Risk Analysis of Adopting Zero Runoff Subirrigation Systems in Greenhouse Operations: A Monte Carlo Simulation Approach

Wen-fei L. Uva, Thomas C. Weiler, Robert A. Milligan, Louis D. Albright, and Douglas A. Haith

Zero runoff subirrigation (ZRS) technology can effectively manage fertilizer input while improving greenhouse production efficiency. However, high capital investment costs and inadequate technical information to growers are impediments for adoption. A Monte Carlo simulation was used to compare the profitability and risks of alternative ZRS system investments for greenhouse operations in the northeastern and north central United States. Results showed that the Dutch movable tray system and the flood floor system were most profitable and least risky for small potted plant and bedding crop flat production, respectively. The trough bench system was least favorable because its profitability was low and highly volatile.

Minimizing fertilizer and water requirements for greenhouse crop production has become increasingly important to growers as many are faced with higher water and fertilizer costs, decreasing availability of quality water, and increasing government regulations to protect surface and ground water (Bot 1992; Deneke et al. 1991; Haver and Schuch 1996). Controlling or reducing nitrate nitrogen fertilization is the first priority in protecting water resources and minimizing the environmental impact of leachate from greenhouse production (Biernbaum 1992; Walker 1990). One promising way to avoid fertilizer loss from greenhouse pot and bedding crop production and improve production efficiency is subirrigation with irrigation solution recirculation, also referred to as zero runoff subirrigation (ZRS) (Burnside 1982; Fynn 1994; Horticultural Water Quality Alliance 1992; Weiler 1992). In a subirrigation system, potted plants are grown on the surface of a leak-proof bench or floor. Irrigation solution from an enclosed holding tank is pumped onto the surface and transported up through the growing medium by capillary action. Water that is not absorbed by the media after a few minutes drains back into the tank for recirculation (Fynn 1994). Subirrigation is widely used in the European greenhouse industry. Molitor (1990) and van Os (1986) suggested that the ZRS technology was first introduced in Europe to improve control over operation, production efficiency and product quality, and later to avoid emissions of water, fertilizers and pesticides into the environment. Studies showed that plants produced under subirrigation systems had equal or better growth and quality compared with plants grown with traditional overhead irrigation systems (Blom and Piott 1992; Deneke et al. 1991; Poole and Conover 1992). However, a survey of greenhouse growers in the United States showed that high initial investment costs and lack of cultural and management information for adopting this technology is an impedi-

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ment to change by greenhouse operations (Uva et al. 1998).

Different ZRS systems are available to greenhouse operators, and each has different characteristics best suited to different production objectives (Bauerle 1990; Fynn 1994). Four commonly used ZRS systems in the United States as identified in an industry survey are ebb-and-flow rolling benches, Dutch movable trays, flood floors, and trough benches (Uva et al. 1998). Purvis et al. (1995) and van Os (1986) argued that although a new technology often provides some benefits over a traditional system, the extra investments required in durable inputs are not always offset by the benefits. The changes in the input-output relationships and associated prices will determine profitability. Uva (1999) used a deterministic modeling approach to estimate the costs and returns of using alternative ZRS systems to produce greenhouse pot and bedding crops. It provided an overview of the profitability of alternative investment scenarios. A sensitivity analysis was conducted to reveal impacts of each uncertain variable on the outcomes by varying the value of selected variables by some percentage above and below their point estimate values. However, this approach did not reflect that the uncertain variables have the potential to vary simultaneously and in different directions. Risk and uncertainty are inherent features of most business ventures and need to be understood for rational decision making. Aggarwal (1993) pointed out that, from a financial perspective, the key factors to be considered when making capital investment decisions are a project's profitability as well as risk. The goal of this study was to calculate the combined impact of the production models' various uncertainties and evaluate the investment opportunities and risks when adopting the ZRS technology for greenhouse pot and bedding crop operations in the northeastern and north central United States. A cost risk analysis was designed using a Monte Carlo simulation method to analyze risks associated with possible input and output variations.

The specific objectives of this study were to: 1) model the costs and returns of greenhouse pot and bedding crop production when using ZRS systems; 2) determine the possible outcomes and relative profitability of using four ZRS systems to produce three major greenhouse pot and bedding crops; and 3) compare the riskiness of the investment projects with alternative ZRS systems for different crop categories.

Materials and Methods

Four commonly used ZRS systems as identified in an industry survey were studied: ebb-and-flow rolling benches (EFB), Dutch movable trays (DMT), flood floors (FF), and trough benches (TB) (Uva et al. 1998). Uva (1999) presented that each ZRS system has different input and management requirements when installed in the greenhouse.

Ebb-and-Flow Rolling Benches (EFB)

Plants are placed on leveled benches in the EFB system. These benches are made of watertight aluminum or rigid plastic and supported on pipe rollers. The benches can accommodate all different pot and flat sizes, and each bench can be irrigated separately, giving growers the flexibility to produce versatile crop mixes in the greenhouses. This system allows growers to use 81% to 93% of the greenhouse space for production.

Dutch Movable Trays (DMT)

The DMT system is a mechanized EFB system. Trays are the growing benches and also serve as the container to transport crops between the greenhouse and work area. Therefore, unlike the other three systems, additional shipping carts are not required. Under this system, plants can be moved with little or no labor, and work crews and production machines remain in the work area where all production tasks can be completed. This means more efficient and specialized working conditions. However, the initial investment and the cost for system maintenance and repair are higher because of the highly mechanized setup. As with the EFB system, flexible spacing on the bench tops can accommodate any size pot or flat. The DMT system allows growers to use 81% to 89% of the greenhouse space for production.

Flood Floors (FF)

The irrigation principles behind the FF system are much the same as those for the bench systems. Plants are placed on leveled watertight concrete floors. There are no ground-level aisles, so all the floor space is potentially available for plant production. The open floor allows work crews to move large quantities of crops in and out of the greenhouse quickly. Nonetheless, performing production tasks on the floor can be more intensive for employees because of the bending involved. The initial investment is lower than the bench systems, and little system maintenance and repair is required. The FF system allows growers to use 86% to 94% of the greenhouse space for production.

Trough Benches (TB)

In the TB system, plants are placed in shallow sloped troughs on the top of rolling bench stands, similar to the EFB systems. Water is fed in at the high end and flows to the lower end of the trough into the holding tank and recirculated. The TB systems are less flexible for spacing pots because once the troughs are made, the trough size can't be changed. Also, it cannot accommodate plug and flat trays. The TB system allows growers to use only 72% to 83% of the greenhouse space for production.

A 100 by 200 foot gutter-connected glass greenhouse with concrete foundation was assumed as the base greenhouse facility in the simulation. This size was chosen as the production unit in this study because it was considered by the industry as the basic unit when constructing a modern greenhouse facility (Uva 1999). Using an economic engineering methodology, the state-of-the-art greenhouse facility model was developed to describe the greenhouse pot and bedding crop operations in the northeastern and north central United States. Each ZRS system was modeled in this 20,000 square-foot greenhouse unit and used to produce alternative cropping scenarios when applicable. The three cropping configurations studied and the representative crop for each configuration were: 1) small potted plants (≤5-inch pots)—represented by geraniums grown in 4½-inch standard pots for the Memorial Day market; 2) large potted plants (≥5-inch pots)—represented by poinsettias grown in 6-inch azalea pots for the Christmas market; and 3) bedding crop flats—represented by impatiens marketed in AC 4–12 (or 1204 with 48 cells) flats for the spring market. A total of 11 production models were simulated because the TB system was not suitable for bedding crop flat production.

The production models were simulated with representative characteristics of greenhouse operations observed in the field, proper installation designs for the four ZRS systems, and reasonable production schedules for the representative crops. To establish parameters for the production models, an industry survey was conducted in 1996 (Uva et al. 1998), and interviews were carried out with greenhouse construction companies, ZRS system suppliers, and greenhouse operations in New York, Ohio, Illinois and Ontario, Canada. Some assumptions are necessary to determine production and investment costs for producing crops using alternative ZRS systems. Although the cropping scenarios are designed for a specific market of the year, year-round production at the greenhouse production capacity was assumed for the 11 production models. The related costs and profits were estimated as dollars per square foot week (SFW) of greenhouse area in production to account for different time periods of production cycles (Brumfield 1994; Stathacos and White 1981). The SFW costs and profits varied according to production length, crop spacing, and the space efficiency of each ZRS system.

A risk analysis of cost uncertainty examines the various costs associated with a project, their uncertainties, and any risks or opportunities that may affect these costs. Risks and opportunities are defined as possible events that increase and decrease the project costs, respectively. In a Monte Carlo simulation, relatively certain input variables are specified by single values, while more uncertain variables are specified by probability distributions. The simulation process involved generating random samples from the probability distributions of the uncertain parameters and repeating the process a large number of times to yield distributions of the results. The possible investment outcomes were calculated based on the capital budgeting model defined by Uva (1999) (figure 1). Special cases of interest were simulated to study the impact of extreme values of selected variables on profitability and risk of the alternative investment projects. The personnel costs and annual inflation rates were selected to simulate the conditions of high labor costs and the possibility of high inflation rates in an economically risky environment, respectively. Fisher's least significant difference (LSD) tests at $P \leq 0.05$ were performed on mean profits in each crop category to compare the profitability of alternative ZRS system production models. The riskiness was compared by the relative variability of the simulation results using coefficient of variation (CV). The following explains how each component was calculated in the model. The cost and return prices were estimated in 1998 dollars. An Excel spreadsheet program was used to perform the simulation.

Model Definition

Each investment project model was divided into five subcategories under which associated cost and return components were included: 1) returns—product prices and shrinkage rates; 2) initial investment costs—costs of greenhouse structure, costs of irrigation systems, and space utilization efficiencies; 3) material costs—costs of plant materials, containers, media, fertilizer, pesticide, and shipping material; 4) indirect variable costs—costs of labor, heating, electricity, and water; and 5) overhead costs—insurance, taxes, interest, and maintenance and repairs. Two sources of information

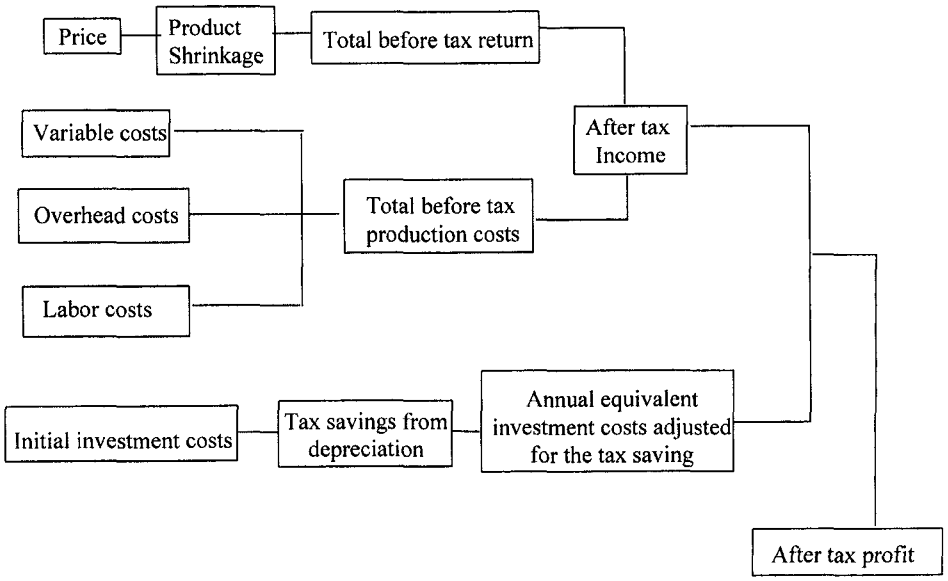

Figure 1. Capital Investment Analysis Model

were used to quantify the uncertainty of the variables in the risk analysis model. Observed data were used when available to derive a distribution to model the variable uncertainty, i.e. interest rates and inflation rates. Experts' opinions were used when data had not been collected in the past, or when the past data did not reflect the future estimates. It was obtained by reviewing industry catalogues and interviewing greenhouse engineers and businesses.

The probability distributions used in this analysis were Uniform, Triangular, and Normal distributions. The minimum (a), most likely (b), and maximum (c) values or means and standard deviations were estimated for uncertain variable inputs (table 1). Uniform distribution was used to model variables which could assume any value in the interval between the minimum (a) and maximum (c) points, and where all the values in this interval are equally likely to occur. Triangular distribution was used to model variables which could assume any value between the minimum (a) and maximum (c) points, but all the values between the two points were not equally likely to occur, with a most likely value (b) and two least likely values (a and c). Normal distribution was used to model variables with value probabilities represented by the bell shape distribution and without definite maximum and minimum values.

Probability distributions for uncertain variable inputs and production requirements were defined from these parameters. Formulae used to generate the random variable (t) from these distributions in the Excel spreadsheet program are:

Uniform Distribution: t = a + (c – a) * RAND( )

Triangular Distribution: If r ≤ (b – a)/(c – a),
t = a + SQRT((c – a) * (b – a) * r)
Otherwise, t = c – SQRT((c – a) * (c – b) * (1 – RAND( ))

Normal Distribution: t = NORMINV (RAND( ), μ, σ)

Where

t = a continuous random variable from a probability distribution
a = the minimum possible value of the random
b = the most likely value of the random
c = the maximum possible value of the random
RAND( ) = a continuous uniform random number between 0 and 1
r = a continuous uniform random number between 0 and 1
SQRT = square root
μ = mean
σ = standard deviation

The envelope method was used to model the variable distribution dependency between the interest rate and the inflation rate. All available data of interest rates and inflation rates from 1978 to 1997 were plotted in a scatter chart. The correlation of the two was calculated to be 0.724. Bounding lines containing the minimum, most likely and maximum observed values were determined (figure 2). The parameters used to predict the interest rate from a triangular distribution for any value of the inflation rate were defined as follows:

minimum interest rate value
= 1.22 * inflation rate – 1.12%

mostly likely interest rate value
= 1.28 * inflation rate + 3.25%

maximum interest rate value
= 1.3 * inflation rate + 6.42%

When one uncertain variable appeared in several formulae in the model, it was represented once only in the spreadsheet, and any other cell that needed its value was referenced to the cell in which the distribution resided to ensure that each variable was represented by one single value in each iteration. There are an infinite number of possibilities of each variable's values associated with each model. Ragsdale (1995) and Vose (1996) suggested a minimum of 100 replications is often necessary to reasonably estimate the characteristics of the underlying population. In this study, 300 iterations were performed for each production model.

Initial Investment Costs

The initial investment costs were assumed to be paid out at the beginning of the project. In this model, the annual equivalent cost of the initial investment for each item in the project adjusted for the tax savings from accounting depreciation was calculated as:

$$c = (C - D_s) * \frac{r * (1 + r)^n}{(1 + r)^n - 1}$$

Where

c = annual equivalent investment cost ($)
C = initial investment cost ($)
D_s = Present value of tax savings from accounting depreciation ($)
r = after-tax real discount rate (%)
n = lifetime of investment item (yrs)

This procedure was used because of unequal useful lives for many of the pieces of equipment and the structure. Implicit in the calculation of annual equivalent costs is the assumption that each item of equipment will be replaced at the end of its useful life by another item having the same cost and the same life (Casler et al. 1988).

An asset was depreciated for tax purposes and generated tax shield for the company. Therefore, the initial capital investments were adjusted for tax savings from accounting depreciation when calculating annual equivalent costs of the investments. The present value (PV) of tax savings from accounting depreciation was calculated by:

$$D_s = D * t$$

Where

D_s = Present value of tax saving from accounting depreciation ($)
D = Present value of total accounting depreciation cost recovery ($)
t = Marginal combined federal and state income tax rate ($)

The weighted average cost of capital (WACC) was used to estimate the firm's cost of capital, and the after-tax real cost of capital (discount rate) was calculated by:

$$R' = (P_e * r_e) + (P_f * r_f)$$

$$r = \frac{1 + R' * (1 - t)}{1 + I} - 1$$

Where

P_e = proportion of financing from equity capital (%)
$P_f = 1 - P_e$ = proportion of financing from borrowed capital (%)
r_e = before-tax cost on equity capital used to finance the investment (%)
r_f = before-tax cost on borrowed capital used to finance the investment (%)
I = inflation rate (%)
R' = before-tax nominal discount rate (%)
t = marginal combined federal and state income tax rate (%)
r = after-tax real discount rate (%)

Product Prices and Material Costs

Product prices were derived from surveying the industry members for wholesale prices and later were adjusted to reflect product shrinkage. Based on the interviews with greenhouse operators, the quality of plants is comparable for each irrigation system when recommended management practices are followed for each production model. This analysis assumes constant management capacity across systems. Therefore, the same price range for

Table 1. Uncertain Variable Distributions and Their Parameters[a]

Variable	Min.	Most likely	Max.	Std. Dev.	Probability Distribution
Returns					
Product price					
4½″ geranium ($/pot)	1.20		2.50		Symmetric Triangular
6″ poinsettia ($/pot)	2.70		5.50		Symmetric Triangular
1204 impatients flat ($/flat)	6.00		7.50		Symmetric Triangular
Shrinkage rate					
4½″ geranium (%)	0		3		Symmetric Triangular
6″ poinsettia (%)	1		4		Symmetric Triangular
1204 impatients flat (%)	0		3		Symmetric Triangular
Initial investment ($)					
Ebb/flow rolling benches		502,500		50,250	Normal
Dutch movable trays		514,500		51,450	Normal
Flood floors		493,100		49,310	Normal
Trough benches		447,500		44,750	Normal
Direct input costs					
Plant material					
geranium cutting ($/cutting)	0.42		0.45		Symmetric Triangular
poinsettia cutting ($/cutting)	0.58		0.70		Symmetric Triangular
impatients seeds ($/1000 seeds)	8.00		25.00		Symmetric Triangular
Container					
4½″ standard pot ($/1,000)	30.00		52.5		Symmetric Triangular
6″ azalea pot ($/250)	12.5		20.0		Symmetric Triangular
288 plug tray ($/100)	55.0		82.0		Symmetric Triangular
1204 flat tray & insert ($/100)	77.6		118.5		Symmetric Triangular
Media					
Metro-mix 360 ($/3 ft^3)	4.11		8.80		Symmetric Triangular
Metro-mix 200 ($/3 ft^3)	4.11		8.80		Symmetric Triangular
Fertilizer					
Peter Excel 15-5-15 ($/25 lb)	12.0		21.6		Symmetric Triangular
Growth Regulator					
Cycocel 11.8% ($/qt)	19.0		24.0		Symmetric Triangular
Bonzi ($/pt)	91.6		112.0		Symmetric Triangular
Indirect variable costs					
Price of gas ($/therm)		0.43		0.04	Normal
Price of electricity ($/$ft^2$/year)		0.25		0.03	Normal
Price of water ($/1,000 gal)		1.65		0.17	Normal
Labor costs					
Supervisory grower salary ($/year)	28,500	32,800	43,000		Triangular
Hourly employee wage ($/hour)	6	9	12		Triangular
Worker's compensation (%)	15		25		Symmetric Triangular
Overhead fixed costs ($/$ft^2$/year)					
Insurance	0.20		0.30		Uniform
Maintenance & repairs of irrigation systems					
Ebb/flow rolling benches		0.10		0.010	Normal
Dutch movable trays		0.15		0.015	Normal
Flood floors		0.05		0.005	Normal
Trough benches		0.05		0.005	Normal
Greenhouse maintenance & repairs	0.10		0.20		Symmetric Triangular
Property tax	0.10		0.20		Symmetric Triangular
Miscellaneous	0.10		0.15		Symmetric Triangular
Greenhouse design & production requirements					
Space efficiency					
Ebb/flow rolling benches (%)	81.0		93.1		Symmetric Triangular
Dutch movable trays (%)	80.6		89.1		Symmetric Triangular
Flood floors (%)	85.5		94.0		Symmetric Triangular
Trough benches (%)	72.0		82.7		Symmetric Triangular
Irrigation requirements					
Ebb/flow rolling benches (gal/ft^2)	0.5		0.8		Symmetric Triangular
Dutch movable trays (gal/ft^2)	0.5		0.8		Symmetric Triangular
Flood floors (gal/ft^2)	0.8		1.0		Symmetric Triangular
Trough benches (gal/ft^2)	0.3		0.8		Symmetric Triangular
Solution uptake rate (%)	15		20		Symmetric Triangular

Table 1. Continued.

Variable	Min.	Most likely	Max.	Std. Dev.	Probability Distribution
Economic parameters					
Cost of equity capital (%)	10	13	20		Triangular
Cost of borrowed capital (%)	6	8.5	10		Triangular
Proportion of equity capital used to finance the investment (%)	0		100		Symmetric Triangular
Total marginal tax rate (%)	20		40		Symmetric Triangular
Annual inflation rate (%)	2.3	3.5	5		Triangular

[a]Cost and return prices were estimate in 1998 values.

each crop was assumed for all applicable ZRS systems. Material costs were estimated from the crop production requirements for that input per unit as determined through available research results and publications. Prices for these inputs were obtained from suppliers' catalogues with an adjustment for quantity and competition markdowns.

Indirect Variable and Fixed Costs

Using weather data, greenhouse information and environmental requirements specified by the user, heating requirements for each production model were calculated by the computer program "LITEDUTY" developed by Dr. Louis Albright of the Department of Agricultural and Biological Engineering at Cornell University. The average wages and salaries for the eastern part of the country were derived from industry surveys and validated by greenhouse operators (Beytes and Shaw 1997). It was assumed that one supervisory grower was in charge of the base greenhouse facility and was responsible for supervising greenhouse workers, overseeing production, and performing tasks including crop management, irrigation and fertilization monitoring and control, chemical application, and maintenance of irrigation systems.

Fixed overhead costs include interest, insurance (on both greenhouse and crops), maintenance and repairs, property taxes, and other miscellaneous items. Maintenance and repair costs are different

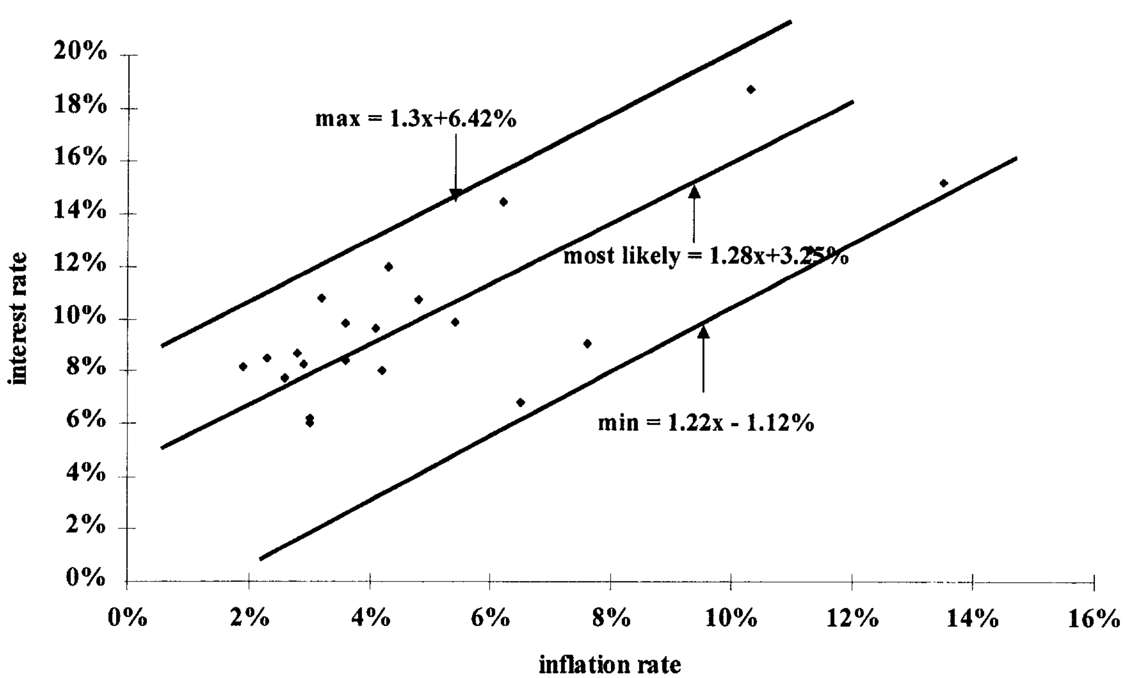

Figure 2. Model the Dependencies Between Inflation Rate and Interest Rate Using the Envelope Method

Table 2. Profitability and Riskiness of Alternative Production Models[a]

	Mean[b]	Std. Dev.	Minimum	Maximum	Coefficient of Variation[c]
		Profit per SFW greenhouse floor			
Irrigation System		($/SFW)			(%)
Small potted plant—4″ Geraniums					
EFB	$0.22***	$0.080	$0.006	$0.424	36.48%
DMT	0.25*	0.079	0.047	0.455	31.08
FF	0.24**	0.083	0.021	0.445	34.82
TB-G	0.19****	0.071	0.006	0.378	37.18
Large potted plant—6″ Poinsettias					
EFB	−$0.003**	$0.018	−$0.053	$0.045	680.2%
DMT	0.006*	0.018	−0.049	0.046	303.3
FF	0.007*	0.019	−0.046	0.054	249.9
TB	−0.001***	0.016	−0.051	0.036	1721.6
Bedding crop—1204 Impatients flats					
EFB	$0.084**	$0.014	$0.041	$0.124	17.12%
DMT	0.083**	0.014	0.043	0.120	16.34
FF	0.092*	0.014	0.047	0.128	15.69

[a]Profits were estimated in 1998 values.
[b]Means within each crop category followed by *, **, ***, and **** are significantly different when performed the Fisher's LSD multiple comparison analysis ($\alpha = 0.05$).
[c]The coefficient of variation is calculated by standard deviation/mean.

for each ZRS system. FF systems require lower maintenance because of the absence of mechanical facilities. For the same reason, DMT systems have higher maintenance and repair costs as the facilities age.

After-Tax Profit

The annual cash flows were adjusted to an after-tax basis using the Component methods (Casler et al. 1988):

$$Z = R(1-t) - E(1-t) - A$$

Where

Z = After-tax profit ($)
R = Receipts, before tax ($)
E = Operation expenses, before taxes ($)
t = Marginal combined federal and state income tax rate (%)
A = Total annual equivalent costs of the investment items ($)

Simulation Results

Table 2 shows the statistical summary of the simulation results for the 11 production models. For small potted plant production, represented by 4½-inch geraniums, the mean profit per SFW greenhouse floor of the production model with DMT systems was significantly higher than that of production models with FF, EFB, and TB systems at P = 0.05. For large potted plant production, represented by 6-inch poinsettias, the mean profit per SFW greenhouse floor of the production model with FF systems was the highest among the four large potted plant production models. However, it was not significantly higher than the production model with the second highest profit, the DMT systems. For bedding crop flat production, represented by 1204 impatiens flats, the production model with FF systems had a significantly higher average profit per SFW greenhouse floor than the other two production models (with DMT and EFB systems).

The risks of the production models were compared by the variability of the simulation results (table 2). The risk of the production model is considered to be higher when the CV of the simulation results is higher. The most risky investment projects among alternative ZRS systems are TB systems for small potted plants and large potted plants, and EFB systems for bedding crop flat production. The least risky investment projects among alternative ZRS systems are DMT systems for small potted plant production, and FF systems for large potted plant and bedding crop flat production.

In the special case simulation of personnel costs, the maximum and most likely parameter values defining the variable distributions were increased to $24/hour and $15/hour from $20/hour and $9/hour, respectively, for hourly labor wage, and $84,000/year and $50,000/year from $43,000/year and $32,800/year, respectively, for supervisory costs, while all other parameter values stayed the same. Table 3 shows the simulation results for this

Table 3. Profit Per SFW Greenhouse Floor of the 11 Production Models for High Labor Cost Simulations[a]

Production Model	Mean[b]	Std. Dev	Minimum	Maximum	Coefficient Of Variation[c]
		Profit Per SFW Greenhouse Floor ($/SFW)			(%)
Small Potted Plant—4″ Geraniums					
EFB	$0.190***	$0.081	$0.007	$0.418	42.75%
DMT	0.228*	0.086	0.023	0.444	37.87
FF	0.213**	0.090	0.015	0.431	42.37
TB	0.158****	0.079	−0.011	0.332	50.12
Large Potted Plant—6″ Poinsettias					
EFB	−$0.017**	$0.023	−$0.073	$0.047	130.2%
DMT	−0.016**	0.020	−0.070	0.046	122.3
FF	−0.013*	0.023	−0.072	0.038	181.9
TB	−0.020**	0.021	−0.073	0.038	1060.0
Bedding Crop—1204 Impatiens Flats					
EFB	$0.072**	$0.016	$0.030	$0.111	22.02%
DMT	0.070**	0.014	0.030	0.105	20.58
FF	0.081*	0.016	0.042	0.130	19.92

[a]Profits were estimated in 1998 values.
[b]Means within each crop category followed by different letters are significantly different when performed the Fisher's LSD multiple comparison analysis ($\alpha = 0.05$).
[c]The coefficient of variation is calculated by standard deviation/mean.

case study. The relative profitability rankings of alternative production models for each crop category were the same as in the general case simulations described above. The risk rankings for each crop category were generally the same except that the riskiness of FF systems exceeded DMT systems were producing large potted plants at higher personnel cost uncertainty.

In the second special case, the maximum and most likely inflation rates were increased to 20% and 7% from 5% and 3.5%, respectively, while all other parameter values were unchanged. Table 4 shows the simulation results for this case study. As in the personnel cost special cases, the relative profitability rankings of alternative production models for each crop category were the same as in the general case simulations. The only change in the risk rankings was that the risks of FF systems exceeded DMT systems when producing large potted plants at higher inflation rate uncertainty.

Discussion

The results from the cost risk analysis showed that different ZRS systems maximize profitability of production of different crop categories, and the profitability ranking of the alternative ZRS systems for all three crop categories remained stable. However, when personnel costs and inflation rates were allowed to take on high values, the profitability of using FF systems to produce the more labor-intensive and time-consuming large potted plants became volatile. The TB system is the most risky and is not competitive compared with the other three irrigation systems studied because of its low average and highly volatile profitability. The results also showed that the most suitable systems for small potted plant and bedding crop flat production were the DMT system and the FF system, respectively. However, the decision-making criteria were not as clear for large potted plant production. The FF system had the highest average profitability and was least risky under most conditions. However, under higher variable uncertainty circumstances of the two special case studies, the FF system was relatively risky compared with the Dutch movable tray system, which had the second highest average profitability. Therefore, the decision of selecting a ZRS system for large potted plant production will depend on whether other crop categories are scheduled to be produced in the same greenhouse area and the greenhouse operator's attitude toward risk.

The majority of greenhouse operations grow more than one type of crop to meet seasonal and customer demands. To maximize total profit, the ZRS system most suitable for the major crop category in the production plan should be adopted. However, when multiple crop categories of small volumes are grown simultaneously in the green-

Table 4. Profit per SFW Greenhouse Floor of the 11 Production Models for High Inflation Rate Simulation[a]

Production model	Mean[b]	Std Dev	Minimum	Maximum	Coefficient of Variation[c]
		Profit per SFW greenhouse floor ($/SFW)			(%)
Small potted plant—4″ Geraniums					
EFB	$0.215***	$0.085	$0.010	$0.469	38.86%
DMT	0.253*	0.085	0.058	0.468	33.78
FF	0.236**	0.090	0.031	0.446	37.88
TB	0.191****	0.071	0.029	0.373	37.20
Large potted plant—6″ Poinsettias					
EFB	$0.005**	$0.020	−$0.050	$0.051	439.6%
DMT	0.010*	0.018	−0.028	0.057	182.2
FF	0.011*	0.020	−0.038	0.060	191.7
TB	−0.001***	0.018	−0.044	0.055	1928.7
Bedding crop—Impatiens flats					
EFB	$0.085**	$0.015	$0.049	$0.119	17.22%
DMT	0.085**	0.016	0.046	0.119	18.51
FF	0.095*	0.015	0.053	0.130	15.93

[a]Profits were estimated in 1998 value.
[b]Means within each crop category followed by different letters are significantly different when performed the Fisher's LSD multiple comparison analysis ($\alpha = 0.05$).
[c]The coefficient of variation is calculated by standard deviation/mean.

house production plan, compromise might be necessary were selecting a ZRS system for a production area depending on available resources. Moreover, if multiple crop categories in large volumes are emphasized in the production plan, more than one type of ZRS system can be installed in different production areas for growing different crop categories. Findings from the 1996 industry survey (Uva et al. 1998) showed that the EFB systems were most commonly adopted by small and medium size operations, and the large operations tended to use more than one type of subirrigation system.

Although the conclusions derived from the results of this study were limited by the fact that only one representative crop was analyzed within each crop category, and this study did not compare the traditional overhead with leaching systems with ZRS systems, this study presented a process which can be used as a tool to compare the profitability of alternative ZRS system investment projects when considering adoption of this technology. A good simulation model can provide substantial information to the greenhouse operators when analyzing a business decision involving estimating future cash flows. The simulation approach might have been considered undesirable by farm businesses because the process of setting up a model is time-consuming, and the computation procedure can be complex. However, the progress of the computer technology makes it possible for greenhouse operators to conduct the simulation and not depend on outside professionals. Greenhouse operations can apply the methods demonstrated in this study and use specific production information from individual operations to analyze the profitability and impact of future events on investment projects.

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