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CHEMICAL WEED CONTROL IN WESTERN CONIFER NURSERY BEDS--RESEARCH AND PROGRAM DEVELOPMENT

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Weeds are the greatest single biological obstacle to the production of high-quality nursery stock in the Pacific Northwest. They are every nurseryman's headache, and weed control is the major item in every nursery budget. Weeds kill seedlings. They are alternate hosts for diseases, they increase lifting costs, and they seriously downgrade the surviving stock.

Consideration for weeds promotes the use of management practices that are poor nursery management, but necessary to survive in face of weed problems. Late sowing is a means of bypassing spring-season weeds. Much of the over-tillage of nursery beds is done out of consideration of weeds. Fumigation is often exclusively for weed control, perhaps to the detriment of mycorrhizae.

The alternatives to fumigation include herbicides, tillage, and hand weeding. Because only a few marginally effective herbicides are registered for use in nurseries, our alternatives are still costly to live with, relying as they do on stoop labor.

In our research and development, we have examined herbicides for weed control at every important stage of seedling development, and have integrated our findings in terms of weed management programs for several species. Our objective in this paper is to present the concept of integrated weed management programs, and to share the results of herbicide tests as they have contributed to the various parts of a program developed from 1974 to 1976. To this end, we have categorized weeds according to when they occur in the life of a seedbed, screened herbicides on conifers at various stages of development in the greenhouse and the field, and applied herbicide plots to operational seedbeds. Finally, we have placed in service a virtually complete chemical weed control program for the past twelve months in a production nursery at Brownsville, Oregon. Our program will be described in terms of the selection of herbicides, and rates and timing of application. Results are expressed in terms of injury, cost of hand-weeding, and production of high-quality 2-0 conifer stock.

Review of the literature

There is considerable information in print about how to kill nursery weeds. Generalizations for this literature are extremely risky, however, because of the different formats in which herbicides have been evaluated and different management and soil systems present in the different test situations.

Miller et al. (1975) identified nursery weeds as a difficult set of problems to cope with, yet a set that had to be dealt with effectively to insure a successful national reforestation program. Among the significant factors they identified as contributing to the difficulty of program development were the small acreage of nursery land in production, the insignificant market potential for herbicides by chemical companies, and high liability for manufacturers whose products could cause damage to the exceedingly valuable seedling crop. Thus, we cannot expect chemical producers to take leadership in developing these practices, nor to file for registrations for nursery uses for those products of potential usefulness.

Perhaps the most significant testing that has been done in this country is the program under the direction of Gjerstad, at Auburn University. Started in 1971, this program has moved vigorously to test herbicides and weed management schemes throughout forest nurseries in the South (Gjerstad and South, 1975). This program pursued the testing of numerous herbicides throughout the South before and after emergence of seedlings. On February 18, 1976, a document was presented to the Environmental Protection Administration requesting that bifenox, butralin, and napropamide (Modown, Amex-820, and Devrinol) be registered for pre-emergent weed control in pine seedbeds. Registration now depends on the EPA and consent of the chemical companies.

The data cited by Gjerstad and South (1975) illustrate that these three herbicides are selective in pine seedbeds, but also leave a substantial amount of hand weeding to be done under certain circumstances. They are consistently effective during the early stages of bed development, but immigrant weeds often begin to develop after six to eight weeks. These either must be pulled by hand or be subjected to a further chemical treatment. The two herbicides registered for controlling later germination of immigrant weeds, diphenamid and DCPA, can be used to reduce the total hand weeding costs if they are included in a season-long program.

The U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station, is cooperating with the Division of State and Private Forestry to implement a program in the Northwest similar to that in the South. As yet, data have not begun to accumulate. Drs. R. E. Stewart, of the U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station, and Larry Abrahamson of the U.S. Forest Service, Ogden, Utah, are managing this program; many at this meeting are cooperators. For both of the regional programs, the principal emphasis has been on obtaining data useful in registration. Because of the amount of data needed for this purpose, both programs are essential. Perhaps as important, they serve to make chemical weed control household words among nurserymen.

Chemical weed control is a familiar proposition in New Zealand. We can draw from their considerable experience with Douglas-fir and radiata pine weed control to learn something about responses of western conifers to herbicides in nursery weed management programs, despite differences in soils and summer rainfall patterns. Van Dorsser (1975) has reported that propazine was effective in controlling broadleaf weeds in pine seedbeds when applied after sowing and before emergence at 1 kg per hectare (0.9 lb per acre) active ingredient to sandy soils. He also indicated that rates of 1 to 2 kg per hectare (0.9 to 1.8 lb per acre) were effective, safe, and inexpensive for post-emergence control. These practices are widely followed in New Zealand. In addition to these routines, he described some new data of potential interest.

Radiata and lodgepole pines were tolerant of nitrofen at 7 kg per hectare (6.3 lb per acre) when applied before emergence, and 14 kg per hectare (12.6 lbs per acre) six weeks after emergence. Van Dorsser reported good weed control at 3.5 kg per hectare, with the higher rates giving control for eight weeks. The same results were listed for applications of atrazine at 1.5 kg per hectare on radiata and 1.0 kg per hectare for lodgepole pine as post-emergence applications. Chloroxuron was effective and selective as a pre-emergence treatment of 4 kg per hectare (3.6 lb per acre) on radiata pine, and at 3 kg per hectare (2.7 lb per acre) on Douglas-fir as a post-emergence treatment. He also indicated that the addition of an oil to the atrazine treatments provided excellent knockdown of certain weeds.

Van Dorsser (1975) and Ahrens (Dr. John Ahrens, Connecticut Agricultural Experiment Station, Windsor, Connecticut, personal communication, February 1976) have identified prometryne as an effective and selective material at 1 kg per hectare after emergence. Van Dorsser also reported tentative data indicating that alachlor, propachlor, and a mixture of terbuthylazine and terbuthylaton are effective on the summer grasses as post-emergence treatments, yet without producing damage to radiata pine.

Gleed (1975) has built a radiata pine program at the Tasman Nursery (New Zealand) based on combinations of herbicides in specific pre- and post-emergence routines. His standard pre-emergence prescription is a mixture of paraquat at 3.5 liters per hectare (0.8 lb per acre) plus propazine at 1.12 kg per hectare (1.0 lb per acre) and DCPA at 6.75 kg per hectare (6.0 lb per acre); after emergence, paraquat is deleted and propazine is doubled to 2.25 kg per hectare (2 lb per acre) active ingredients. Gleed also reported that fumigation with methyl bromide and chloropicrin was used for pathogen control, but that its unfortunate tendency to kill mycorrhizae and its inadequate control of weeds led to its use primarily for critical disease problems. Even where fumigation is used, post-emergence applications are prescribed because of the need for residual weed control. He reported that injury to radiata seedlings occurs when propazine is applied to cotyledon-state radiata at rates of 2.25 kg per hectare or greater (2 lb per acre). Gleed's cost data indicate that the cost of weed control has been reduced to 62¢ per thousand seedlings when production is 700,000 per hectare (about 300,000 per acre), or $434.50 per hectare ($175.90 per acre). Gleed (1975) reported that atrazine, carbetamide, cacodylic acid, chloramben, ioxonil, octanoate, nitrofen, pentanochlor, phenmedipham, prometryne, terbutryn, trifluralin, and napropamide were screened to determine whether new developments would displace the program described above. Of those tested, he indicated that only napropamide was equal in effectiveness to those in use.

Balneaves (1975), also from New Zealand, has reported that nitrofen and paraquat are useful in growing Douglas-fir. In his program, paraquat is used before emergence at 0.6 kg per hectare (0.5 lb per acre) to control weeds emerging before Douglas-fir appears. As soon as Douglas-fir reaches the cotyledon stage, nitrofen is applied at 7 kg per hectare. When a crop of weeds has appeared and reached the first secondary-leaf stage, the nitrofen application is repeated. No damage was reported at rates of up to 16 kg per hectare (14.1 lb per acre) on Douglas-fir seedlings. The above program of herbicides was originally developed for cold soils. Under cold soil conditions, Balneaves (1975) indicated that Douglas-fir emerges over such a prolonged period that four hand weedings were needed before all the seedlings were 12 weeks of age, the earliest stage at which they could tolerate propazine.

In the Pacific Northwest, Newton and Zavitkovski (1965) reported that Douglas-fir, grand fir, and ponderosa pine were less sensitive to atrazine and propazine than were numerous weed species when the herbicides were incorporated in soil. Propazine, in particular, appeared to have the greater margin of selectivity; both were capable of causing germination failure on conifers. Ponderosa pine was less sensitive to both herbicides than were either Douglas-fir or grand fir. More recently, Newton (1975) reported that methazole showed excellent selectivity in Douglas-fir seedbeds when applied at rates of 1.7 to 3.3 kg per hectare of active ingredient as a pre- or post-emergence application on clay loam soils. At that time, he also reported that testing was under way with atrazine, DPX 3674 (Velpar), and Destun.[1] These were preliminary data; this report will continue on some of the same experimental material, plus some additional data.

Research and Development Approach

Our research in the development of chemical weed control in a forest nursery addressed four critical questions: Which herbicides can be used in the presence of conifer seedlings, and at what times of year are they safe at given rates of application? At what times of year, and at which rates of application, can the most common weeds be controlled by chemicals found to be safe on conifers? How can a series of herbicide applications be programmed so as to prevent, without injury to the conifers, the development of a weed cover between applications? How do we minimize the time needed to develop the basic data, test at the specific level, and finally test programs to our satisfaction? These questions had not been considered previously over a two-year rotation system, and we were generally without guidance except for some early data on pre- and post-emergence treatments in new seedbeds.

The approach adopted to answer these questions was as follows. To test the sensitivity of conifers to herbicides in various age classes of seedlings, we established a screening system described by Newton (1976) that would provide for an evaluation of sensitivity at two-week intervals around the date of conifer emergence. Similarly, a screening was also conducted in year-old seedbeds, so that we had data from the laboratory for germinating seeds and field tests on year-old seedlings. These data were examined, and a field test system was devised for application to new germinating seeds and seedlings in the field. All series of tests were designed to utilize herbicides with labeled uses on the principal weed species of concern in the nursery; initial choices of candidates were based on some basic principles of herbicide structure, behavior, and observed activity in other crops.

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[1]Trade names of several herbicides or adjuvants will be used here where common names have not been designated by the Weed Science Society of America as of date of publication.

Plots established to observe injury to seedlings were also evaluated for weed control, and the weed control activity was related to the seasonality of weed development and the potential for residual compared to contact activity. In this way, programming of application and residual effect was geared to the time of expected crop resistance and emergence of the weed groups.

Data gathered in laboratory and field test plots were used to develop several test programs for operational weed control with applications of several herbicides in sequence to prevent weed development. To telescope the process of screening and program development, some of these tests were conducted off-season in the laboratory, and some of the operational tests were conducted when there were still some risks unresolved in marginal test data. At the date of reporting, however, we do have a chemical weed control program needing only registration of its component parts, 28 months since we treated our first test plot. A description of the tests and data toward this end follow.

Weed Control Experiments

Plot tests in one-year-old seedbeds. Our first tests were established to test for control of winter and spring weeds in year-old Douglas-fir. Plots were established in bed-run material, with applications in December and March to replicated 9-meter bed segments. Herbicides were applied with a homemade pressure sprayer consisting of a compressed air cylinder and regulator system driving liquid through a handheld boom equipped with standard Teejet 65015 nozzles, delivering 119 liters per hectare (13 gallons per acre) at 2.1 kg per cm^2 (30 psi) and 3 mph walking speed.

Plots were evaluated in June, with data recorded in terms of injury to seedlings and ocular estimates of weed control. The assumption was made at this time that injured seedlings at this stage of development would show clear signs of damage or stunting after second-year growth was well along. Re-examination in late summer confirmed the validity of this assumption, when bed inspection did not reveal signs of latent injury. Table 1 illustrates the results of these tests. These and all other data reflect results obtained exclusively on a silty clay loam soil with 4-5% organic matter and pH of 6.5.

These plots illustrated that diphenamid, DCPA, propazine, simazine, atrazine, 2,4-D, methazole, and low rates of glyphosate can be used safely in dormant Douglas-fir seedbeds. There are few winter weeds that cannot be controlled by one or another, but residual effects of the spring treatments produced substantial control of summer weeds as well. The triazines, in particular, gave good extended weed control, and the mixture with glyphosate increased the spectrum of activity without increasing soil residues of triazines to potentially damaging levels.

Greenhouse tests of phenological sensitivity. The tests in year-old seedbeds clearly could not be conducted under analogous circumstances in new seedbeds. The difference in season, stage of growth, and weed composition precluded any findings from one extending to the other. Because of this constraint, it was necessary to consult the literature and a large array of labels from registered and experimental herbicides to determine which materials had the potential for controlling pigweed, lambsquarter, henbit, common groundsel, catsear, ryegrass, smartweed, curly dock, and numerous other weeds of somewhat lesser importance. These were the summer weed species for which we had an

Table 1. Weed Control and Seedling Vigor in Douglas-fir Dormant, Year-old Seedbeds. Treatments Applied Mid-December and Mid-March.

Herbicide	Application	Month	Seedling vigor[1]	Amount of control
	kg/ha			%
Alachlor	2.2	Dec	3	70
	3.3	Dec	-	-
	2.2	Mar	2	20
	3.3	Mar	1	70
Asulam	3.3	Dec	3	65
Atrazine	2.2	Dec	1	85
	3.3	Dec	1	95
+ (2,4-D)	2.2 + (1.1)	Dec	1	90
	2.2	Mar	1	70
	3.3	Mar	1	95
Bromoxynil	0.275 + (0.275)	Dec	1	70
+ (MCPA)	0.55 + (0.55)	Dec	1	85
	0.275 + (0.275)	Mar	1	70
	0.55 + (0.55)	Mar	2	75
Bulab-37	3.3	Mar	1	20
	6.6	Mar	1	40
CJCP	1.1	Dec	1	65
	2.2	Dec	3	80
DCPA	11.6	Dec	1	50
	13.2	Dec	1	20
	10.5	Mar	1	40
	13.2	Mar	1	60
+ (Glyphosate)	13.2 + (0.83)	Mar	1	85
Diphenamid	5.3	Dec	1	50
	7.0	Dec	1	80
	4.6	Mar	1	20
Glyphosate	1.65	Dec	2	60
	3.3	Dec	4	90
	0.825	Mar.	1	80
Methazole	2.2	Mar	1	70
	4.4	Mar	1	85
Oxadiazon	4.4	Mar	1	70
	8.8	Mar	3	70
Pronamide	0.825	Dec	1	60
	1.65	Dec	1	75
	0.825	Mar	1	70
	1.65	Mar	1	75
Propazine	2.2	Dec	1	95
	3.3	Dec	1	80

Table 1. (continued)

Herbicide	Application	Month	Seedling vigor[1]	Amount of control
	kg/ha			%
Simazine	2.2	Dec	1	85
	3.3	Dec	1	90
+ (2,4-D)	2.2 + 1.1	Dec	1	90
+ (2,4-D) + (Dalapon)	2.2 + 1.1 + 2.2	Dec	1	90
	2.2	Mar	1	85
	3.3	Mar	1	95
+ (Glyphosate)	3.3 + (0.825)	Mar	1	100
Trifluralin	2.2	Dec	2	70

[1]Vigor rating: 1, equivalent to hand-weeded plots; 2, measurable stunting; 3, tip burning, severe stunting; 4, live trees, no bud-break, and various degrees of defoliation; and 5, dead trees.

abundant seed source around the nursery and in the soil, and which we could anticipate in competition with newly emerged seedlings. We used the greenhouse to obtain two years' data in one season to bring our seedbeds under chemical control in one year.

The test procedure, described by Newton (1976), is summarized as follows: Flats were filled with nursery soil and settled with water in December. They were taken into the greenhouse and maintained at 20°C (68°F) under fluorescent-supplemented daylight extended to 16 hours. Douglas-fir seeds were stratified for one month and germinated in a germinator for planting in the flats with radicles 6-20 mm in length. Thus, only viable germinating seeds were planted, and they were inserted into prepared holes in the soil and covered lightly. Twenty or more seeds were planted in each flat at each of six planting dates, about two weeks apart.

Herbicide was applied to each flat 3 days after the fifth planting, immediately before emergence. The final planting was installed after treatment.

Herbicides were applied with a homemade plot sprayer, again powered by the same air cylinder and pressure regulation apparatus. The sprayer itself was a three-nozzle boom on wheels that was built to straddle a flat and to deliver the spray from a height of 50 cm (20 inches) above the soil surface. The herbicide reservoir was mounted on the boom, with a remotely operated gate valve. The apparatus delivered 202 liters per hectare (22 gallons per acre) at 2 miles per hour.

Seventeen flats were treated with this system in February. Two passes were made over each flat, with half the flat covered for one of the passes. Each flat except two received a nominal dose and a double rate, applied from 10 days before planting to 61 days after emergence. The other two were "row"-treated with a single nozzle turned so as to spray a swath 2 inches wide.

This test was devised to determine the width of dispersion after treatment with certain residual herbicides with potential for directed application. Although weed control was not a part of these tests, we did not hand-weed the flats until after the herbicides had had time to show considerable effect. In this way, some crude information was produced on weed control as well as seedling injury.

Table 2 summarizes the effects of these tests on survival, with remarks about the apparent consequences of herbicide activity and sensitivity to dosage.

Field tests of promising herbicides to new seedbeds. Data from the greenhouse tests were summarized and interpreted as a basis for the plots to be established in new seedbeds. Methazole clearly had remarkable selectivity and ability to control weeds if applied as a foliar treatment to any but newly emerging seedlings. There was also the suggestion that low rates of atrazine could be used effectively, especially if applied in combination with an adjuvant, such as Mor-Act, that would prevent major movement in soil. Velpar had also shown that pre-emergence applications at a low rate resulted in very vigorous seedlings despite some mortality, and propazine showed considerable safety as late post-emergence treatments. Perfluidone (Destun) had been described elsewhere as having selective control potential for yellow nutsedge. Even though this had not been screened earlier, the importance of this weed suggested a trial.

The above herbicides were screened in nursery beds as pre- or post-emergence treatments. Pre-emergence treatments were applied June 13, 9 days after sowing of 60-day stratified Douglas-fir seed. Pre-emergence treatments with methazole and Velpar were applied in 100-foot segments to achieve good sampling over variable beds; atrazine and Perfluidone were applied to 30-foot plots. Post-emergence plots included 30-foot plots with atrazine and propazine, and 100-foot plots with methazole. Date of application was July 13, about 25 days after mean emergence; a few secondary needles were emerging from prominent buds on cotyledon-stage seedlings. All plots were treated with the equipment described earlier as used on the one-year-old beds. Weed development at the pre-emergence application was at the half-inch stage of growth, with most weeds either in the cotyledon stage or not yet emerged. Post-emergence treatments were applied with a dense overstory of pigweed and lambsquarter roughly 10 inches tall, with seedlings clearly in an understory condition and 100 percent canopy closure.

Pre-emergence plots were evaluated at the time the post-emergence treatments were applied. At this time, seedling damage and mortality were recorded, and an ocular estimate was made of weed control (Table 3). At this time, all of the pre-emergence plots, except those in one replication treated with methazole or the highest rate of Velpar, were treated again, this time with a uniform rate of methazole, 2.0 kg per hectare (1.8 lb per acre).

Within three weeks, response to the post-emergence treatments obviously was not sufficient to release the seedbeds from overhead competition. At this time, they were mowed with a rotary mower operated at about 6 inches above the ground, and the weed residue was raked off the beds. All plots were examined cursorily in October, and in July, or their second year, all plots were inventoried and the events leading to the final results summarized. The final results are tabulated in Table 4.

Table 2. Seedling Survival and Responses to Greenhouse Application of Herbicides in Relation to Time of Application. Twenty Seedlings Planted Unless Otherwise Stated.

Chemical	Active ingredients nominal rate		Herbicide applied: Days pregermination		Days postgermination				Damage at 2X rate
	kg/ha	lb/A	10	5	20	34	48	61	
Control			7/40[2]	22/30[2]	20	14	17	17	--
Atrazine (Aatrex 80W)	0.88	0.8	5	2/30	2	15	13	16	yes
Norea (Herban 80W)	2.7	2.4	1	0/30	1	10	12	11	no
Simazine (Prinup 80W)	1.3	1.2	4	0/30	0	4	10	16	yes
Pronamide (Kerb)	0.4	0.37	3/30	8/30	0	7	8	13	yes
Simazine (row)	4.4 (in row)	4.0	3	9/30	4	9	17	16	--
Atrazine (row)	3.3 (in row)	3.0	6	7/30	0	2	10	16	--
Methazole (Probe 3G)	1.7	1.5	8/30	21/30	17	16	15	20	no
Glyphosate (Roundup	1.1 ℓ/ha	1 pt/A	15/30	21/30	6	8	6	5	yes
Desmedipham (Betanex)	0.8	0.7	10/30	18/30	0	10	15	13	yes
Methazole (Probe 75W)	1.8	1.5	18/30	12/30	11	18	18	20	no[1]
Propazine (Milogard 80W)	1.7	1.6	7/30	12/30	8	7	16	20	no
Profluaralin (Tolban 4E)	1.1	1.0	11/30	16/30	3	16	17	15	yes
Bulab 37 (Buban 37)	3.3	3.0	16/30	7/30	13	16	18	17	yes
GS 14254 (Sumitrol 50W)	1.1	1.0	17/30	22/30	0	10	15	17	yes
DPX 3674 (Velpar)	1.0	0.9	15/30	12/30	2	4	3	1	yes
Procyazine (Cycle 80W)	1.3	1.2	19/30	17/30	5	13	14	15	yes
Phenmedipham (Betanal)	0.8	0.7	12/30	23/30	1	9	14	13	yes

[1]Except at 20 days postgermination.
[2]First numeral is number surviving; second numeral is number planted.

Table 3. Weed Control by Preemergence Herbicides Applied to Germinating Douglas-fir.

Chemical	Active rate	Weed control	Mortality in 1975
	kg/ha	%	%
Velpar	0.25	< 20	1 (supp)
Velpar	0.5	50-70	--
Velpar	0.75	spotty 30-90	0
Velpar	1.0	75-95	Heavy
Probe 75W	1.7	75-95	0
Probe 75W	2.5	95+	0
Probe 75W	3.3	100	2
Atrazine (plus Mor-Act)	0.62	50-95	15-25
Atrazine (plus Mor-Act)	0.83	90-95	20-40
Atrazine (plus Mor-Act)	1.1	95-100	40-60
Destun	1.7	Poor; 10-20	
Destun	2.2	Poor	
Destun	2.8	30-40; (100 for grass)	
Destun	3.3	70-100	

Table 4. Density of 2-0 Douglas-fir Seedlings in Seedbeds Treated in First 40 Days with Herbicide, the Better of Two Replications.[1]

Herbicide	Active rate	2-0 Seedlings per sq ft			
		Preemergence		Postemergence	
		Total	> 9 in. top	Total	> 9 in. top
	kg/ha				
Atrazine plus	0.62	4.4	1.9	6.0	4.6
Mor-Act adjuvant	0.83	6.7	2.8	6.9	5.1
(1 qt/A)	1.1	4.2	1.8	5.2	3.8
Methazole	1.7	12.2	9.7	6.6	1.8
	2.5	13.0	12.1	4.9	2.0
	3.3	11.3	10.0	8.8	3.9
Velpar	0.25	5.0	2.8	--	--
	0.5	6.4	4.2	--	--
	0.75	3.4	2.1	--	--
	1.0	4.3	3.3	--	--
Propazine	1.4	--	--	4.9	2.4
	1.8	--	--	8.1	5.7
	1.7	5.4	0.4	--	--
	2.2	6.4	0	--	--
	2.8	2.8	0.3	--	--
	3.3	3.6	0.2	--	--

[1]One replication was affected by pathogens unrelated to treatment. These data are considered a reasonable indication of expected results from specified treatment on silty clay loam soil. Seed density = 20 per square foot.

Several events complicated the interpretation of these plots. Fusarium root rot caused some spotty mortality that was more serious in one bed than in the other three of the four beds treated. The application of methazole to the plots treated earlier appeared to aggravate an antagonistic reaction between methazole and atrazine, so it was difficult to follow mortality of seedlings in atrazine plots without confusing the kinds of injury. There was a considerable continuation of mortality on pre-emergence atrazine plots, which suggests need for caution when considering application of methazole to soil carrying triazine residues.

The best weed control and best seedling count and condition were recorded in plots that were treated before emergence with the two higher rates of methazole. Retreatment was done on plots already sustaining losses from Fusarium, and the slight reduction in vigor and inventory could have been the result either of disease or retreatment. In any event, the pre-emergence treatment at the two higher rates provided good enough weed control so that retreatment was unnecessary. No other herbicide was as effective or selective as methazole. Atrazine, Velpar, and Perfluidone all caused serious damage at this timing.

Miscellaneous weed control trials. Several additional tests were conducted to examine seasonal effects on conifers and effects on other species, or to place under control some weed problems that were clearly severe enough to threaten the seedling crop. Several were large scale, based on data from elsewhere, and although not formally done as research, they furnished important data on a scale that permitted evaluation of labor savings as well as seedling performance.

At the time of the pre-emergence tests alluded to above, many seedbeds were demonstrating the "green-haze" effect of heavy weed populations emerging before seedlings. In place of the traditional use of weed oils, we did a large test with paraquat. This herbicide, applied at 0.6 kg per hectare (0.5 lb per acre) completely cleaned the seedbeds without crop injury about 5 days before emergence. It did not furnish residual weed control.

Several problems with fall weeds cropped up that demanded attention. Annual bluegrass is particularly troublesome in fall and spring. Its notorious sensitivity to pronamide and the pending registration of pronamide on conifer plantations stimulated a test at low rates for this purpose. Pronamide is applied traditionally in the fall, and has little activity except on grasses. We thus applied the compound at the rate of 0.6 kg per hectare (0.5 lb per acre) to an incipient bluegrass problem area in October. The herbicide controlled the bluegrass and chickweed effectively without injuring 5-month-old Douglas-fir. It was not effective at this rate in controlling velvet grass or ryegrass that later posed a serious problem as a winter-spring set of weeds. To combat these grasses, we applied atrazine at the rate of 2.2 kg per hectare (2.0 lb per acre) in January. Observing no response in these moderately resistant grasses by early March, an additional 2.8 kg per hectare (2.5 lb per acre) was applied to some beds again at that time. The two consecutive applications of atrazine caused extensive damage; many of the seedlings subsequently recovered to a large extent in a third year. In the meantime, the single treatment appeared adequate and noninjurious when applied in March or April.

Another winter weed problem of consequence in spots was white clover. This weed developed to the extent that several beds were in an understory condition by late winter. Hand weeding is very tedious and notoriously ineffective for this weed. Experience in reforestation weed control suggested that the phenoxys should be selective during winter months, and 2,4-D was applied in February at the rate of 1.1 kg per hectare (1.0 lb per acre). When it became apparent that this treatment provided inadequate control, the beds were treated with the same rate of 2,4,5-T amine, which again proved unsuccessful. An application of 1.1 kg per hectare of 2,4,5-T ester finally brought control in late March. These tests illustrated that control of winter broadleaf weeds is clearly possible, and that the phenoxy herbicides can be used without injury to Douglas-fir between December and March, even with some repetition. Damage to pines or true firs is likely at this season, however. Because the phenoxys are nonresidual herbicides, these data are valid for nurseries on all soil types; the data from tests of residual herbicides need local testing to adjust rates for differences in soil-retention capacity.

We did one post-emergence series of tests on several pine species. Seedbeds that had been treated with paraquat before emergence were treated 30 days after emergence with methazole. Ponderosa pine seedbeds were treated when weeds were in the four-leaf stage at rates of 1.7 to 3.3 kg per hectare (1.5 to 3.0 lb per acre); other pines received only 2.4 kg per hectare (2.2 lb per acre) as post-emergence treatments. These post-emergence treatments gave nearly perfect weed control at all rates, and without major injury to the pines at any rate. Some foliage tip burning was present on Scots and lodgepole pine, however, which shows some analogy to data from Ahrens and from Gjerstad and South (1975) indicating that pines are sensitive to methazole. The important finding from this test was that treatment of four-leaf-stage weeds with methazole gives excellent control, and that the use of paraquat before emergence keeps weeds from developing beyond that stage before three seedlings are hardy enough to tolerate effective amounts of methazole.

Several plots were established on a sub-operational basis to evaluate some promising operations for residual weed control in spring where certain triazine-resistant weeds such as ryegrass were present. In mid-March, Velpar was applied over Scot's pine, ponderosa pine, and Douglas-fir 1-0 seedlings and again in late March at the rate of 1.0 kg per hectare (0.9 lb per acre). A mixture of glyphosate and simazine was applied over Douglas-fir 1-0 seedlings at the same time, with rates of the ingredients at 0.6 liter per hectare (1/4 qt per acre) of glyphosate and 3.3 kg per hectare (3.0 lb per acre) simazine. Atrazine was applied at 3.3 kg per hectare (3.0 lb per acre) to Douglas-fir adjacent to the glyphosate-simazine mixture. In June, several beds of second-year seedlings were treated with methazole at a rate of 2.3 kg per hectare (2.1 lb per acre). All of these plots produced outstanding weed control. Each was at least an acre in size. Out of the entire lot, Velpar controlled weeds best and caused a very minor amount of injury in ponderosa and lodgepole pines, but none in Douglas-fir. Methazole again produced some injury in Scot's pine; in this treatment, the usual procedure of irrigating methazole to rinse off conifer foliage in the second day was not followed, and injury was severe despite the seedlings being in their third year. Addition of the low rate of glyphosate to March-applied simazine gave control of weeds normally resistant to post-emergence applications of simazine. Glyphosate is highly injurious to actively growing conifers, however.

Effect of Chemical Control on Hand Weeding Requirements

Records were maintained on 11 acres of seedbeds sown in 1975 and given the following chemical weed control program. Beds were treated before seeds cracked with paraquat on June 11. Seedlings were not large enough to tolerate DCPA before a very large population of weeds emerged after the paraquat had been applied. Hand weeders were sent to work on the area to clean up the beds as a holding action until confirming data from plots became available. By July 30, weeds had completely dominated the seedbeds despite 176 weeder-hours per acre. Seedbeds were therefore mowed with a rotary mower elevated to 6 inches, and the most favorable of the test herbicides, methazole, was applied as a post-emergence treatment at 2.7 kg per hectare (2.25 lb per acre). Hand weeding was continued until the herbicide began to demonstrate effect, at which time, a total of 186.5 hours per acre had been invested. At this time, all beds were gone over one more time to clean up all dead material and surviving weeds, and all summer handweeding ended on August 21. With the beds clean, diphenamid was applied at the rate of 7.7 kg per hectare (7.0 lb per acre) on September 1. One additional patrol for weeds was completed in October, requiring 15 weeder-hours per acre. The seedbeds entered the winter clean and remained clean well into the winter. During the winter, 2,4-D, then 2,4,5-T, were applied each at 1.1 kg per hectare (1 lb per acre) to control clover. In the spring of 1976, the large plots in various parts of the 11 acres had triazines, Velpar, and glyphosate-triazine mixtures applied, with the degree of weed control described earlier. Diphenamid was applied at 8.8 kg per hectare (8.0 lb per acre) in May. As of August 1, the total hand-weeding labor for the second year was 15 hours per acre; one more patrol of perhaps 2 hours per acre will probably be necessary to clean up the occasional pigweed.

Before this crop of seedlings, our weed control program had relied almost entirely on hand weeding, plus some spot applications of pronamide and phenoxys and low rates of atrazine in second-year beds. Past hand-weeding labor had approximated 1,000 hours per acre per year, or 2,000 hours for a crop of 500,000 Douglas-fir per acre, or about $12.00 per thousand. In this first crop of seedlings produced under a chemical program, the total hand weeding amounted to 203.5 hours, or which 186.5 was needed as the result of not having a residual pre-emergence treatment.

We anticipate that the use of methazole as a pre-emergence treatment at the rate of 3.3 kg per hectare (3.0 lb per acre) will keep future beds perfectly clean until diphenamid can be applied and maintained through the first summer. Under this routine, a maximum of 10 hours per acre can be expected, with again about 15 hours the second year, for a total of 25 hours per acre for two years, or $0.15 per thousand.

The few remaining hours of hand weeding labor are important. The low cost of hand weeding at this level is probably justified simply to have a crew on hand to weed spots skipped in application and the occasional resistant weed that must be pulled for seed source control, or for various other maintenance chores that can't all be charged against weed control. Reducing costs further is a matter of low priority, and subject to increasing risks of damage to seedlings from over-usage of herbicides.

Program Alternatives

The data gathered lead to a general interpretation of herbicide activity on Douglas-fir (Figure 1). The conclusion is reached that one or another can be used safely at each stage of seedling development (Figure 2). Seasonal sensitivity curves thus developed are useful for scheduling herbicide use (Figure 3). Of the herbicides for which data suggest safe use in forest nurseries, the following discussion of each herbicide suggests how it can be tested for use in a particular nursery or used without serious risk.

1. Methazole is a foliage-active residual herbicide that can be applied before emergence or at any time as a broadcast foliar spray on Douglas-fir more than 30 days old. Rates tested will not necessarily apply to light-textured soils, but its low solubility suggests a degree of safety in light soil. Do not reapply at intervals closer than 60 days; do not use surfactant. Allow spray to rest for two days, then water in with light irrigation. This chemical may injure pines.

2. At present, atrazine should not be applied until seedlings are in the spring of their second year. Effectiveness is through soil and foliar uptake, and is enhanced by addition of a weed-oil-emulsifier adjuvant. Atrazine normally should not be applied earlier than late March to avoid the heavy rains and cool winds that cause excessive uptake by 1-0 seedlings. Atrazine can be used safely under limited circumstances on Douglas-fir and most pines. True firs are more sensitive. Do not apply more than 3.0 kg per hectare on heavy soils or 1.6 kg per hectare on light soils, and do not irrigate in the first two weeks after application. We may eventually begin using atrazine in the fall, but data are not available yet.

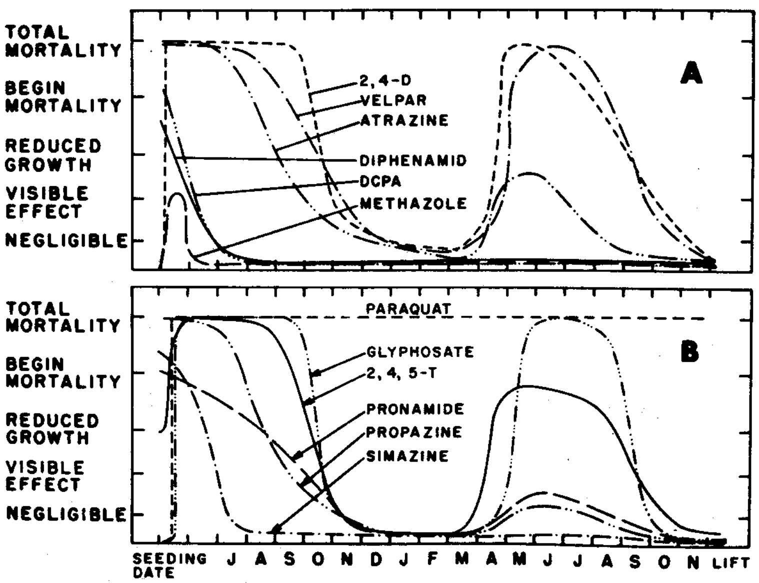

Figure 1. Sensitivity of Douglas-fir seedlings to herbicides through a full production cycle for bare-root stock in silty-clay loam. Only herbicides with potential for safe weed control at some season were considered.

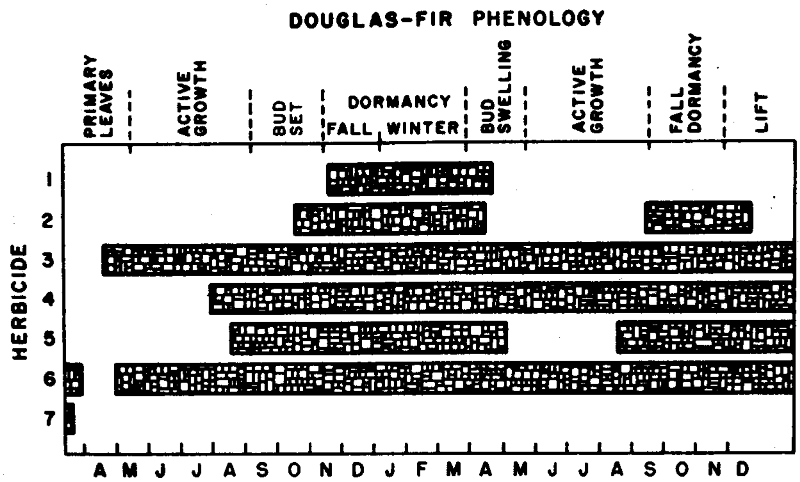

Figure 2. Relation between the phenology of Douglas-fir and potentially safe use of 12 herbicides.

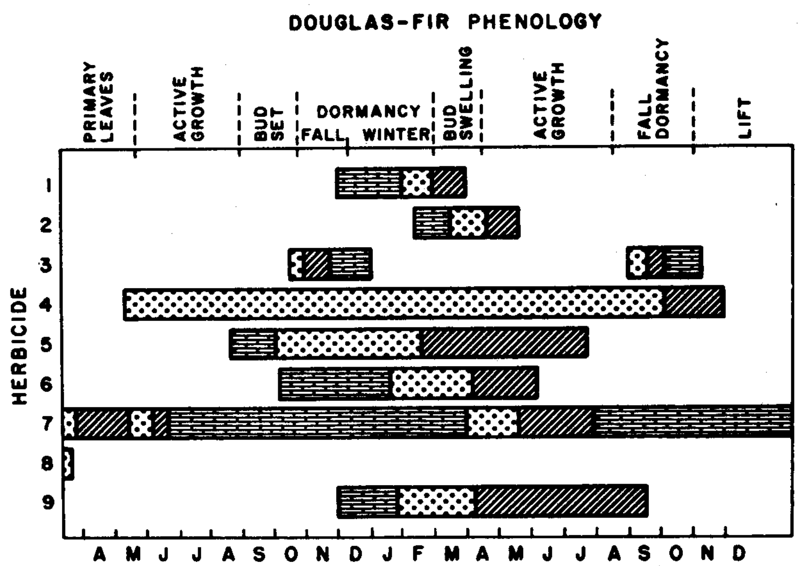

Figure 3. Recommended times of application (dotted part of bar) and periods of expected weed control for 12 herbicides in Douglas-fir seed beds. Diagonal shading indicates additional period of probable safe use if weeds demand. Bricked areas of the bars indicate periods of probable difficulty. Herbicides are:

1. 2,4-D, 2,4,5-T, and glyphosate
2. Velpar, atrazine.
3. Pronamide.
4. DCPA and diphenamid can be applied any time within period to provide 4-12 weeks control.
5. Simazine.
6. Propazine.
7. Methazole (do not apply during emergence).
8. Paraquat (never apply to emerged seedlings).
9. Glyphosate-simazine mixture.

3. Velpar is a relative of the triazines that can be used at low rates of application with extreme effectiveness on all conifers tested. It is quite soluble and acts in soil and foliage. Application should be restricted to the late dormant season, as with atrazine, in second-year or older seedlings. Do not exceed 1.0 kg per hectare on fine-textured soils, nor apply to new, actively growing foliage. Do not use a surfactant. This product gives excellent residual weed control, despite its solubility, and may produce slight tip burning in certain pines at this maximum rate. Velpar will control weeds after emergence at considerably lower rates than 1.0 kg per hectare. Damage may increase in sandy soil. It is very promising for many weed problems with second-year seedlings.

4. Propazine is used similarly to atrazine, except that it has slightly less injurious effects on first-year seedbeds while providing less efficacy. It may be applied to conifers at rates up to 2.2 kg per hectare on medium-texture soils 60 or more days after seedlings have emerged; we recommend waiting to 90 days. It is probably inferior to atrazine in the spring of the second season, but may be superior on light-textured soils because of low solubility.

5. Simazine may be used for residual weed control at almost any time after conifers are 45 days old, with rates increasing toward the end of the first summer. It has negligible foliar activity. Applications are recommended for all unless mixed with glyphosate for foliar activity before bud bursting in spring. Simazine has very long residual activity, and heavy rates may lead to germination inhibition in seedbeds worked up less than a year after the last application at rates over 3.3 kg per hectare.

6. Diphenamid is a seed-germination inhibitor that has no post-emergence activity. It is used on clean seedbeds to keep them clean at any season. It is very selective on conifers from 30 days after emergence, and there are reports of selectivity before emergence. Apply any time from 30 days after emergence.

7. DCPA is used similarly to diphenamid.

8. Phenoxy herbicides can be used very effectively for dormant season broadleaf control. They are injurious on true firs at any time, and are injurious to pines after early January. They are effective in mixture with triazines. Being active only through foliage, rates of application will not usually vary among nurseries. Of these, 2,4-D is usually applied; 2,4,5-T is particularly effective on clover.

9. Glyphosate is another foliar-active herbicide that is selective between September and April on most conifers when applied at rates less than 1.8 liter per hectare (3/4 qt per acre). This is more than is required for most weeds, and the herbicide has no soil

activity. It is perhaps less active on leguminous weeds than others. In mixture with simazine, glyphosate gives virtually perfect control of all weeds season-long in the second year. It is very effective, but apply it only during winter dormancy.

10. Paraquat is a contact herbicide, nonselective, and limited to preconifer-emergence seedbed cleanup.

11. Pronamide is a fall-applied residual herbicide that is useful for control of annual grasses at rates not exceeding 0.6 kg per hectare (0.5 lb per acre). Do not apply except in fall. It will not control most broadleaf weeds.

12. Bromoxynil-MCPA combinations provide soil residual and contact activity at low rates of application during periods of winter dormancy. These herbicides are probably not affected substantially by soil texture, but do provide a fair margin of selectivity on Douglas-fir. We do not have other seasonal data.

We do not recommend additional testing of the other products tested. Napropamide and bifenox, however, did not appear in our tests, and are showing substantial promise at several points in the program. They should be evaluated carefully.

These herbicides are all useful at some point in a weed program. None is effective for completing the entire job alone; a weed-free nursery bed takes 18 months of maintenance, and few treatments last longer than four months at the most. Using data from Figure 1a and 1b, Figures 2 and 3 illustrate how several weed-management strategies can be formulated. These are examples; attention to the details outlined in this paper will permit substitutions and combinations in various places and lead to a very large array of potential programs. The ones illustrated have been put to work and have produced high-quality seedlings at low cost.

Few of the above compounds are registered. DCPA, diphenamid, and simazine have labels permitting uses in nurseries and ornamentals. Stoddard's solvent is a registered oil product useful principally as a pre-emergence herbicide on germinating weeds. Phenoxys are broadly registered for use in forests and for release of Douglas-fir and other conifers, as are atrazine and pronamide. Registration clearance for use of new products in nurseries is necessary for an effective weed control program. The data being gathered by Steward and Abrahamson will be used in support of registration proposals. Because of the complexity of weed control over two years, they will need many more herbicides in their requests to the EPA than were needed in the South. They will need cooperation and careful observation from cooperators.

Conclusions

Herbicides have been tested that illustrate possibilities for continuous weed control throughout the lives of coniferous seedbeds. These include soil residual herbicides, systemic foliar herbicides and contact desiccants. Foliar herbicides can be used at the same rates regardless of soil, with effectiveness and safety being a matter of season and dosage. Residual herbicides must be applied at a season when they do not harm the conifers at the time of application, and when their residual properties extend the period of control through seasons when trees are sensitive to other materials. Dosage varies by soil type. Only one herbicide, methazole, shows apparent selectivity in Douglas-fir regardless of season, and it will cause severe injury to Scot's pine and perhaps to other pines.

Keeping a clean seedbed is essential to the vigor of the seedlings. Maintaining a weed-free nursery is also a way of preventing disease problems related to suppression or small seedling size, and prevents a build-up of weed seeds. Keeping the seedbed clean requires continuous surveillance. Application of the next herbicide before the effects of the last chemical dissipate is often essential for weed prevention.

Each nursery will have to conduct its own research and development program. The equipment is simple to build, once the operator understands what is required. Once the equipment is on hand, it can be used with great versatility. Weed control no longer requires fumigation, or excessively large payrolls, in the research phase. It does require that test plots be small, so that the operator can avoid large losses when a particular treatment does not suit his nursery. We lost about 100,000 seedlings in large test plots, for example.

Registration is needed for program implementation. Registration requires both data and desire on the part of the users, manufacturers, and EPA.

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