse engineering economic analysis software, namely

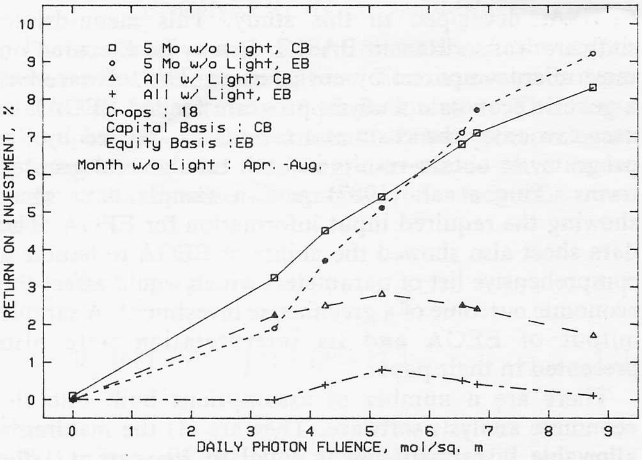


Fig. 3—Capital basis and equity basis ROI's vs. supplemental daily photon fluence. (Reference harvest date=10/1; electricity rate= \$0.075 kWh^{-1}; tomato market price index=1.0).

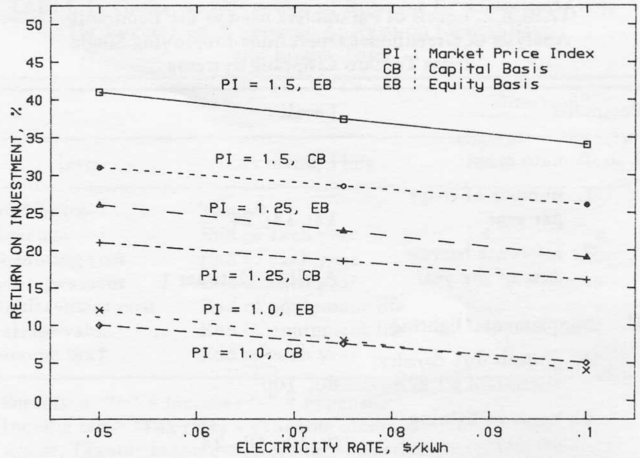


Fig. 5—ROI vs. electricity rate for different tomato market price indices. (Reference harvest date=10/1; number of crops=18; supplemental daily photon fluence=8.64 mol m^{-2}).

parameter numbers 3 through 7 were varied. A total of 159 cases were studied. The results presented in the following section are all based on the October 1 reference harvest date.

Figure 2 shows the overall ROI on capital basis versus the daily photon fluence added by supplemental lights. The daily photon fluence was calculated based on the photon flux density of the supplemental lighting and the number of hours of lighting per day. The other parameters used were 7 months of lighting per year, \$0.10 kWh^{-1} electricity rate and 1.0 tomato market price index as indicated in the footnote of Table 2. Within the range studied, the ROI was found to increase with an increase in the usage of supplemental lighting. The eighteen crops per year production scheme appeared to be superior to the other two schemes.

Figure 3 shows, quantitatively, that it is not economical to have the supplemental lights on for the entire year. In obtaining the result shown in Fig. 3, an electricity rate of \$0.075 kWh^{-1} and a tomato market price index of 1.0 were used. Also shown in Fig. 3 is the existence of a critical Capital Basis ROI, above which it is better to have a bank loan (i.e. Equity Basis ROI is higher than Capital Basis ROI). This critical ROI is depending on several factors such as interest rate on the loan, income tax rate, etc. In this case, it has a value of 6.3%.

By combining the effects of Figs. 2 and 3, increasing the tomato market price index to 1.5 (i.e. multiply the base price by 1.5), and showing investment only on Capital Basis, Fig. 4 was created. The electricity rate used is \$0.10 kWh^{-1}. The increase of tomato market price has a significant effect on ROI's. This effect can be realized by comparing the highest ROI in Fig. 2 with the highest ROI in Fig. 4. By changing the price index from 1.0 to 1.5 and keeping everything else the same, the ROI increased from 5.1% to 27.5%.

Figure 5 emphasizes relative effects between the tomato market price index and electricity rate on ROI for both capital basis and equity basis. The number of crops per year is 18 and the daily photon fluence is 8.64 mol m^{-2}. Based on this result, a 25% increase in tomato market price will at least double the ROI.

Based on the concept of break-even as defined above, the number of years of operation to reach break-even in relation to the expected rate of return on investment is shown in Fig. 6. This information can be used to estimate the risk involved in making the investment. For

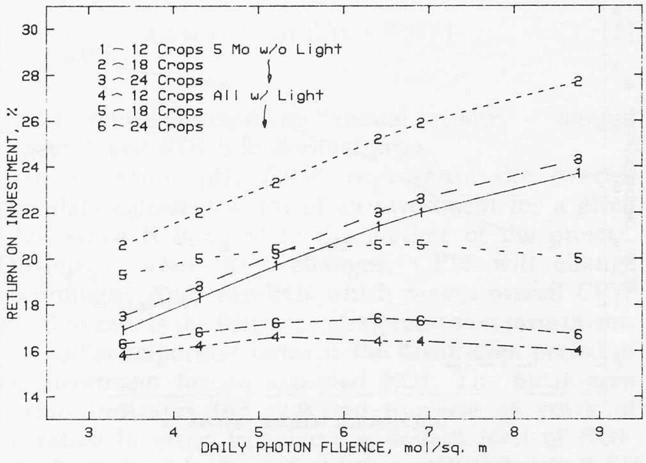


Fig. 4—Capital basis ROI vs. supplemental daily photon fluence. (Electricity rate=\$0.1 kWh^{-1}; tomato market price index=1.5; reference harvest date=10/1).

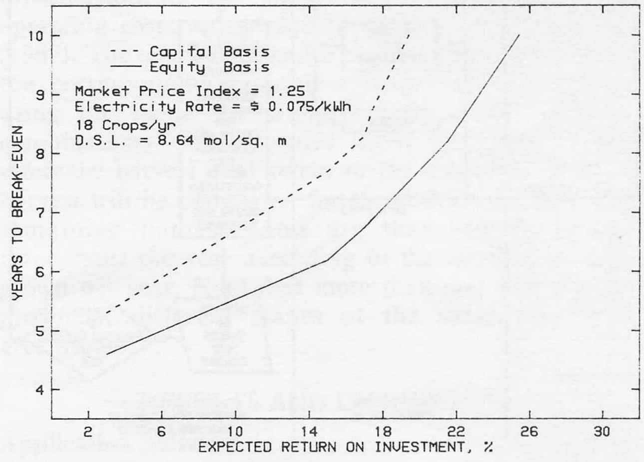
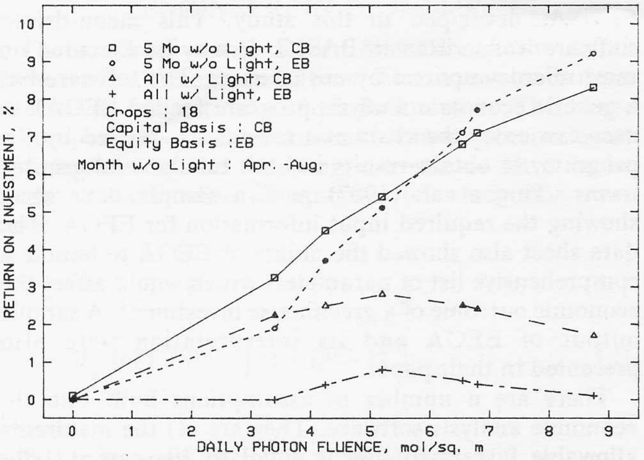


Fig. 6—Number of years to reach break-even in relation to expected rate of return on investment.



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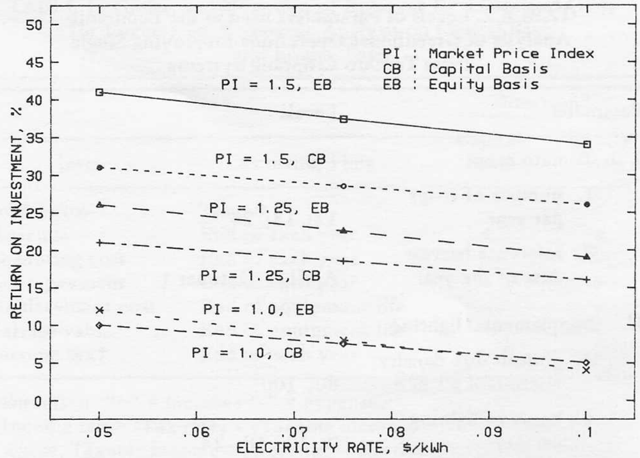

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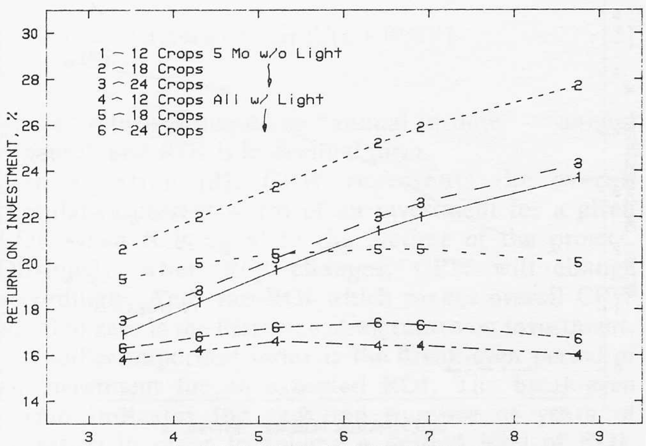

Fig. 4—Capital basis ROI vs. supplemental daily photon fluence. (Electricity rate=$0.1 kWh^{-1}; tomato market price index=1.5; reference harvest date=10/1).

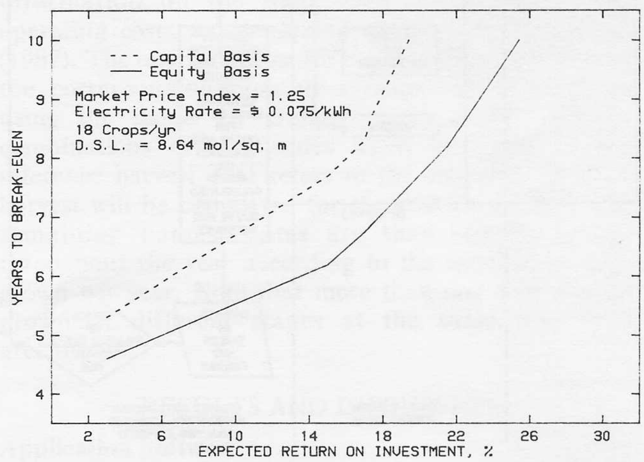

Fig. 6—Number of years to reach break-even in relation to expected rate of return on investment.

TABLE 2. Levels of Parameters used in the Economic Analysis of Greenhouse Operations Employing Single Truss Tomato Cropping Systems

Parameter	Levels
I. Tomato crop	
1. number of crops per year	12; 18; 24
2. reference harvest date of the year	April 1; October 1
II. Supplemental lighting	
3. photon flux density, micro-mol s^{-1} m^{-2}	80; 100
4. hours of lighting per day	0; 12; 18; 24
5. months of lighting per year	0; 7 (September-March); 12
III. Prices	
6. electricity, \$$kWh^{-1}$	0.05; 0.075; 0.10
7. tomato market price index*	1.0; 1.25; 1.5

*Reference prices when market price index equal to 1.0 (Powley, et al., 1987):

month:	Jan	Feb	Mar	Apr	May	Jun
price, \$ kg^{-1}:	2.64	3.08	3.08	3.08	2.64	2.64
month:	Jul	Aug	Sep	Oct	Nov	Dec
price, \$ kg^{-1}:	1.32	1.32	1.32	2.64	2.64	2.64

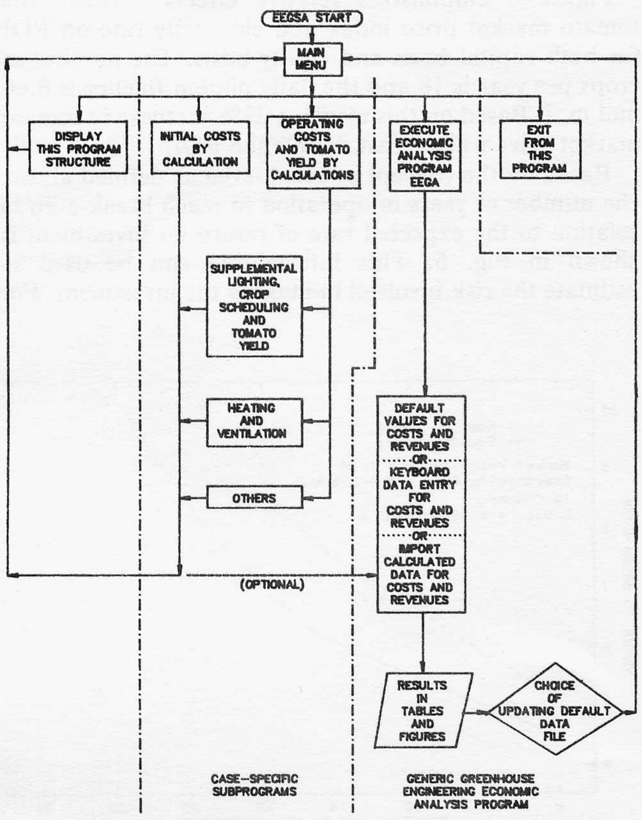

Fig. 1—The structure of the engineering economic analysis software for the greenhouse design/operations.

EEGSA, developed in this study. This menu-driven software was written in BASIC. It may be executed on most microcomputers by novice users. The software has a generic economic analysis program (called EEGA). A user can enter the costs and revenues data, led by the program, to obtain results in both tabular and graphic forms. Ting et al. (1987) gave a sample data sheet showing the required input information for EEGA. The data sheet also showed the ability of EEGA to handle a comprehensive list of parameters which would affect the economic outcome of a greenhouse investment. A sample output of EEGA and its interpretation were also presented in their paper.

There are a number of assumptions built into the economic analysis software. They are (1) the maximum allowable investment life is equal to 20 years, (2) the actual investment life is equal to the service life of the greenhouse super structure, (3) the loan life is less than or equal to the investment life, (4) the number of loan payments per year may only be 1, 2, 3, 4, 6 or 12, (5) zero salvage values are used in depreciation calculations, (6) the number of years of equipment depreciation is less than or equal to its service life which is greater than zero, and (7) a non-zero positive number must be used as the bank loan.

Several case-specific supporting sobprograms are included in EEGSA (Fig. 1). The users have an option to use them in calculating certain costs and revenues. They were written based on published technical information related to the design and operation of certain types of greenhouses. Some examples are the crop and supplemental lighting scheduling, yield prediction and annual sales estimation for greenhouse operations employing single truss tomato cropping systems.

Economic Analysis of Single Truss Tomato Cropping System

A two-stage approach was taken in testing the effects of the combinations of parameter values in Table 2. In the first stage, parameter numbers 1 through 5 were varied. The results showed that only the cases of 18 crops per year with the reference harvest date October 1 needed to be further investigated. Therefore, in stage 2,

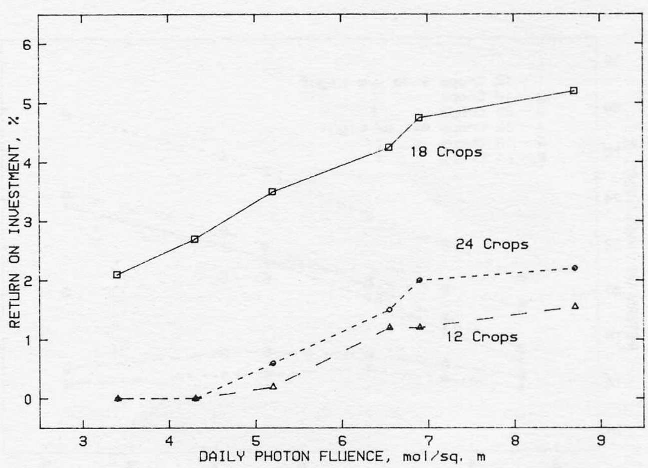

Fig. 2—Overall ROI on capital basis vs. the daily photon fluence added by supplemental lights. (Reference harvest date=10/1; months of lighting per year=7; electricity rate=\$0.1 kWh^{-1}; tomato market price index=1.0).