Pest Management in the United States Greenhouse and Nursery Industry: IV. Weed Control

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Summary. Members of the American Association of Nurserymen and the Society of American Florists were surveyed as to their use of herbicides and nonchemical alternative weed control practices for 1993. Glyphosate was the top-ranking herbicide among the total of 37 reported, in terms of number of respondents and estimated total amounts

of active ingredients applied. It was used by all but two of the respondents that used herbicides in their operations. Oryzalin was the top-ranked preemergent herbicide, and was second only to glyphosate in number of respondents and amount of active ingredient applied. The highest estimated use in amounts of active ingredient applied was in the southeastern (43% of total) and north-central (27% of total) regions, nearly two to three times the estimated use in the northeastern or western regions. However, there were only about 50% more respondents in the southeastern or north-central regions compared to the other regions. About 56% of herbicide active ingredients used were in field sites, 22% in container sites, 19% in perimeter areas, and 3% in greenhouses. Large firms (annual sales more than \$2,000,000) used the greatest estimated total amount of active ingredients, while small firms (annual sales more than or equal to \$500,000) tended to use nonchemical alternatives the most. Nearly all respondents used handweeding or hoeing as part of their weed control program. Mowing was used by 84% of the respondents, 71% used tractor cultivation, and 66% used mulches (includes gravel and black plastic). Alternative methods were rated as somewhat effective to very effective by 65% or more of the respondents who used them.

Chemical weed control in nursery and greenhouse crops has always been a challenge since the target pest and the crop are obviously more closely related than other groups of pests are to those crops. The need for crop safety takes precedence over herbicide efficacy (Bingham, 1984). Hence, many types of herbicides have been developed based on selectivity. For example, some postemergent herbicides like sethoxydim (Vantage) can be applied over-the-top of many ornamental species to kill grass weeds selectively. Preemergent herbicides like oxadiazon (Ronstar) have been developed to control grass and broadleaf weeds in the presence of crops. Nonselective herbicides like glyphosate, which (Roundup) must be applied as directed sprays around ornamentals, are commonly used in field plantings and around the perimeters of production areas. The greenhouse and nursery industry will probably continue to rely on chemical weed control products into the future, but the methods of application, the amounts applied, etc., may have to be modified given increased environmental concerns. Moreover, the best use of any chemical product is in an integrated system that

maximizes the benefits of chemical and nonchemical weed control strategies.

According to a survey of nursery and greenhouse growers in the U.S. by SRI (SRI International, 1992), herbicides accounted for 18% of the chemicals used for pest control (compared to 38%, 42%, and 0.5% for fungicides/bactericides, insecticides/miticides, and growth regulators, respectively). In a survey of Florida's woody ornamental industry, Norcini et al. (1991) noted that 56% of the respondents used preemergent herbicides while 71% used postemergent herbicides; nearly half the respondents used both. Ronstar and Roundup were the most frequently used pre- and postemergent herbicides, respectively. Growers with smaller acreages were less likely to use herbicides. Gilliam et al. (1990) reported on the costs of weed control methods used in container production nurseries. Nurseries averaged three applications of preemergence herbicides annually, with the primary herbicides applied being OH-2 (oxyfluorfen and pendimethalin), Rout (oxyfluorfen and oryzalin), and Ronstar. The annual per acre cost of applying OH-2 or Rout was \$800 to \$1100 or \$2000 to \$2800 per hectare. Hand weeding costs ranged from \$246 to \$567 per acre, or \$600 to \$1400 per hectare. These data indicate that chemical weed control is very expensive and that small operators may not be able to afford it.

Many professionals can report observational shifts in use of specific weed control methods, but no comprehensive national study has been conducted on methods used by the greenhouse and nursery industry. The objectives of this study were to provide baseline data for herbicide use and the use of nonchemical weed control practices on a national, regional, firm size, and site (container, field, greenhouse, perimeter) basis. This information will facilitate the monitoring of changes in weed control practices, reveal areas of research and extension that should be addressed, and aid in evaluating the impact of research/extension programs and chemical industry marketing strategies. The following paper presents the results of a survey conducted with the assistance of the American Association of Nurserymen and the Society of American Florists. Survey respondents were asked to report the use of chemical and nonchemical weed control methods for 1993.

This survey was conducted and data were analyzed as detailed in Garber et al. (1996).

Results and discussion

Chemical weed control. Almost 81% of the respondents (575) used one or more herbicides. The total estimated amount of active ingredient used by the nursery and greenhouse industry in 1993 was 1,401,536 lb, or about 635 t. Glyphosate was the top-ranking herbicide among the total of 37 reported. It was used by all but two of the respondents who used herbicides, and it accounted for almost half of the estimated total

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amount of active ingredient applied (Table 1). This is not surprising since glyphosate is an effective product and is one of the most widely familiar among growers of many types of crops. It is also registered for use on all sites listed in the survey. Oryzalin was the top-ranked preemergent herbicide and the second-ranked herbicide overall. It was used by 52% of the respondents and accounted for 22% of the estimated total amount of active ingredient applied. Like glyphosate, its use is also firmly entrenched in the industry. The widespread reported use of oryzalin is probably due to the following: 1) it is labelled for use in all sites in this survey, 2) it controls grass and some broadleaf weeds, 3) it is a component of three other products registered for use in nurseries (Rout, premixed with oxyfluorfen; Snapshot DF, premixed with isoxaben; XL, premixed with benefin), and 4) it can be tank-mixed with postemergent herbicides (including glyphosate) for residual weed control. Glyphosate and oryzalin have also developed a good word-of-mouth reputation, which has helped them maintain their market share.

No other herbicide comprised more than 10% of the estimated total amount of active ingredient applied or was used by more than 38% of the respondents. However, several herbicides were reported as used by 20% or more of the respondents (listed in decreasing order of number of respondents in Table 1): oxyfluorfen, simazine, isoxaben, oxadiazon, and trifluralin. Oxyfluorfen was used by 38% of the respondents but accounted for only 4% of the estimated total amount

active ingredient applied. Its high use frequency is not surprising since oxyfluorfen is sold alone (Goal), is included in two popular premixed products (Rout and OH-2), and has some postemergence activity. The low percentage of total amount active ingredient may reflect the relatively low application rate (recommended dosage 0.25 to 2 lb a.i./A, or 0.28 to 2.24 kg a.i./ha) compared to other herbicides labelled for use in ornamental crops.

The average amount of active ingredient per respondent for the three top-ranking herbicides among the 37 reported were 371 lb (169 kg) for glyphosate, 280 lb (127 kg) for trifluralin, and 272 lb (124 kg) for oryzalin. However, the analysis of variance did not detect any significant differences among the least-squares means. Significant chi-squares indicated the influence of region ($\chi^2 = 191.4$, $P < 0.01$) and firm size ($\chi^2 = 99.8$, $P < 0.01$) on the number of respondents using various herbicides.

The highest estimated use in terms of amount of active ingredients applied was in the southeastern region, where respondents accounted for 44% of the total amount applied (Table 2), about 3-fold more than in the northeastern or western regions. Growers in the north-central region accounted for 26% of the estimated total amount applied. However, there were 50% more respondents in the southeastern or north-central regions than in the northeastern or western regions, and more reported uses of herbicides in the southeastern (776) and north-central (775) regions than in the

northeastern (457) or western (519) regions. Differences undoubtedly reflect weed pressure, type of site (container, field, greenhouse) where the crop is produced, and production acreage in a region. Relatively high use of herbicides would be expected in the southeastern region because of the longer growing season and greater weed pressure resulting from increased temperatures and rainfall. A high proportion of respondents utilizing field production in the north-central region may explain the relatively high herbicide use, because glyphosate plus oryzalin accounts for 88% of the estimated total amount of active ingredients applied. Glyphosate and oryzalin are commonly tank-mixed and applied to field plantings to provide postemergent weed control with residual preemergent activity. The relatively low herbicide use in the northeastern region may be due to the shorter growing season and cooler temperatures resulting in less weed pressure. Also, the use of primarily glyphosate, oryzalin, oxyfluorfen, and metolachlor would coincide with a large percentage of field production among the respondents in the northeastern region. Finally, herbicide applications in states such as California with a very high degree of regulation could have reduced the overall amount of herbicides applied in the western region. For example, concerns about groundwater contamination may be the reason that only 12% of the estimated total amount of simazine (22% of respondents) used nationwide was used in the western region. When active ingredient was analyzed for each chemical herbicide independently, effect

Table 1. Estimated use of chemical herbicides in the United States nursery and greenhouse industry in 1993.

Herbicide		Respondents		Estimated total active ingredient	
Chemical name	Trade name(s)	No.	% ²	lb ³	% ⁴
Glyphosate	Roundup, Kleenup	573	81	659742	47
Oryzalin	Surflan	370	52	306608	22
Oxyfluorfen	Goal	267	38	56604	4
Simazine	Princep, Sim-Trol, Simazine	207	29	13837	1
Isoxaben	Gallery	163	23	41103	3
Oxadiazon	Ronstar	149	21	18740	1
Trifluralin	Treflan, Preen	141	20	139734	10
Pendimethalin	Southern Weedgrass Control, Pendulum, Stomp	128	18	22963	2
Napropamide	Devrinol, Ornamental Herb. 5G	91	13	7652	1
Paraquat	Gramoxone	89	12	21254	2
Dichlobenil	Casoron, Dyclomec, Norosac	88	12	16308	1
Fluazifop	Fusilade, Ornamec	70	10	1925	<1
Diquat	Diquat Herbicide H/A, Reward	57	8	29985	2
Metolachlor	Pennant	43	6	31938	2
Sethoxydim	Vantage	28	4	4051	<1
K ⁺ salts of fatty acids	Sharpshooter, DeMoss	27	4	4217	<1
Pronamide	Kerb	9	1	1644	<1
All others reported ⁵		40	6	15814	1

²As a percentage of total respondents = 712; table in descending order of number of respondents.

³Estimated total active ingredient used in the United States for each herbicide.

⁴Pounds of active ingredient for a specific herbicide expressed as the percentage of the total pounds used of all herbicides = 1,741,039 lb (789 MT).

⁵Does not include fumigants.

Table 2. Estimated regional use of chemical weed control in the United States nursery and greenhouse industry in 1993.²

Herbicide	No. of respondents using an herbicide				Estimated total active ingredient (lb)			
	Region							
	Northeastern	Southeastern	North-central	Western	Northeastern	Southeastern	North-central	Western
Glyphosate	116	161	181	114	95907	298860	210057	74917
Oryzalin	77	101	119	69	63896	67920	109877	64915
Oxyfluorfen	45	85	80	55	12098	29319	6533	8655
Simazine	54	51	71	29	4180	3621	4323	1715
Isoxaben	14	69	57	22	2932	27640	7304	3228
Oxadiazon	25	53	31	38	2727	9194	1647	5172
Trifluralin	10	59	58	12	2690	119555	87901	8700
Pendimethalin	11	51	33	33	2758	15896	1308	3002
Napropamide	17	15	23	34	1777	760	2025	3090
Paraquat	11	41	21	15	1353	12054	2586	5261
Dichlobenil	19	9	32	27	4210	2106	4648	5344
Fluazifop	12	25	21	11	240	1018	393	274
Diquat	7	19	8	23	238	18941	191	10615
Metolachlor	18	9	5	10	14375	4171	1556	11837
Sethoxydim	5	11	11	1	121	3598	275	58
K ⁺ salts of fatty acids	7	10	6	4	2145	1858	143	71
Pronamide	1	1	4	3	15	224	1203	201
All others ³	6	6	13	16	3490	2979	2372	14388
Total	---	---	---	---	195154	619713	365229	221443

²The number of responses and pounds active ingredient summed across regions may differ slightly with figures in Table 1 because some respondents omitted data about their region. Data in this table was based on 130 respondents from the northeastern, 172 from the southeastern, 186 from the north-central, and 116 from the western region.

³Does not include fumigants.

of region was not significant for any of the 17 top-ranked herbicides.

The top two herbicides used in each region (based on number of respondents and estimated total pounds) were glyphosate and oryzalin, except in the southeastern region. Glyphosate and oryzalin

were also the top two herbicides in the SRI study (SRI International, 1992). In the southeastern region, trifluralin was second in total pounds (fifth in number of respondents). This may have been due to relatively high use of Snapshot TG, a granular combination of isoxaben and trifluralin. Almost

86% of the trifluralin and 67% of the isoxaben nationwide was used in the southeastern region. The ratio of the amount of trifluralin to the amount of isoxaben used in the southeastern region was 4.3:1, about the same ratio of trifluralin to isoxaben in Snapshot TG (4:1). Granular herbicides are

Table 3. Reported use of chemical herbicides for 1993 in the United States greenhouse and nursery industry by site.

Herbicide	No. of respondents ²				Active ingredient (lb) ³			
	Field	Container	Greenhouse	Perimeter	Field	Container	Greenhouse	Perimeter
Glyphosate	398	68	126	362	134008	18220	5209	5351
Oryzalin	257	118	48	90	59081	14756	1816	23847
Oxyfluorfen	128	166	23	32	4229	10754	385	416
Simazine	174	16	8	45	404	494	28	476
Isoxaben	95	84	10	11	4604	7162	177	43
Oxadiazon	57	97	16	12	1521	3292	201	124
Trifluralin	73	83	8	10	7206	28657	2953	23
Pendimethalin	26	112	16	13	2200	3891	68	38
Napropamide	64	39	6	7	1490	732	68	39
Paraquat	58	9	15	37	3510	915	130	1081
Dichlobenil	67	8	1	27	4547	168	285	317
Fluazifop	64	11	0	8	623	13	0	16
Diquat	25	6	28	35	3461	1233	1308	1904
Metolachlor	34	4	1	9	7759	260	23	196
Sethoxydim	20	6	3	2	310	309	5	508
K ⁺ salts of fatty acids	2	2	19	8	32	8	808	162
Pronamide	9	0	0	0	662	0	0	0
All others ⁴	21	8	5	11	2205	2682	98	440
Total	---	---	---	---	237852	93546	13562	83146

²Number of respondents using herbicides by location were: field, 449; container, 257; greenhouse, 184; perimeter, 371.

³Number of pounds active ingredient summed across sites may not agree with figures in Table 1 because some respondents omitted data about their sites.

⁴Does not include fumigants.

Table 4. Reported use of chemical herbicides for 1993 in the United States nursery and greenhouse industry by firm size².

Herbicide	No. of respondents ¹			Active ingredient (lb) ¹		
	Firm size					
	Small	Medium	Large	Small	Medium	Large
Glyphosate	222	200	143	28595	59573	123252
Oryzalin	129	119	112	22158	24526	52232
Oxyfluorfen	71	86	102	2037	2641	11023
Simazine	73	73	56	1085	1465	1827
Isoxaben	36	53	72	1507	3764	6951
Oxadiazon	58	45	43	1102	1655	2412
Trifluralin	34	44	61	16975	9509	12400
Pendimethalin	23	42	58	139	700	5396
Napropamide	25	29	36	329	544	1476
Paraquat	25	26	37	1090	1009	3984
Dichlobenil	40	23	24	716	1439	2882
Fluazifop	19	26	24	100	231	247
Diquat	8	21	28	197	1163	6592
Metolachlor	11	12	16	423	2100	5595
Sethoxydim	8	8	11	611	393	126
K ⁺ salts of fatty acids	3	11	13	226	291	563
Pronamide	0	5	4	0	182	480
All others ⁴	6	15	19	474	1095	4448
Total	---	---	---	77784	111185	241886

²Firm size based on 1993 sales: small (less than or equal to \$500,000), medium (\$500,000–\$2,000,000), and large (>\$2,000,000).

¹The number of responses and pounds active ingredient summed across regions may not agree with figures in Table 1 because some respondents omitted data about their firm size. Data in this table was based on responses from 285 small firms, 225 medium firms, and 165 large firms.

⁴Does not include fumigants.

frequently used by growers of containerized plants and the southeastern region has a high percentage of container production. In Florida, for example, about 80% of ornamental production is in containers. Metolachlor, reported as number three (number of pounds) for the northeastern region, is commonly used in field production. The wide range of ornamental species tolerant to metolachlor and/or amount of field production may explain its relatively high use in the western region. A broad range of crops, from tropical to temperate species, are grown in California, Oregon, or Washington (83% of the respondents in the western region).

Sixty-three percent of the growers who used herbicides in field plantings used about 56% of herbicide active ingredients. Almost equal amounts were used in container sites and on nursery/greenhouse perimeters (22% and 19%, respec-

tively) (Table 3), although 16% more respondents used herbicides for perimeter weed control (52%) than for weed control in container crops (36%). The lowest reported use of herbicides was within greenhouses (3% active ingredient). The low use rate in greenhouses is not surprising since few herbicides are labelled and/or safe for this site. SRI International reported similar trends, with the majority of herbicides applied to field or container nurseries (SRI, 1992).

The specific herbicides used in each site seemed to reflect label considerations, efficacy, and ease of use. For example, preemergent herbicides are used much more frequently for weed control in container-grown plants since the use of postemergent herbicides (except for grass herbicides) is severely limited. Not surprisingly then, the top six products used in container production

based on number of respondents were all preemergent herbicides: (listed in decreasing order) oxyfluorfen, oryzalin, pendimethalin, oxadiazon, isoxaben, and trifluralin. With respect to total pounds, trifluralin was the number one herbicide. This indicated use of granular trifluralin as well the premixed combination of trifluralin and isoxaben marketed as Snapshot TG. Oxyfluorfen was used by the most respondents although the amounts of trifluralin, glyphosate, and oryzalin were each greater. In the cases of trifluralin and oryzalin, this simply may have been a reflection of relative use rates. Both are generally applied at higher rates than oxyfluorfen.

This trend differed considerably in field, greenhouse, and perimeter locations. In these cases, the primary herbicide applied was glyphosate (based on number of respondents and total amounts

Table 5. Experience with alternatives to chemical weed control in the United States greenhouse and nursery industry in 1993.

Chemical alternative	Respondents ²		Rating of alternative (% response)			
	No.	% ¹	Not effective	Somewhat effective	Very effective	Effective but impractical
Handweeding, hoeing, etc.	666	97	4	38	33	25
Mowing	556	84	9	61	27	3
Cultivation (tractor)	468	71	3	46	44	7
Mulches (including gravel and plastic)	436	66	3	44	45	8
Media sterilization (steam)	198	31	4	29	46	21
Soil solarization	133	21	10	36	29	25

²Respondents were queried as to whether or not they have used a particular weed control alternative and, if so, to rate its effectiveness: 630–686 (depending on the alternative) of the 712 total respondents provided data for this question.

¹Percent of respondents who answered this question that have used a particular chemical weed control alternative.

Table 6. Regional use of alternatives to chemical weed control in the greenhouse and nursery industry in 1993.

Chemical alternative	Region (% response) ²			
	Northeastern	Southeastern	North-central	Western
Handweeding, hoeing, etc.	96	98	95	99
Mowing	90	92	87	62
Cultivation (tractor)	63	70	78	69
Mulches (includes gravel and plastic)	72	66	61	69
Media sterilization (steam)	34	33	24	38
Soil solarization	16	28	16	24

²Percent of respondents calculated by number of respondents using the alternative divided by total respondents in the respective region who stated whether or not they used a particular alternative. Depending on the alternative, 38–152 respondents in the Northeast, 177–192 in the Southeast, 192–211 in the North Central, and 122–131 in the West provided data for this table.

applied) (Table 3). It was used by 98%, 89%, and 68% of the respondents who used herbicide for weed control in perimeter, field, and greenhouse locations, respectively. Although other herbicides were reported as used in field and perimeter locations, oryzalin was the primary herbicide applied after glyphosate. The use of glyphosate and oryzalin (total amounts applied) for field and perimeter locations combined was 82% and 92%, respectively. Although many other herbicides were reported for field and perimeter use, they were not in substantial amounts of active ingredient.

Glyphosate, oryzalin, diquat, and the potassium salts of fatty acids, the four herbicides specifically registered for greenhouse use at the time of the survey, were four of the top five top-ranking herbicides by the respondents. While other herbicides were reported as used in greenhouse sites, these uses may have resulted from greenhouse perimeter applications and grower confusion as to the definition of a greenhouse (retractable side structures, overwintering structures, etc.).

The total amount of herbicide use in general was directly related to firm size (Table 4). Large firms (sales more than \$2,000,000) used 56% of the total amount of the active ingredients, while

medium-sized firms (sales of \$500,001 to \$2,000,000) used 26% of the total. This was not surprising since large firms produce the greatest number of plants. Similar results were reported by Norcini et al. (1991) for Florida's woody ornamental industry. Trifluralin was the major exception to this trend. Nearly 44% of the total amount of trifluralin was used by small firms (sales less than \$500,000); medium and large firms accounted for 24% and 32% of the usage, respectively.

Analysis of variance conducted for each herbicide independently indicated significant influence ($P < 0.05$) of the size of the firm on the active ingredient for eight herbicides (dichlobenil, glyphosate, napropamide, oxadiazon, oxyfluorfen, paraquat, pendimethalin, and simazine). The larger firms used more active ingredients of these eight chemicals than small or medium firms. However, size was not an important factor for other herbicides. Unlike the trend of active ingredient being used more as firm size increased, the percentage of respondents who used a particular herbicide varied with the specific herbicide (Table 4).

Alternatives to chemical weed control. Nineteen percent of respondents did not use herbicides. It cannot be concluded from the data in

this survey that all 18% used alternative methods of weed control; however, almost all respondents used handweeding or hoeing (97%) as part of their weed control program (Table 5). Other major alternatives to chemical weed control were mowing (84%), tractor cultivation (71%), and mulching (66%). Media sterilization, which is primarily applicable to greenhouse and container production, was used less frequently (31% of respondents). Soil solarization was the least used of all methods (21% of respondents). Wider use of this technique may not be feasible since solarization depends on sufficient number of full sun days to generate the heat needed to kill weed seeds, and many regions of the country do not have sufficient sunny days. Most respondents using alternative methods rated them somewhat effective to very effective, although none of the alternatives was deemed very effective by more than 46% of the respondents (Table 5). More than 20% of the respondents reported handweeding, solarization, and media sterilization as effective but impractical. Other alternative methods reported by only a few respondents included the following: cover crop (4 respondents), weed control mats (3), sanitation (2), and use of ammonium nitrate (2). Maintaining grass strips between

Table 7. Experience with alternative to chemical weed control with respect to firm size^{2,3}.

Chemical alternative	Effectiveness rating (% response)											
	Not effective			Somewhat effective			Very effective			Effective but impractical		
	Firm size											
	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
Handweeding, hoeing, etc.	3	3	4	38	40	39	33	33	35	27	24	22
Mowing	7	10	13	63	63	55	29	24	28	2	3	4
Cultivation (tractor)	3	4	0	41	51	48	48	41	42	8	4	10
Mulches (includes gravel and plastic)	3	2	5	42	49	39	47	41	49	8	8	7
Media sterilization (steam)	5	1	5	23	35	29	46	46	46	26	18	20
Soil solarization	7	12	12	39	44	18	30	19	41	24	25	29

²Respondents were queried as to whether or not they have used a particular alternative and, if so, to rate its effectiveness; depending on the alternative, 46–269 small firms, 52–227 medium-sized firms, and 34–165 large firms provided data for this table.

³Size of firm based on 1993 sales: small (\$0–\$500,000); medium (\$500,001–\$2,000,000) and large (>\$2,000,000).

rows, preventing seeding, preemergence weed barrier, flame thrower, heat, clean buffer areas, and cultivation by mules were also reported.

Use of the six major weed control alternatives showed about the same distribution over the four regions (Table 6). The only alternatives rated as very effective by more than half the respondents were in the western region—media sterilization by steam (59%) and tractor cultivation (52%) (results not shown). A slightly higher use of solarization was reported in the southeastern region (4% to 12%) than the other three regions. However, there was not much agreement among respondents from different regions on the effectiveness of soil solarization. For example, 19% to 40% of the respondents found it very effective and 5% to 23% found it ineffective (results not shown).

Nonchemical weed control alternatives tended to be used more by small firms than medium or large firms. The maximum number of respondents from small, medium, or large firms that used an alternative was 265, 227, and 165, respectively. However, the number of respondents who used a specific alternative varied considerably by firm size (results not shown). Use of handweeding, tractor cultivation, and mulching were not affected by firm size, with trends similar to those nationwide (Table 5). In contrast, small firms reported slightly more (15% to 18%) use of mowing and substantially more use of media sterilization (94% vs. 38% and 35% for medium and large firms, respectively) and solarization (64% vs. 24% and 21% for medium and large firms, respectively) for weed control. Interestingly though, 41% of respondents from large firms rated solarization as very effective but only 30% of respondents from small firms rated it very effective (Table 7). The relatively high use of media sterilization and solarization by small firms may have been because a large proportion of respondents from small firms were involved with container or greenhouse production. Many medium and large firms resorted to the other four methods as alternatives to chemical weed control, although those that used media sterilization and soil solarization were generally as satisfied (i.e., somewhat effective plus very effective) with these methods as the small firms (Table 7).

Implications for university research and extension programs

University faculty should consider initially targeting large firms in their research and extension programs because this would seem to have the greatest initial impact. Since large firms were the greatest consumers of herbicides, significant reductions in total herbicide use could be realized if large firms increased their use of nonchemical alternatives, or reduced their chemical utilization by using current herbicides more effectively and by applying herbicides that are effective at lower

rates of active ingredients. Moreover, larger firms have more resources available to invest in experimenting with new or modified weed control practices. Incentives to growers on a local, state, or national level would further encourage use of alternative practices or more effective herbicides.

Based on the results of this survey, specific areas of weed control research that could be addressed are the following: 1) reduction in overall use of glyphosate through use of herbicidal soaps or nonchemical alternatives, 2) finding alternatives for herbicides that pose a relatively high risk of contaminating groundwater, and 3) nonchemical alternatives, especially for practices like soil solarization. Almost 30% of respondents from large firms rated this practice as effective but impractical. However, refinement of this technique could greatly increase its use by the greenhouse and nursery industry.

Follow-up surveys need to be conducted so that more specifics can be obtained about weed control practices. For example, detailed information about frequency of weed control practices and rates used could be procured by interviewing growers individually. This was one of the issues that we were unable to address in this survey because growers were asked to provide information about all of their pest control practices. In the interest of obtaining a high response rate, we had to limit the amount of information we could ask for with regard to chemical pesticide use (herbicides, insecticides/acaricides, fungicides/bactericides, fumigants, and plant growth regulators) and nonchemical alternatives.

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Pest Management in the United States Greenhouse and Nursery Industry: V. Insect and Mite Control

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Summary. A national survey of the greenhouse and nursery industry provided data on insecticide/miticide use in 1993. Respondents reported using 46 different compounds, and the industry used an estimated 2.8 million pounds of active ingredients to control insect and mite pests. The most frequently used material

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