A Survey on the Planning and Adoption of Zero Runoff Subirrigation Systems in Greenhouse Operations

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Adoption of technology to achieve environmental stewardship is a high priority among greenhouse businesses. One promising way to avoid fertilizer- and pesticide-containing effluent from greenhouse productions is to use zero runoff subirrigation (ZRS) systems (Horticultural Water Quality Alliance, 1992; Molitor, 1990; van Os, 1994; Vernooij, 1991). Management of the environment in ZRS systems is different from the traditional overhead watering with leaching (Biernbaum, 1992; Fynn, 1994; Gabriels et al., 1986; Weiler, 1992). Greenhouse managers' greatest concern about adoption of ZRS systems is the impact on their ability to produce high-quality plants in an economical way to stay competitive in the market (Martens, 1991; Ruijs and van Os, 1991).

Implementing ZRS systems to manage fertilizer and pesticide inputs while improving production efficiency requires more than acquiring a system. Evaluating the cost and benefits of such a technological investment involves more than estimating the initial investment. Such investments affect many aspects of business operations, receipts, and expenses—both financial and environmental (Horticultural Water Quality Alliance, 1992; Josko, 1991; Weiler, 1992). Therefore, the impact of adopting ZRS systems on resource reallocation and profitability of greenhouses is an important research topic.

This study reports the results of a survey of the industry to establish benchmarks of management practices and system performance for greenhouse production with ZRS systems. The three methods of subirrigation and irrigation solution recirculation emphasized in this survey are: 1) ebb-and-flow benches, also called flood benches; 2) flood floors, where crops are grown on the floor and subirrigated by ebb and flood; and 3) trough benches, on which containers are placed in long rows of shallow, sloped gutters and irrigation solution flows intermittently.

The objectives of the survey were to: 1) characterize decision-making issues related to adoption of ZRS systems, e.g., types of systems, operating practices, product quality, and labor practices; 2) identify the costs and benefits of using such systems; 3) identify management issues and concerns among greenhouse operators regarding adoption of this technology; and 4) identify whether firm size and the surface area employed impact adoption of ZRS systems.

Development of the survey was assisted by the Cornell Institute for Social Economic Research (CISER). A 37-item questionnaire was designed to gather information from greenhouse operators who had adopted ZRS systems. Questions covered characteristics of the businesses, characteristics of the adopted ZRS systems, changes in the production practices, effects of the system on labor management, and costs and receipts.

A list of 80 greenhouse establishments in 26 states was compiled from information provided by suppliers of greenhouse ZRS systems, trade magazines, and personal communication. To participate in this survey, greenhouse growers had to be using ZRS systems currently, or to have previously tried a system; they were initially contacted by mail, with follow-up telephone interviews. Fifty greenhouse establishments participated in the survey in Spring 1996, and all were currently using ZRS systems.

Firms with production areas of <4645 m^2, between 4645 to 18,580 m^2, and >18,580 m^2 were grouped into small, medium, and large categories, respectively. Zero runoff subirrigated areas of <1858 m^2, between 1858 and 4645 m^2, and >4645 m^2 were grouped into small, medium, and large zero effluent area categories, respectively. Among the 50 firms surveyed, 10, 21, and 19 firms were categorized as small, medium, and large firms, respectively; and 19, 15, and 16 firms were categorized as firms with small, medium, and large zero effluent area, respectively.

For most survey questions, respondents checked a response that best described their situations from a set of alternatives. When "none of the above" was chosen, the respondents were asked to provide comments. Chi square distributions were used to test the independence of two variables, e.g., size of firm and type of system adopted. Frequency counts of survey responses were used to calculate the chi square test statistics. The frequencies of responses were then converted to relative frequencies (percentages) and presented in the report. Ratings were applied to questions measuring degrees of relative importance or satisfaction of a subject. Response ratings were arranged as a scale of ordinal levels from one (the lowest rating) to six (the highest rating). We performed an analysis of variance (ANOVA) on the average ratings of the importance of seven reasons to adopt ZRS systems and separated means by Fisher's least significant difference (LSD) test at $P \leq 0.05$. ANOVA procedures were used to test the effects of size of operation and size of zero effluent area on average cost of each ZRS system and the average rating of satisfaction with the services provided by the supply industry.

CHARACTERISTICS OF THE BUSINESSES

Most greenhouse operations with ZRS systems were large. Seventy-eight percent of those surveyed had annual gross sales >$500,000, 12% had between $100,000 and $500,000, and only 2% had <$100,000. According to the U.S. Dept. of Agriculture's summary of floriculture crops for 1995 (U.S. Dept. of Agriculture, 1996), the distribution of floriculture production firms with >$500,000, between $100,000 and $500,000, and <$100,000 in annual gross sales was 16%, 30%, and 54%, respectively. Similarly, the surveyed operations had large production areas. Only 20% had <4645 m^2; 42% had between 4645 and 18,580 m^2; and 38% were >18,580 m^2. For 62% of the surveyed operations, wholesale was the sole marketing channel for their products. Of the remaining 38% involved in retail activities, 64% also sold wholesale. These results are consistent with general findings that small firms lag behind larger firms in their plans to adopt technology (Craig and Noori, 1985). Large-scale operations adopted ZRS systems because of greater access to capital and human resources, allowing them to experiment with new technologies.

The surveyed businesses responded that they converted only a small portion of their production area to ZRS systems in order to keep investment costs and the risk of adopting a new technology low. Sixty percent of the surveyed businesses had converted less than one-third of their production area to zero effluent. However, many are continuing or planning to expand their ZRS areas. Most growers had a relatively short-term experience with this technology; 36% had <3 years' experience and only 10% had >10 years' experience. Size of operation was not related to either proportion of greenhouse area converted to ZRS, or years of experience in adopting ZRS systems (Table 1).

Received for publication 21 Apr. 1997. Accepted for publication 6 Oct. 1997. This research was supported by the Kenneth Post Foundation. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.
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ISSUES FOR ADOPTING A ZRS SYSTEM

Survey participants were asked to rate the importance of seven reasons to adopt the zero effluent technology (Table 2). The most important reasons were "improve product quality," "cut production costs," "increase production efficiency," and "more control over operation"; "environmental concerns" and "government regulations" were less important reasons. In agreement with the results of a similar study in Europe, growers chose subirrigation mainly because it improves the efficiency of their operations by saving labor and conserving water and fertilizer (Molitor, 1990).

System type. The system most commonly used by survey participants was ebb-and-flow benches (Table 3). Both size of operation and size of zero effluent area influenced the type of system adopted. Ebb-and-flow bench systems were most common in small- and medium-sized operations, as well as when the size of the zero effluent area was small or medium. Large operations and operations with large-scale zero effluent production areas tended to use more than one type of subirrigation system. The large operations were also more likely to choose flood floors as the sole ZRS system.

A supplier was the most common source of ZRS systems, especially for medium-sized operations (Table 3). Most greenhouse operators (66%) found in-house resources were sufficient for regular technical maintenance and repairs of ZRS systems, and only 2% depended solely on the suppliers for system maintenance and repairs. Large operations tended to use more computer control on their ZRS systems.

Management of recirculated solutions. To achieve zero effluent production, 94% of the surveyed growers recirculated and reused the collected irrigation solutions, 3% diverted the collected solutions to a sanitary sewer, and 3% used both methods.

One common concern in the industry about producing crops with recirculation systems was the potential for spreading disease through recirculated nutrient solutions. Survey data showed 84% of operations did not treat the recirculated solutions to control pathogens before reuse. Although not tabulated here, the majority of growers (78%) did not find pathogen problems to be associated with the recirculated water; 20% of the growers indicated they experienced fewer disease problems; and only 2% said they experienced disease problems related to the use of zero effluent production systems. Thirty-one percent of the growers said use of chemicals was reduced in their pest and pathogen management programs, and 53% said they used the same disease management practices before and after the adoption. The remaining growers indicated that they adjusted their disease management practices after the adoption, including injecting bromine into the recirculation solution and using more vigorous sanitary practices.

Growers who experienced fewer disease problems after adopting zero runoff subirrigation systems responded that because foliage stayed dry and system surfaces dried quickly after irrigation, foliar pathogens were reduced. Growers agreed that good sanitation practices were essential to disease-free production. Several growers expressed concern about the spread of pathogens via recirculation of irrigation solutions collected from greenhouse areas that were watered by overhead systems. They identified the need for affordable and effective disinfection systems to deal with this problem. While 96% of the growers surveyed found no root-zone problems caused by using ZRS systems, nearly half (48%) recognized the need to closely monitor the root-zone environment, including pH and electrical conductivity (EC) of the nutrient solutions, and substrate analysis.

Production adjustments. Participants were asked what production adjustments they made after the installation of ZRS systems (Fig. 1). Eighty-four percent of the growers adjusted

Table 1. Proportion of greenhouse area converted to zero runoff subirrigation (ZRS) systems and years of experience with these systems as affected by size of operation.

	Firm size[z]			
Survey	Small	Medium	Large	All
Greenhouse area converted to ZRS systems (%)				
<1/3	70	62	53	60
1/3 to 2/3	0	33	24	23
>2/3	30	5	24	17
	Chi square (4 df) = 6.94[NS]			
Years of experience with ZRS systems (%)				
0–3 years	30	24	53	36
4–6 years	70	48	21	42
7–9 years	0	19	10	12
>10 years	0	9	16	10
	Chi square (6 df) = 10.18[NS]			

[z]Based on total production areas: small is <4645 m^2, medium is 4645 to 18,580 m^2, and large is >18,580 m^2.
[NS]Nonsignificant.

Table 2. Rating of the importance of reasons for deciding to adopt zero runoff subirrigation systems.

Reason for decision	Mean rating[z]	Standard error	Median	Minimum	Maximum
Improve product quality	5.39 a[y]	0.14	6	1	6
Cut production costs	4.91 ab	0.17	5	2	6
Increase production efficiency	4.83 b	0.15	5	2	6
More control over operation	4.64 bc	0.18	5	3	6
Public concern for the environment	4.15 dc	0.19	4	1	6
Government regulations	3.94 d	0.24	4	1	6
Concern for worker safety	3.40 e	0.23	3	1	6

[z]Ratings are on a scale of 1 to 6, where 1 is not an important reason, and 6 is very important.
[y]Mean separation by LSD multiple comparison analysis ($\alpha = 0.05$).

Table 3. Type of zero runoff subirrigation (ZRS) systems adopted, sources of acquiring the systems, sources of system maintenance and repair, and methods of system monitoring and control as affected by size of operation and size of zero effluent area.

	Firm size[z]			Size of zero effluent area[y]			
Survey	Small	Medium	Large	Small	Medium	Large	All
Type of system (%)							
Ebb-and-flow benches only	50	86	29	74	80	14	58
Flood floors only	0	10	24	5	7	29	13
Trough benches only	40	0	0	16	7	0	8
Multi-systems[x]	10	5	47	5	7	57	21
	Chi square (6 df) = 35.41***			Chi square (6 df) = 25.73***			
Sources of acquiring the system (%)							
Developed in-house	40	5	21	21	7	16	18
Acquired from a supplier	50	76	42	63	80	14	58
Both	10	19	37	16	31	44	24
	Chi square (4 df) = 9.31*			Chi square (4 df) = 8.76[NS]			
Sources of system maintenance and repair (%)							
In-house	60	71	63	58	67	75	66
Supplier	0	5	0	5	0	0	2
Both	40	24	37	37	33	25	32
	Chi square (4 df) = 0.81[NS]			Chi square (4 df) = 2.41[NS]			
Methods of system monitoring and control (%)							
Computer	20	10	41	11	13	47	23
Manual	60	29	12	50	20	13	29
Both	20	62	47	39	67	40	48
	Chi square (4 df) = 11.67*			Chi square (4 df) = 11.39*			

[z]Based on total production areas: small is <4645 m^2, medium is 4645 to 18,580 m^2, and large is >18,580 m^2.
[y]Based on ZRS production area: small is <1858 m^2, medium is 1858 to 4645 m^2, and large is >4645 m^2.
[x]Two or more ZRS systems among ebb-and-flow benches, flood floors, and trough systems were adopted.
[NS, *, ***]Nonsignificant or significant at $P \leq 0.05$ or 0.001, respectively, by chi square tests.

fertilization practices, and of these growers, 83% indicated they used lower fertilization rates after installation. Sixty-six percent of the surveyed growers changed their irrigation schedule or timing; 36% said they irrigated less frequently; and 12% said they watered more frequently. Twenty percent of the growers indicated computerization helped them to irrigate more precisely. Fifty-eight percent made adjustments to their greenhouse space utilization. Reasons attributed to the more efficient use of greenhouse space included the use of rolling benches and the greater flexibility of subirrigation systems vs. drip tubes.

LABOR ISSUES

Managers were asked how they trained employees to operate the new systems, and also how employees reacted to the change to a nontraditional production practice. Seventy-six percent of the growers found some kind of training for employees was necessary to operate the new systems (Table 4). Training needs included system control and operation, computer operation, cultural practice adjustments, and maintenance and repair of the system. Among those managers who answered that training was necessary, 63% found in-house training was sufficient to orient employees to operate the new system, 29% sought some form of assistance from the suppliers to train the employees, and only 8% depended solely on the suppliers for training (Table 4). Managers did not find learning difficult.

Twenty-six percent of the managers reported employee resistance to using the new system (Table 5). Reasons cited for resistance included fear of the unknown, fear of using computers, unwillingness to change, and perceived inconvenience caused by the new cropping system, such as bending required by growing crops on floors and less aisle space caused by installation of rolling benches. Five managers remarked that they noticed more resistance from older employees and middle managers. Managers found that maintaining good communication with employees before and during the change reduced frustration and eased the transition. For employees with difficulties, offering additional training programs, as well as flexible arrangements to allow transfer to other production tasks when the problem persisted, also reduced frustration. Most operations (92%) did not report an effect on their employee turnover rates (Table 5).

Ninety-two percent of the growers surveyed said less labor was required by the ZRS systems compared with the previous systems, and 8% noted no change in labor requirements. Labor savings varied widely, and depended on the system replaced and the previous degree of automation.

COSTS AND BENEFITS OF USING ZRS SYSTEMS

Managers were asked to evaluate the costs and benefits of their investment in ZRS technology. They were asked to compare their previous overhead leaching watering systems with current ZRS systems as to major costs and benefits.

Costs. Cost estimates for ebb-and-flow benches were the highest for the three major subirrigation methods studied. The average equipment costs for ebb-and-flow benches, flood floors, and trough benches were \$50.70, \$27.66, and \$31.22/m^2, respectively (Table 6). Size of operation and size of ZRS area had no significant effect on the average costs of any of the three systems. Note that the level of sophistication of the plumbing, wiring, and computer control system influences the final costs. For instance, the costs of computer systems used to control ZRS systems ranged from \$2.48 to \$21.53/m^2, according to the growers. Ninety percent of the managers indicated that the costs for maintenance and repair of the new systems were low. Ninety-four percent of the managers responded that the increased utility costs for operating ZRS systems were so minimal that they did not record them. Managers believed it was easier to maintain their new system than a drip irrigation system. The cost of construction materials for different subirrigation systems, the difference between costs of new construction and retrofitting, and the need to remove existing benches

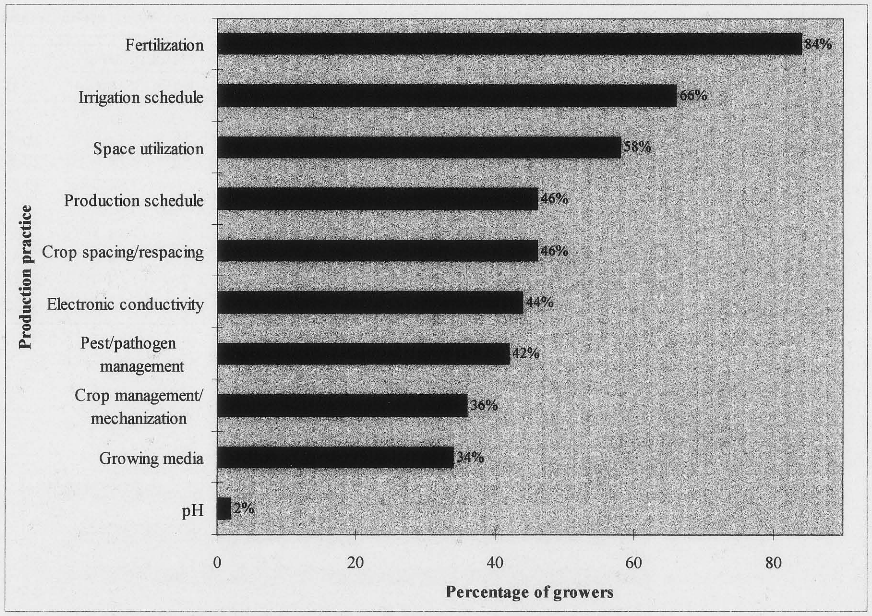

Fig. 1. Production practices adjusted after adopting zero runoff subirrigation systems.

Table 4. Labor training required to operate zero runoff subirrigation systems by size of operation.

Training required	Firm size (%)[z] Small	Medium	Large	Total	Training provider	Firm size (%)[z] Small	Medium	Large	Total
Yes	80	62	89	76	In-house	71	79	47	63
					Supplier	0	7	12	8
					Both	29	14	41	29
						Chi square (4 df) = 4.10[NS]			
No	20	38	11	24		N/A			
	Chi square (2 df) = 4.27[NS]								

[z]Based on total production areas: small is <4645 m^2, medium is 4645 to 18,580 m^2, and large is >18,580 m^2. Percent within column.
[NS]Nonsignificant.

Table 5. Employee resistance and change in employee turnover rate after using zero runoff subirrigation systems by size of operation.

Survey	Firm size[z] Small	Medium	Large	All
Employee resistance (%)				
Yes	20	14	42	26
No	80	86	58	74
	Chi square (2 df) = 4.25[NS]			
Change in employee turnover rate (%)				
Yes (decreased)	20	0	11	8
Yes (increased)	0	0	0	0
No change	80	100	89	92
	Chi square (4 df) = 3.95[NS]			

[z]Based on total production areas: small is <4645 m^2, medium is 4645 to 18,580 m^2, and large is >18,580 m^2.
[NS]Nonsignificant.

Table 6. Costs of zero runoff subirrigation (ZRS) systems and satisfaction with the technology and services available from the supply industry as affected by the size of operation and the size of zero effluent area.

	Firm size^z			Size of zero effluent area^y			
Survey	Small	Medium	Large	Small	Medium	Large	All
			Average costs ($/m^2)				
Ebb-and-flow benches	48.12^{NS}	53.18^{NS}	47.69^{NS}	48.12^{NS}	53.18^{NS}	47.69^{NS}	50.70
Flood floors	N/A	35.52^{NS}	25.62^{NS}	N/A	35.52^{NS}	25.62^{NS}	27.66
Trough benches	39.72^{NS}	21.53^{NS}	51.78^{NS}	48.44^{NS}	25.40^{NS}	51.78^{NS}	31.22
			Average rating of satisfaction^x				
System performance	4.5^{*x}	4.7*	3.7*	4.2^{NS}	4.8^{NS}	3.8^{NS}	4.27
Ease of operation	4.8^{NS}	4.8^{NS}	4.0^{NS}	4.6^{NS}	4.9^{NS}	4.0^{NS}	4.48
Technical support	4.2^{NS}	3.9^{NS}	3.2^{NS}	3.7^{NS}	4.2^{NS}	3.3^{NS}	3.72
Reliability	5.1*	4.6*	3.8*	4.6^{NS}	4.6^{NS}	4.4^{NS}	4.40

^{z}Based on total production areas: small is <4645 m^2, medium is 4645 to 18,580 m^2, and large is >18,580 m^2.
^{y}Based on ZRS production area: small is <1858 m^2, medium is 1858 to 4645 m^2, and large is >4645 m^2.
^{x}Ratings are on a scale of 1 to 6, where 1 is not satisfied, and 6 is very satisfied.
$^{NS, *}$Nonsignificant or significant at $P \leq 0.05$ by one-way analysis of variance within rows.

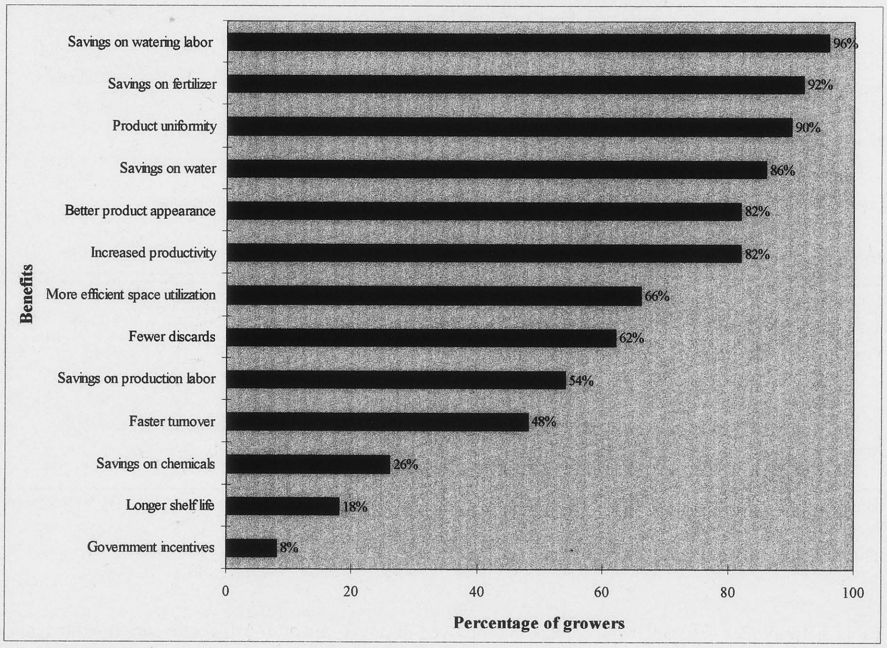

Fig. 2. Benefits received from using zero runoff subirrigation systems.

and irrigation systems were factors that influenced the initial investment.

Benefits. The top three benefits from investing in ZRS systems perceived by growers were savings on irrigation labor, savings on fertilizer, and more uniformity of products. Savings on water, better product appearance, and increased productivity were also key benefits (Fig. 2). The greatest economic benefit of using subirrigation systems was the reduced requirement for labor. Labor savings were obtained during irrigation and also during crop handling, because of improved flexibility for plant spacing, elimination of drip tube distribution, etc. Fertilizer costs were reduced by lower fertilization rates as well as recirculation of the nutrient solution. The perceived benefits from using ZRS systems were not affected significantly by size of operation.

Eighty-six percent of the participants thought the investment in a ZRS system would pay for itself. Fifty-eight percent of these respondents said that the costs would be recovered within 5 years, 25% said between 6 to 10 years, 5% said >10 years, and the remaining 12% said they did not know. Growers recognized that adoption of a ZRS system is a long-term investment, and that the payback is not immediate. Greenhouse operators appeared to believe that they were achieving the intended outcomes and efficiencies from their investment. Ninety-four percent of the growers indicated that they were happy with the ZRS system they adopted. They also appreciated the value of intangible benefits, such as public perception and environmental stewardship.

The managers were also asked to rate the degree of satisfaction with system performance, ease of operation, and reliability of zero effluent technology, as well as services available from the supply industry. Although they were generally satisfied with the ZRS technology and service available from the supply industry, large operations seemed to be less satisfied. The degree of satisfaction differed significantly by firm size for system performance and reliability (Table 6).

Although the survey results showed that large operations were most likely to adopt ZRS technology, economies of size could not be verified in this study. Cost of the systems and most of the production and management practices did not differ significantly with either size of operations or scale of zero effluent production areas. The need for more readily available cultural and management information was repeatedly identified. Trial and error were common when making adjustments to crop growth conditions under ZRS systems, which could be costly for growers. While many surveyed growers claimed that the investment had catalyzed other positive changes in their operations, they also indicated that high investment costs, slow return on investment, and management difficulties are perceptions that limit widespread use of ZRS systems by commercial growers.

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