Economic Analysis of Adopting Zero Runoff Subirrigation Systems in Greenhouse Operations in the Northeast and North Central United States

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Abstract. Zero runoff subirrigation (ZRS) technology is a promising method of managing fertilizer and pesticide inputs while improving production efficiency. However, high capital investment costs and inadequate technical information available to growers are major impediments to initiating the change. This study quantifies costs and returns associated with adopting ZRS systems and compares the profitability of four alternative ZRS systems (ebb-and-flow benches, Dutch movable trays, flood floors, and trough benches) for greenhouse operations in the northeastern and north central United States. The capital investment analysis showed that the Dutch movable tray system was most profitable for small potted plant production, and the flood floor system was most profitable for large potted plant and bedding crop flat production. Sensitivity analysis showed that changes in cost variables generally did not affect the profitability rankings of the alternative ZRS investment projects. Nonetheless, the flood floor system gained slight advantages when the product price increased, and the Dutch movable tray system gained advantages as the hourly labor cost increased.

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 to protect water resources and minimize the environmental impact of leachate from greenhouse production (Biernbaum, 1992; Walker, 1990). Production of pot and bedding plants is the focus of this study because of its economic importance to the greenhouse industry in the northeastern and north central United States.

One promising way to avoid fertilizer loss from greenhouse pot and bedding crop production and to improve operation 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 leakproof 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. However, a review of the literature and a survey of greenhouse growers showed that high initial investment costs and lack of cultural and management information for adopting this technology are impediments to change by greenhouse operations in the United States (Argo and Biernbaum, 1995; Horticultural Water Quality Alliance, 1992; Uva et al., 1998).

Several ZRS systems are available to greenhouse operators, and each has different characteristics that are best suited to various production objectives (Uva, 1999). Although a new technology often provides many benefits over a traditional system, the extra investments required in durable production inputs are not always offset by the benefits (Purvis et al., 1995; van Os, 1986). From a financial perspective, the key factors to be considered when making capital investment decisions are

a project's profitability and potential risk (Aggarwal, 1993). This study evaluated the economics of alternative ZRS systems for greenhouse pot and bedding crop growers in the northeastern and north central United States. Traditional overhead irrigation systems were not included in the comparisons because environmental stewardship is an important issue for greenhouse operations. Zero runoff production is required for greenhouse operations in many European countries (Molitor, 1990), and this may be the case in the United States in the future.

The goal of this study was to develop a capital investment analysis model adapted to greenhouse production systems and provide greenhouse operators information to make better investment decisions when choosing a ZRS system. Our specific objectives were to: 1) estimate the costs and returns of producing greenhouse pot and bedding crops when using ZRS systems; 2) compare the relative profitability of using four ZRS systems to produce three major greenhouse pot and bedding crops; and 3) evaluate the impact of changes in cost variables on profitability.

Materials and Methods

A capital investment analysis was conducted to compare the relative profitability of four alternative ZRS systems in greenhouse operations. A 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. An economic engineering approach was used to estimate the initial capital investment, production costs, and product prices for alternative greenhouse production models. The models were simulated with representative characteristics of greenhouse operations and proper installation designs of the four ZRS systems, as observed in the field, and reasonable production schedules for the representative crops. To establish benchmarks for the production models, a greenhouse industry survey was conducted in 1996 to gather information on growers' experiences with ZRS systems (Uva et al., 1998). Subsequently, two grower panel discussions were held in July 1997 to review the results of the survey and to enable more in-depth discussion on issues of managing ZRS systems. Interviews were carried out with greenhouse construction companies, ZRS system suppliers, and greenhouse operators in New York, Ohio, Illinois, and Ontario, Canada, to validate parameters used in the models.

The costs and returns were compared to assess the relative profitability of using alternative ZRS systems to produce several greenhouse crops. The sensitivity of the results to various production prices, wage rates, and operational conditions was investigated by altering values of the selected variables, one at a time, from the baseline value. Changes of the selected variable are expressed by variation from the baseline value from +100% to -50%. The variables included in the sensitivity analysis were total initial investment costs, total

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labor costs, discount rate, product price, and useful life of ZRS systems.

The four commonly used ZRS systems were included in this study: ebb-and-flow rolling benches (EFB), Dutch movable trays (DMT), flood floors (FF), and trough benches (TB). Each has different investment, input, and management requirements when installed in the greenhouse (Uva, 1999). Estimates of these requirements are shown in Tables 1, 2, and 3. A 30.5- × 61.0-m (100- × 200-ft) gutter-connected glass greenhouse with concrete foundation was selected as the base greenhouse facility. Each ZRS system was designed in the 1858-m² (20,000-ft²) model greenhouse and used to produce alternative cropping scenarios when applicable. The three cropping configurations considered and the representative crop for each configuration were: 1) small potted plants—represented by geraniums grown in 11.4-cm standard pots for the Memorial Day market; 2) large potted plants—represented by poinsettias grown in 15.2-cm azalea pots for the Christmas market; and 3) bedding crop flats—represented by impatiens marketed in AC 4-12 (48-cell) flat trays for the spring market. Eleven production models were simulated because the TB system was not suitable for bedding crop flat production.

Using economic engineering methodology, some assumptions of parameter values were necessary to determine production and investment costs for producing crops using alternative ZRS systems (Table 1). Although the cropping scenarios are designed for a specific marketing time 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 meter-week (SMW) greenhouse area and per square-foot week (SFW) greenhouse area in production to account for different lengths of production cycles (Brumfield, 1994; Stathacos and White, 1981). The SMW and SFW costs and profits varied according to production length, crop spacing, and the space efficiency of each ZRS system.

Initial investment costs. Initial investment costs for each model were determined by consulting greenhouse equipment suppliers. The initial investment costs were assumed to be paid out at the beginning of the project. 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 (%); and *n* = lifetime of investment item (years).

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

Table 1. Some estimated cost and return parameters in the capital investment analysis.

Parameter	Estimated value ^z	Percentage
Product price		
11.4-cm geranium	\$1.85/pot	
15.2-cm poinsettia	\$4.10/pot	
4–12 impatiens flat	\$6.75/flat	
System space use efficiency		
Ebb-and-flow bench system		87.0
Dutch movable tray system		85.0
Flood floor system		90.0
Trough bench system		77.0
Labor		
Manager/grower salary		
Average labor wage	\$9.00/h	
Worker's compensation/year		20.0
Heating cost—natural gas (with 75% efficiency)	\$0.43/therm ^y	
Electricity cost	\$0.06/kwh	
Water cost	\$6.44/1000 L	
Maintenance and repair of the irrigation system (% of the initial system investment/year)		
Ebb-and-flow rolling bench system		0.5
Dutch movable tray system		0.7
Flood floor system		0.3
Trough bench system		0.4
Firm's marginal tax rate (including federal and state income tax)		30.0
Annual inflation rate		3.0
Cost of equity capital		14.0
Cost of borrowed capital		8.5
Salvage values	\$0.00	

^zCost and return prices were estimated at 1998 values.

^yOne therm equals 1000 kcal.

Table 2. Initial capital investment costs of zero runoff subirrigation (ZRS) systems.

	Estimated useful life	ZRS system			
		EFB	DMT	FF	TB
Initial capital investment cost	-- Yrs --	----- \$1000 -----			
Greenhouse structure	20	185.000	185.000	185.000	185.000
Thermal curtain	10	25.000	25.000	25.000	25.000
Heating system	25	70.000	70.000	70.000	70.000
Irrigation system ^z	Various ^y	150.000	170.000	140.000	95.000
Computer ^x	7	20.000	20.000	20.000	20.000
Electrical service	20	40.000	40.000	40.000	40.000
Pest management equipment	7	4.500	4.500	4.500	4.500
Crop movement system	Various ^y	8.000	N/A ^w	8.600	8.000
Total capital investment cost		502.500	514.500	493.100	447.500
Annual equivalent cost adjusted for the tax saving		33.829	34.482	31.475	29.921
		----- \$ -----			
Cost per SMW in production ^v		0.398	0.420	0.366	0.398
Cost per pot/tray^v					
11.43-cm (4 1/2") geranium		0.072	0.075	0.065	0.072
15.24-cm (6") poinsettia		0.699	0.731	0.631	0.696
4–12 impatiens flat tray		0.599	0.627	0.541	N/A

^zThe irrigation system costs include materials and installation labor for the irrigation facilities, plumbing, and storage tanks required for the irrigation system.

^yThe estimated useful lives of the irrigation systems for the four ZRS systems were: EFB–15 years, DMT–15 years, FF–20 years, and TB–15 years. The estimated useful lives of the crop movement systems for the four ZRS systems were: EFB–10 years, DMT–not available, FF–10 years, and TB–10 years.

^xThe computer system was used to control heating, cooling, shading, fertilization, and irrigation.

^wThe cost of the crop movement system for the DMT system was included in the irrigation system.

^vThe cost per SMW is calculated by annual equivalent cost/(1858 m² * 52 weeks * % space efficiency). The cost per pot is calculated by initial capital cost per SMW * SMW in production.

be replaced at the end of its useful life by another item having the same cost and the same life (Casler et al., 1988).

Although the accounting depreciation was not considered in calculating costs of production using ZRS systems, an asset was depreciated for tax purposes and generated tax shield

for the company. Therefore, initial capital investments needed to be 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 (\$); and 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. To determine the cost of capital, the investment projects were assumed to be financed equally from equity capital (50%) and borrowed capital (50%). Thus, the after-tax real cost of capital (discount rate) of 4.73% 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 (%), and r = after-tax real discount rate (%).

Product prices and direct variable costs. Product prices were derived from industry surveys for wholesale prices and later adjusted to reflect product shrinkage. Based on 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 price for each crop was assumed for all applicable ZRS systems. The shrinkage rates used were 2% for poinsettias in 15.2-cm pots, 1% for 11.4-cm geraniums and 4–12 impatiens flats, based on grower interviews. Direct variable costs were estimated from the crop production requirements for that input per unit based on research publications and grower manuals (Baas et al., 1995; Ball, 1991; George, 1990; Holcomb, 1994; White, 1993). 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 Dept. of Agricultural and Biological Engineering at Cornell Univ.

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). We assumed that one supervisory grower was in charge of the 1858-m² (20,000-ft²) greenhouse and responsible for supervising greenhouse workers, overseeing production, and performing tasks, including crop management, irrigation and fertilization monitoring and control, chemical application, and main-

tenance 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 differ for each ZRS system. The 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 (%); and A = total annual equivalent costs of the investment items (\$).

Figure 1 graphically portrays the process of capital investment analysis. Interviews were conducted with greenhouse construction companies, ZRS system suppliers and five greenhouse operations in New York, Ohio, Illinois,

and Ontario, Canada, to validate the data used in the greenhouse production models. The costs and returns were estimated in 1998 dollars.

Results

Capital investment analysis. The initial capital investment per each product unit was ranked from high to low in the order of the DMT system, the EFB system, the TB system, and the FF system for all three cropping scenarios (Table 2). Although the total initial capital investment was higher for the FF system than for the TB system, the unit cost for the TB system was higher for the two applicable representative crops. The FF systems achieved higher greenhouse space utilization efficiency than did TB systems.

Labor requirements to accomplish production tasks for each crop differ for each alternative ZRS system. The DMT system is the most efficient for tasks involving crop movement, and the FF system is less labor-efficient for spacing and pinching the crops because of the bending involved while working with crops

Table 3. Allocated labor costs when using zero runoff subirrigation (ZRS) systems to produce greenhouse crops.²

Labor costs	ZRS system			
	EFB	DMT	FF	TB
	----- Cost/pot (\$) -----			
Small potted plants: 11.43-cm (4 1/2") geranium				
Direct labor costs ³	0.24	0.11	0.23	0.24
Allocated supervisory grower costs ⁴	0.08	0.09	0.08	0.09
Total labor costs	0.32	0.20	0.31	0.33
Large potted plants: 15.24-cm (6") poinsettia				
Direct labor costs	0.54	0.33	0.53	0.52
Allocated supervisory grower costs	0.82	0.84	0.79	0.92
Total labor costs	1.36	1.17	1.32	1.44
Bedding crop flats: 4–12 impatiens flat				
Direct labor costs	0.48	0.40	0.44	N/A
Allocated supervisory grower costs	0.35	0.36	0.34	N/A
Total labor costs	0.83	0.76	0.78	N/A

²The labor costs were estimated in 1998 values.

³Direct labor cost was calculated by total time required (h) × labor wage/h.

⁴Allocated supervisory grower costs (including overhead labor costs) were calculated by [(supervisory grower salary per year)/(1858 m² × 52 weeks × space efficiency)] × (SMW required per unit).

Fig. 1. Capital investment analysis procedure flow chart.

Table 4. Capital investment analysis of producing small potted plants: 11.43-cm (4 1/2") geraniums under alternative zero runoff subirrigation (ZRS) systems.

	ZRS system			
	EFB-G	DMT-G	FF-G	TB-G
----- Costs (\$/pot) -----				
<u>Direct variable costs</u>				
Plant material	0.435	0.435	0.435	0.435
Container	0.041	0.041	0.041	0.041
Media	0.060	0.060	0.060	0.060
Growth regulator	0.008	0.008	0.008	0.008
Fertilizer	0.004	0.004	0.005	0.003
Pesticide	0.002	0.002	0.002	0.002
Label	0.021	0.021	0.021	0.021
Shipping package	0.087	0.087	0.087	0.087
<u>Indirect variable costs</u>				
Heating	0.026	0.027	0.026	0.030
Electricity	0.015	0.015	0.014	0.017
Water	0.002	0.002	0.003	0.002
Labor costs	0.324	0.195	0.307	0.338
Overhead costs	0.034	0.038	0.030	0.035
Total before tax costs	1.060	0.935	1.039	1.078
----- Returns (\$/pot) -----				
Price	1.850	1.850	1.850	1.850
Product shrinkage (1%)	-0.020	-0.020	-0.020	-0.020
Total before tax return	1.832	1.832	1.832	1.832
Taxable income per pot	0.772	0.897	0.793	0.754
Minus tax (30%)	0.232	0.269	0.238	0.226
Minus initial capital cost ²	0.072	0.075	0.065	0.072
Profit per pot	0.468	0.553	0.490	0.456
Profit per m² per week³	2.282	2.626	2.465	1.970

²Initial capital costs are the initial investment costs adjusted for tax saving from depreciation.

³Profit per SMW greenhouse floor was calculated by [(profit per pot)/SMWs in production] * space efficiency of the production model.

Table 5. Capital investment analysis of producing large potted plants: 15.24-cm (6") poinsettias under alternative zero runoff subirrigation (ZRS) systems.

	ZRS system			
	EFB-P	DMT-P	FF-P	TB-P
----- Costs (\$/pot) -----				
<u>Direct variable costs</u>				
Plant material	0.64	0.64	0.64	0.64
Container	0.07	0.07	0.07	0.07
Media	0.15	0.15	0.15	0.15
Growth regulator	0.04	0.04	0.04	0.04
Fertilizer	0.04	0.04	0.06	0.04
Pesticide	0.02	0.02	0.02	0.02
Label	0.02	0.02	0.02	0.02
Shipping package	0.11	0.11	0.11	0.11
<u>Indirect variable costs</u>				
Heating	0.19	0.19	0.18	0.21
Electricity	0.14	0.15	0.14	0.16
Water	0.01	0.01	0.02	0.01
Labor costs	1.35	1.17	1.32	1.43
Overhead costs	0.33	0.37	0.30	0.34
Total before tax costs	3.12	2.98	3.07	3.24
----- Returns (\$/pot) -----				
Price \$4.10	\$4.10	\$4.10	\$4.10	
Shrinkage (2%)	-0.08	-0.08	-0.08	-0.08
Total before tax return	4.02	4.02	4.02	4.02
Taxable income per pot	0.90	1.04	0.95	0.38
Minus tax (30%)	0.27	0.31	0.29	0.23
Minus initial capital cost ²	0.70	0.73	0.63	0.70
Profit per pot	-0.07	-0.02	0.04	-0.15
Profit per m² per week³	-0.03	-0.00	0.02	-0.07

²Initial capital costs are the initial investment costs adjusted for tax saving from depreciation.

³Profit per SMW greenhouse floor was calculated by [(profit per pot)/SMWs in production] * space efficiency of the production model.

Table 6. Costs of producing plugs for the spring bedding crop: 1204 impatiens flat under the alternative zero runoff subirrigation (ZRS) systems.

	ZRS system		
	EFB-I	DMT-I	FF-I
----- Costs (\$/tray) -----			
<u>Direct variable costs</u>			
Plant material ²	4.752	4.752	4.752
Container	0.685	0.685	0.685
Media	0.129	0.129	0.129
Growth regulator	0.004	0.004	0.004
Fertilizer	0.001	0.001	0.002
<u>Indirect variable costs</u>			
Heating	0.356	0.365	0.346
Electricity	0.074	0.076	0.072
Water	0.001	0.001	0.001
Labor	0.730	0.640	0.690
Overhead fixed costs	0.170	0.190	0.150
Total costs before tax	6.900	6.850	6.830
Germination rate	90%	90%	90%
Total before tax costs per seedling	0.027	0.026	0.026

²288 seeds are planted in a plug tray.

Table 7. Capital investment analysis of producing spring bedding crops: 4–12 impatiens flat under the alternative zero runoff subirrigation (ZRS) systems.

	ZRS system		
	EFB-I	DMT-I	FF-I
----- Costs (\$/tray) -----			
<u>Direct costs</u>			
Plant material ²	1.276	1.268	1.265
Container	0.971	0.971	0.971
Media	0.359	0.359	0.359
Growth regulator	0.004	0.004	0.004
Fertilizer	0.003	0.003	0.003
Pesticide	0.006	0.006	0.006
Label	0.190	0.190	0.190
<u>Indirect variable costs</u>			
Heating	0.094	0.097	0.091
Electricity	0.050	0.051	0.048
Water	0.001	0.001	0.001
Labor	0.710	0.645	0.669
Overhead fixed costs	0.113	0.125	0.101
Total before tax costs	3.777	3.720	3.708
----- Returns (\$/tray) -----			
Price	6.750	6.750	6.750
Shrinkage (1%)	-0.068	-0.068	-0.068
Total before tax return	6.682	6.682	6.682
Taxable income per tray	2.905	2.962	2.974
Minus tax (30%)	0.868	0.886	0.889
Minus total initial capital cost ²	0.599	0.627	0.541
Profit per tray	1.438	1.449	1.544
Profit per m² per week³	0.829	0.818	0.926

²Total before tax seedling costs from plug production. A 4–12 flat has 48 seedlings.

³Initial capital costs are the sum of the initial investment costs allocated to the plug and flat trays and adjusted for tax savings from depreciation.

⁴Profit per SMW greenhouse floor was calculated by [(profit per pot)/SMWs in production] * space efficiency of the production model.

Fig. 2. Sensitivity of the profitability of the alternative ZRS production models to product prices, Northeastern and North Central United States, in 1998 values.

Fig. 3. Sensitivity of the profitability of the alternative ZRS production models to initial investment costs, Northeastern and North Central United States, in 1998 values.

on the floor. Rolling platforms suspended from an overhead monorail are often installed to aid workers. The labor costs were highest for TB systems when producing the small (11.4-cm geraniums) and the large potted plants (15.2-cm poinsettias), and for EFB system when producing bedding plant plugs and flats (4–12 impatiens flats) (Table 3).

Tables 4, 5, 6, and 7 present the enumerated cost and return items for the capital investment analyses and compare the relative profitability of the four ZRS systems for the three crop categories. For production of small potted plants, the highest profit per SMW greenhouse area was generated by the DMT system, followed by the FF system (Table 4). For production of large potted plants, the FF system model was the most profitable, followed by the DMT system (Table 5). For production of bedding plant flats, the FF system generated the highest profit, and the EFB system produced the second highest profit, followed closely by the DMT system (Tables

6 and 7). The TB system was the least profitable for the two applicable crop categories—production of small and large potted plants.

Sensitivity analysis. Conclusions resulting from computing alternative project values based on a single set of assumptions can be misleading and imprudent because of inherent environmental uncertainties. Sensitivity analysis answers the question: “How will the decision be affected by changes in the parameter values of the model?” The results showed that changes in product prices and cost variables generally did not affect the profitability rankings among irrigation systems for the three crop categories (Figs. 2–6). However, the FF system had slight advantages when the product price increased. When the product price was 40% higher than the baseline, the profitability of the FF system exceeded that of the DMT system for producing small potted plants (Fig. 2). While the flood floor system generally generated the highest profitability for production of large potted plants, the difference

between the profitability produced by FF systems and DMT systems fell as initial investment costs decreased. When the initial investment costs were below 40% of the baseline values, the profitability of the model with the DMT system exceeded that of the model with the FF system (Fig. 3).

When labor costs were high, the DMT system had the highest profitability for production of small and large potted plants (Fig. 4). However, advantage was lost to the other ZRS systems as total labor costs decreased. When producing large potted plants, the profitability of the FF system exceeded that of the DMT system when total labor costs fell below 30% above baseline. Although the DMT system did not generate the highest profitability for production bedding plant flats, it showed the same response to changes in total labor costs in relation to the EFB system. This result might explain the popularity of the DMT system in Europe, where labor costs are higher than in the United States. Changes in the

Fig. 4. Sensitivity of the profitability of the alternative ZRS production models to total labor costs, Northeastern and North Central United States, in 1998 values.

discount rates used by the firms and the useful lives of the equipment did not affect rankings of profitability among alternative ZRS systems (Fig. 5). Although changes in the useful lives of the equipment did not affect rankings of profitability among alternative ZRS systems, as useful life increased, profitability of the DMT and EFB systems increased in relation to the FF system for production of large potted plants and bedding plant flats (Fig. 6).

Discussion

The results showed that profitability of ZRS systems varied with crops. Although the total initial investment costs were perceived by greenhouse growers as a very important cost item when evaluating such systems, our results showed that such costs alone should not be used to select the system. Total initial investment costs in a 1858-m² greenhouse for

the four ZRS systems from high to low, respectively, are the DMT system, the EFB system, the FF system, and the TB system (Table 2). Despite the lowest initial costs of adoption, the trough bench system was not as competitive as a ZRS technology. The greenhouse production models with trough bench systems showed the lowest profitability among the four ZRS systems for the two applicable crop categories (production of small and large potted plants). In contrast, although the DMT system had the highest initial investment costs, it had the highest profitability among the four ZRS systems when producing small potted plants. The economic impact of low space utilization efficiency of the TB systems, the higher labor efficiency of the DMT and FF systems, and the competitive investment cost and low maintenance and repair costs of the FF systems offset the benefit of low initial investment costs offered by the TB systems.

Fig. 5. Sensitivity of the profitability of the alternative ZRS production models to discount rates, Northeastern and North Central United States, in 1998 values.

Although the conclusions derived were limited by the fact that only one representative crop was analyzed within each crop category, this study demonstrated a process that can be used as a tool to compare the potential profitabilities of alternative ZRS system investment projects. Without a comprehensive economic analysis, greenhouse managers sometimes might select an investment project that is not the most competitive among the alternatives. For instance, based on the industry survey, the EFB system was the most common ZRS system among greenhouse growers who had adopted the technology because of its availability in the market (Uva et al., 1998). However, when the EFB system's relatively high initial investment, maintenance and repair, and labor costs were considered, it was not superior to the other three ZRS systems studied. This reinforces the view that growers need more sophisticated investment

Fig. 6. Sensitivity of the profitability of the alternative ZRS production models to the equipments' useful lives, Northeastern and North Central United States, in 1998 values.

analysis strategies to make intelligent investment decisions and optimize profitability.

Each greenhouse operation has a different production schedule and its own unique market demand. When making a decision based on the investment analysis, one should recognize that compromise might be necessary when selecting a ZRS system for a production area. The ZRS system best suited for the major crop category in the production plan should be chosen. However, when multiple crop categories of small volumes are to be grown simultaneously in the greenhouse production plan, the Dutch movable tray system might be more suitable than the flood floor system. The rationale is that even though the flood floor system was ranked first for production of large potted plants and bedding plant flats, the Dutch movable tray system can be better adapted to versatile irrigation regimes and labor requirements, and it ranked at least second in profitability for all three crop categories studied.

Moreover, if multiple crop categories in large volumes are emphasized in the greenhouse production plan, more than one type of ZRS system can be installed in different production areas to grow different categories of crops, thereby maximizing total profit.

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