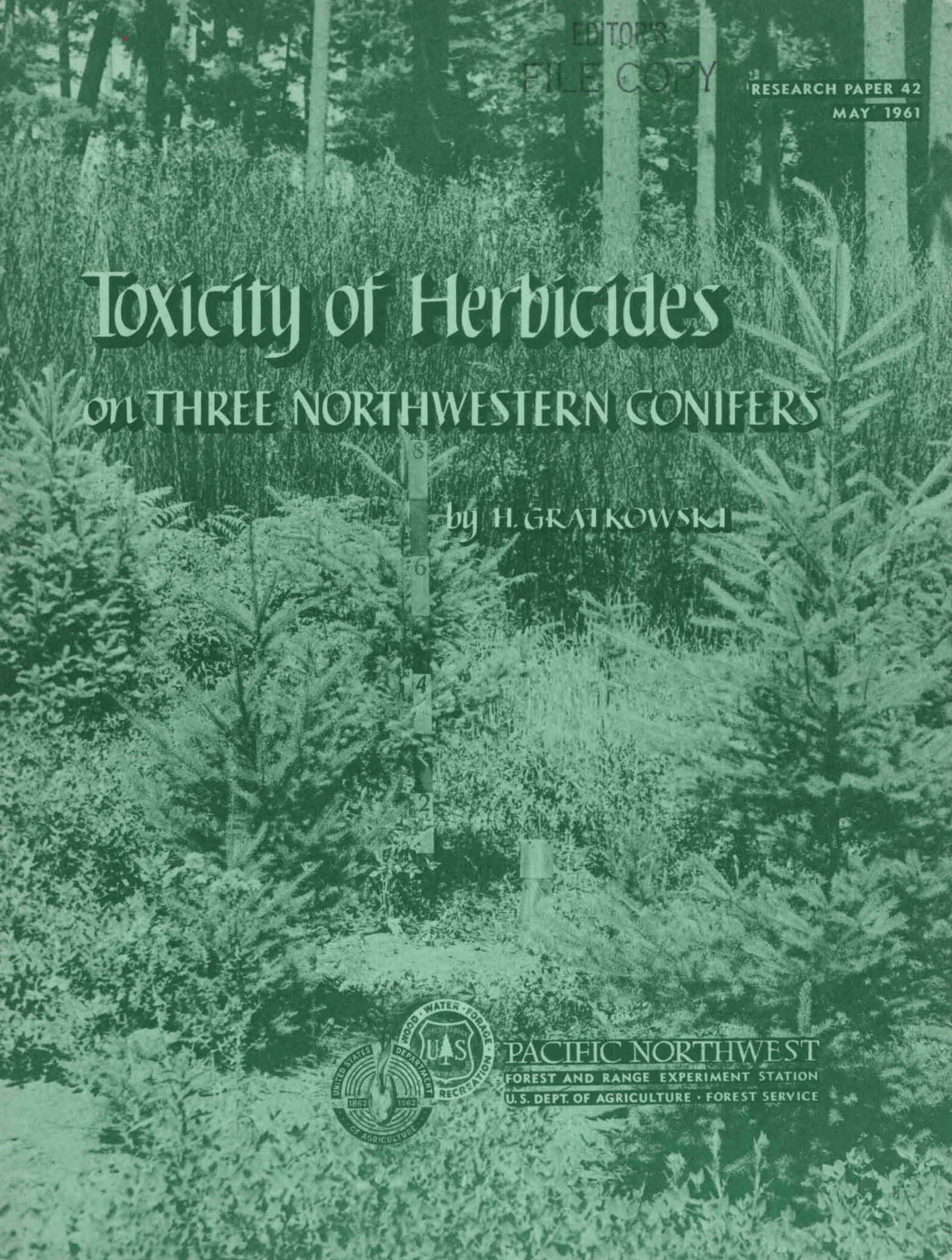
RESEARCH PAPER 42
MAY 1961

Toxicity of Herbicides on THREE NORTHWESTERN CONIFERS

by H. GRATKOWSKI



PACIFIC NORTHWEST
FOREST AND RANGE EXPERIMENT STATION
U.S. DEPT. OF AGRICULTURE · FOREST SERVICE

SUMMARY

Vigorous natural reproduction of Douglas-fir, sugar pine, and ponderosa pine in southwestern Oregon was sprayed with 1/2-pound aehg solutions of low volatile esters of 2, 4-D and 2, 4, 5-T during 1956. When treated, the trees averaged 4 to 8 feet in height. Treatments were applied during the period of active growth in midsummer and repeated in early autumn after height growth had ended and buds were set. The chemicals were applied in three different carriers: (1) water, (2) water plus spreader-sticker, and (3) a 5-percent diesel oil emulsion. Extent of damage from these treatments was determined by examination in October 1957 and September 1958.

Early autumn foliage sprays of 2, 4-D and 2, 4, 5-T were far less damaging than midsummer sprays on all three conifers in southwestern Oregon. Both pines sustained severe damage and a high percentage of mortality from midsummer sprays. Douglas-fir appeared to be more resistant than ponderosa pine and sugar pine. The pines were injured more by 2, 4-D than by 2, 4, 5-T, but Douglas-fir was moderately resistant to both herbicides. During both seasons, damage to the conifers was greatest when the herbicides were applied in a diesel oil emulsion.

Results of this study indicate that chemical release of Douglas-fir reproduction from brush competition may be possible in southwestern Oregon. But successful chemical release of ponderosa pine and sugar pine reproduction without damaging the trees is questionable. Even on Douglas-fir, if possible, the herbicides should be applied in a water solution and use of oil in the carrier should be avoided or minimized in summer spraying.

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ON THREE NORTHWESTERN CONIFERS

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H. Gratkowski

May 1961

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CONTENTS

INTRODUCTION

Thousands of acres of conifer reproduction overtopped by brush are scattered throughout the extensive brushfields of southwestern Oregon. Douglas-fir (Pseudotsuga menziesii), ponderosa pine (Pinus ponderosa), and sugar pine (Pinus lambertiana) occur most frequently in brushfields, but white fir (Abies concolor), incense-cedar (Libocedrus decurrens), Port-Orford-cedar (Chamaecyparis lawsoniana), Shasta red fir (Abies magnifica var. shastensis), and other species are also encountered. In addition, thousands of acres of naturally or artificially established conifers on logged-off lands have been engulfed in dense brush that developed after logging. In all cases brush species compete with the conifers for light, soil moisture, and nutrients. Aerial application of herbicides shows promise as an effective and economical method for releasing the conifers from brush competition, increasing their survival, and speeding reclamation of brush-covered sites.

Brushfields usually contain several conifer species in mixture with a large variety of brush species. Each species may respond differently to herbicides. If possible, chemicals and carriers used in release projects should control the brush with a minimum of damage to the conifers.

Low volatile esters of the hormone herbicides--2, 4-D and 2, 4, 5-T--have proved to be the most effective herbicides for controlling woody plants in southwestern Oregon (Gratkowski, 1959),[1/] and will undoubtedly be used in this area to release conifers from brush competition. Before attempting large-scale release projects, however, we need to know the effect of these herbicides on conifers. The study described in this publication was designed to determine the effect of 2, 4-D and 2, 4, 5-T in three different carriers on ponderosa pine, sugar pine, and Douglas-fir saplings.

Response of these three conifers to herbicides is presented pictorially in this publication because the photographs show differences much more clearly and concisely than would be possible with verbal descriptions documented with tables, graphs, and charts. Each photograph shows a tree exhibiting an average response to a particular treatment.

Differences in response to summer and autumn sprays with a given herbicide and carrier can be quickly seen by comparing opposing photographs on facing pages. Differences between herbicides during the same season are also easily compared by folding over the intervening page. Photographs showing effects of the two herbicides in comparable carriers will then lie side by side. Comparisons between tree species may be made in a similar manner.

STUDY CONDITIONS

Three different study sites were selected, each representing an area judged most suitable for growth of one of the three conifers. Each site also represents a general area where the particular conifer is most often found in competition with brush on cutovers or in brushfields. Resistance of Douglas-fir to herbicides was studied in the Oregon Coast Range. Sugar pine and ponderosa pine were studied in the Cascade Range.

[1/] Names and dates in parentheses refer to Literature Cited, p. 24.

Herbicides

Only two chemicals--low volatile esters of 2, 4-D and 2, 4, 5-T--were used, since earlier tests proved them by far the most effective and economical herbicides for foliage sprays on brush species in southwestern Oregon. Propylene glycol butyl ether esters[2] were selected as being typical of the low volatile esters available in commercial formulations. Five trees of each species were sprayed to drip point with 1/2-pound aehg[3] emulsions of the two chemicals. This treatment not only coated all foliage with as much spray as it could retain, but also wetted much of the stem and trunk surface as well. Although an accurate comparison is impossible, this treatment is estimated to be equivalent to application of 1 to 3 pounds acid equivalent per acre. Amounts of spray solution per tree varied with size of tree and amount of foliage. All trees were sprayed with a knapsack sprayer using moderate pressure and a hollow cone nozzle adjusted to deliver a fine spray.

Carriers

Three carriers potentially most useful for aerial spraying were used: (1) water, (2) water plus spreader-sticker, and (3) oil-in-water emulsion containing 5-percent diesel oil by volume. Oil carriers were not included.

Seasons

To determine effects of the herbicides at different levels of physiological activity in the conifers, spray treatments were applied during two seasons--midsummer and early autumn. Phenology was used as a guide in judging physiological activity and selecting dates of treatment. Brush species are most susceptible to herbicides when the majority of the new leaves have reached full development but stems are still elongating. If conifers were resistant to herbicides during this period, release projects would most logically be carried out during early summer. Therefore, early July was selected for the summer treatments.

A second possible season for application of herbicides is in autumn after growth has ceased and buds are set on conifer reproduction. Dormant season applications of herbicides have resulted in reduced sprouting and increased kill of some evergreen brush species (Crafts and Stewart, 1954). In contrast, preliminary tests in southwestern Oregon indicated that conifers are more resistant to herbicides after height growth has ended. Therefore, early autumn seemed a time when conifers might be released from evergreen brush competition with little damage to the trees. Douglas-fir was sprayed in September and the pines in early October.

In an informal trial, 1-pound aehg formulations of 2, 4-D and 2, 4, 5-T in water were also sprayed on ponderosa pine just before the first flush of growth in May. These treatments were not repeated on Douglas-fir or sugar pine.

2/ Chemicals for the study were provided by The Dow Chemical Co., Midland, Mich.

3/ Acid equivalent per hundred gallons of spray solution.

RESPONSE OF PONDEROSA PINE

In southwestern Oregon, ponderosa pine is far more abundant in the dry interior valleys and in the Cascade Range than in the Coast Range. Therefore, a young stand of ponderosa pines on the lower northwest slope of Mount McLoughlin was selected for treatment. The study area is about 25 miles northeast of Medford in the Cascade Range. The overstory consists of scattered large California black oaks (*Quercus kelloggii*) and old-growth ponderosa pines. Douglas-fir is also present in the vicinity, but natural reproduction on the plot is almost entirely ponderosa pine. Deerbrush ceanothus (*Ceanothus integerrimus*) and saskatoon serviceberry (*Amelanchier alnifolia*) predominate in the sparse brush understory.

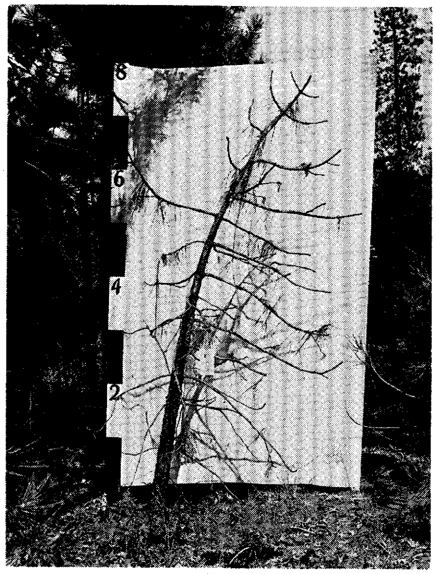
Although the young ponderosa pines were less vigorous in appearance and growing more slowly than comparable trees on open sites, they were typical of trees growing under brush in the vicinity (fig. 1). When sprayed, the trees were about 6 feet tall, and height growth averaged 6.6 inches per year for the 2 years preceding. To minimize losses from insects and disease, only the most vigorous trees were selected for treatment.

Spring treatments were applied on May 16, when buds were just beginning to swell but stem growth had not yet started. Summer treatments were applied on July 10, while the trees were still growing. Autumn treatments were applied on October 15, long after height growth was completed and buds were set.

Figure 1.--Typical appearance of untreated ponderosa pines.

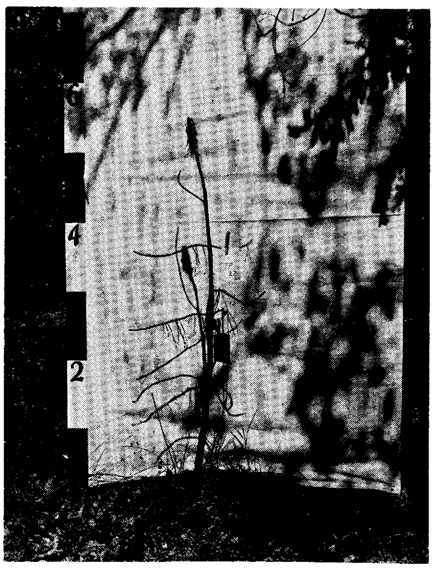
2, 4-D on Ponderosa Pine

Summer



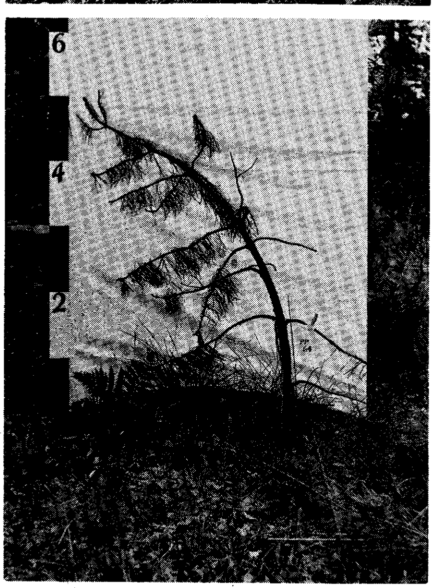
Carrier: Water

All trees killed. 2, 4-D was much more toxic than 2, 4, 5-T on ponderosa pine during midsummer. This great difference in toxicity of the two herbicides is not evident in autumn treatments.



Carrier: Water plus spreader-sticker

Most trees were killed by this treatment; the remaining trees were severely damaged. This carrier seemed to be slightly less damaging than water or emulsion carriers, but the difference is too small to be of practical significance.



Carrier: Emulsion

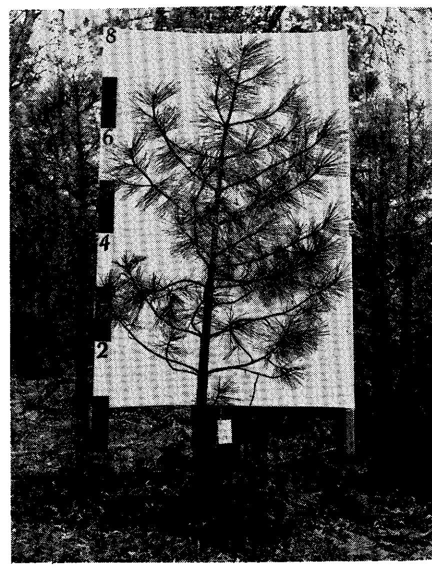
Almost all trees died from this spray. Since damage and kill were extremely high with 2, 4-D even in water carriers, use of oil in the carrier caused no significant increase in damage.

2, 4-D on Ponderosa Pine

Autumn

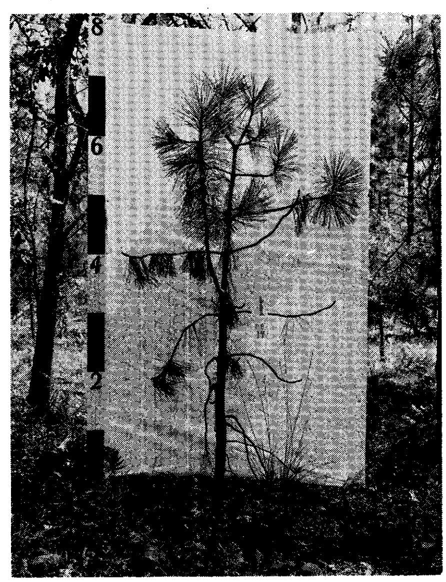
Carrier: Water

2, 4-D caused far less damage in autumn than in summer. Most trees showed no damage from the autumn spray. One tree lost the following year's leader growth, but suffered no permanent damage. Compare with summer treatment on opposite page.



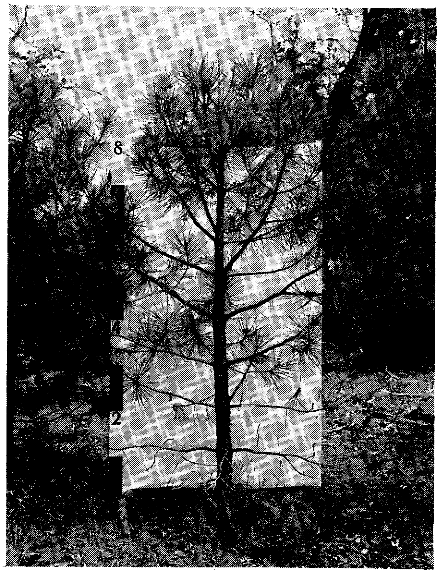
Carrier: Water plus spreader-sticker

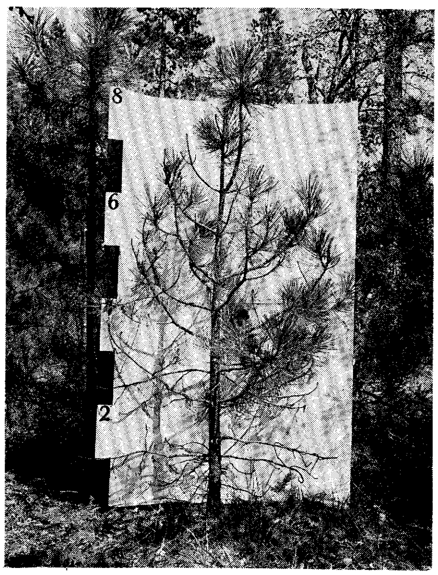
Results with this carrier were similar to those with the water carrier above. Both caused no damage of practical importance.

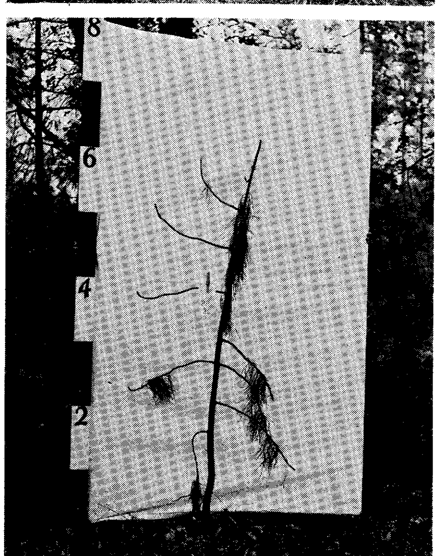


Carrier: Emulsion

Appreciably more damage than with the water carriers above. All trees were still alive 2 years after treatment, but had sustained appreciable leader damage, stem kill, and almost complete defoliation. The tree shown is recovering after having lost 80 percent of its foliage.







2, 4, 5-T on Ponderosa Pine

Summer

Carrier: Water

2, 4, 5-T was far less toxic than 2, 4-D in summer sprays. All trees were living 2 years after treatment. But even 2, 4, 5-T caused extensive defoliation and an undesirable amount of leader and stem kill in summer.

Carrier: Water plus spreader-sticker

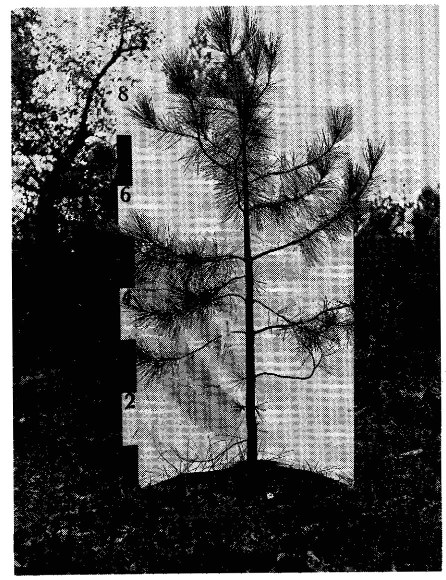
Effects were similar to those with the water carrier above. Only one tree was killed, but the others were severely damaged.

Carrier: Emulsion

Use of oil in the carrier resulted in a pronounced increase in damage and kill. All but one of the trees were killed. The single survivor is so severely damaged that it will probably die.

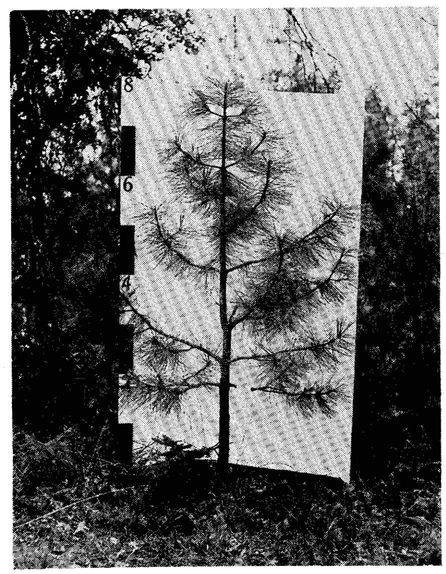
2, 4, 5-T on Ponderosa Pine

Autumn



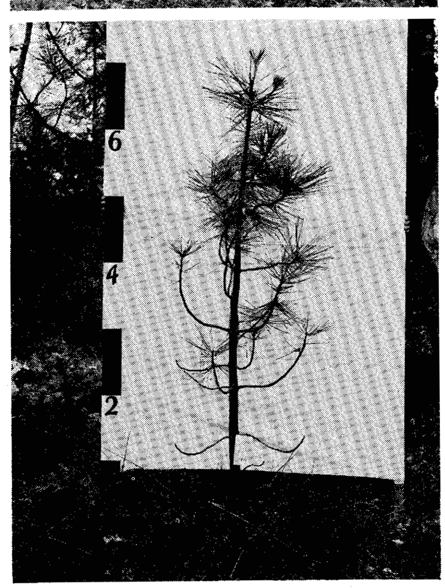
Carrier: Water

No evident damage from this spray. One tree was later killed by beetles, but this appears to have been a chance occurrence not related to spray treatment. The remaining trees showed no damage, not even slight defoliation.



Carrier: Water plus spreader-sticker

No damage from this treatment. As with 2, 4-D, ponderosa pine showed less damage from autumn sprays of 2, 4, 5-T than from summer sprays.



Carrier: Emulsion

Use of oil in the carrier again caused increased damage to ponderosa pine. Defoliation averaged 50 percent, and some leaders and stems were killed back. But the fact that no ponderosa pines were killed with the emulsion carrier is additional evidence of increased resistance to herbicides in autumn.

Summary for Ponderosa Pine

Season.--Ponderosa pine shows a pronounced increase in resistance to herbicides in autumn. Autumn sprays, after height growth is completed and buds are formed, are far less damaging than summer sprays applied during the period of active growth. Results indicate that this seasonal susceptibility begins in the spring, at least as early as when buds begin to swell, and continues into the summer throughout the season of active leader growth. Unfortunately, the limited number of treatments in this test do not allow more precise dating or phenology to show when the susceptible period has ended and resistance has been developed.

Herbicides.--2, 4, 5-T is less toxic than 2, 4-D in both summer and autumn sprays, but the difference between the two herbicides is less pronounced in autumn. In summer treatments, 2, 4-D in a water carrier killed all pines sprayed with the solution. A corresponding treatment with 2, 4, 5-T damaged but did not kill the pines. In autumn sprays, however, neither 2, 4-D nor 2, 4, 5-T caused any significant amount of damage when applied in water carriers.

Carriers.--Use of oil in the carrier greatly increases damage from herbicides during both seasons. This information is directly applicable in ground spraying, but no direct comparison is possible with low-volume aerial spraying. In this study emulsion carriers contained 5 gallons of diesel oil per hundred gallons of spray solution. Since trees were sprayed to drip point, this would probably be equivalent to application of 10 to 15 gallons of diesel oil per acre. In addition to improving coverage and penetration of the hormone herbicides, this amount of diesel oil alone would probably have some herbicidal effect on reproduction. Oil-in-water emulsions for aerial spraying, on the other hand, usually contain only 1/2 to 2 gallons of oil per acre. The contrast in effect of emulsion carriers vs. water carriers in aerial spraying, therefore, would probably be appreciably less than the contrast so evident in these tests.

Influence of sprays on height growth.--Autumn spraying reduced height growth of ponderosa pine only when oil was used in the carrier. Of the two herbicides, 2, 4-D caused a significant reduction in height growth when applied in an emulsion carrier during October and is less desirable than 2, 4, 5-T for use on this species. All spray treatments during the growing season produced unacceptable amounts of damage and mortality, drastically reducing height growth on those trees that survived.

RESPONSE OF SUGAR PINE

In southwestern Oregon, sugar pine is most abundant in the Cascade Range, where it usually grows in mixture with other conifers. This part of the study was carried out on the South Umpqua Experimental Forest, 27 miles east of Myrtle Creek, Oreg. Young sugar pines under an open stand of old-growth sugar pines, Douglas-fir, and western hemlock were chosen for treatment. Brush density is light to moderate, mostly Pacific madrone (*Arbutus menziesii*), hairy manzanita (*Arctostaphylos columbiana*), and salal (*Gaultheria shallon*). Influence of the overstory is reflected in rather sparse foliage and relatively slow growth of the young sugar pines (fig. 2). Because some saplings in the area were infected with white pine blister rust (*Cronartium ribicola*), special effort was made to treat only healthy trees that showed no symptoms of the disease.

Only summer and autumn treatments were evaluated on sugar pine. The summer sprays were applied in early July during the growing season. Autumn treatments were applied in October, after growth had ceased.

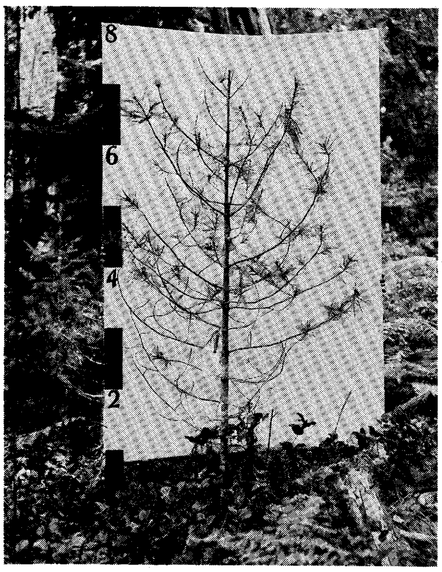
Figure 2.--Typical appearance of untreated sugar pines.

2, 4-D on Sugar Pine

Summer

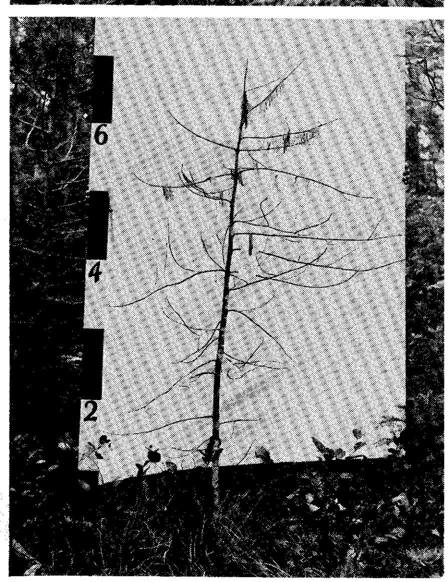
Carrier: Water

Sugar pine reproduction was killed or severely damaged by this spray. 2, 4-D caused more defoliation and damage than 2, 4, 5-T on sugar pine. This corresponds with the effect of the two herbicides on ponderosa pine.



Carrier: Water plus spreader-sticker

Extensive damage resulted from this treatment. Two of the five trees were dead and the others were still severely damaged 2 years after spraying. Results are similar to those obtained with the water carrier above.



Carrier: Emulsion

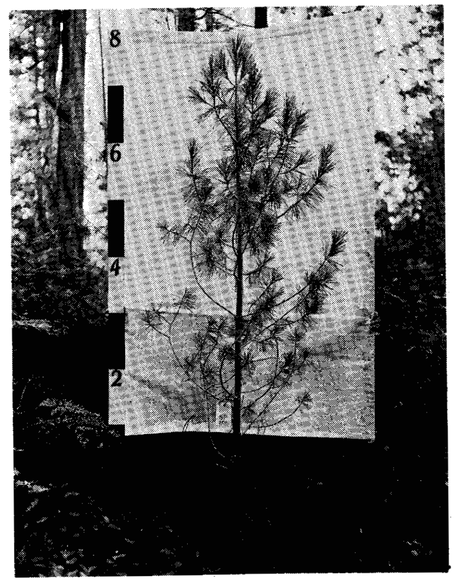
Use of oil in the carrier resulted in increased kill. All but one tree were dead 2 years after treatment. The remaining tree was severely damaged.

2, 4-D on Sugar Pine

Autumn

Carrier: Water

2, 4-D was far less toxic on sugar pine in autumn than in summer. The autumn spray caused only negligible damage. Compare with midsummer treatment on opposite page.

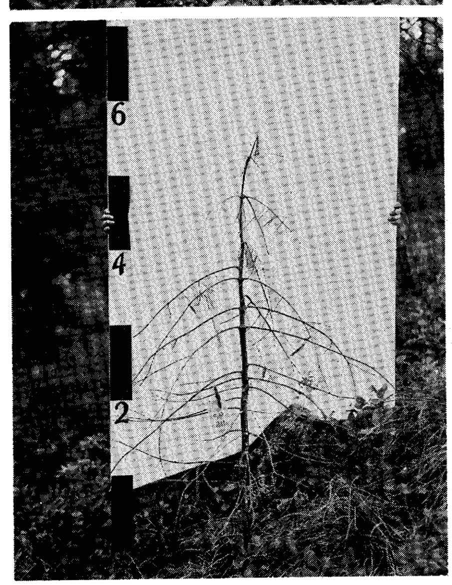


Carrier: Water plus spreader-sticker

Little or no damage from this spray. Results were similar to those obtained with the water carrier above.

Carrier: Emulsion

Emulsion carriers caused as much mortality in autumn as in summer treatments on sugar pine. All but one tree were killed by this spray treatment.

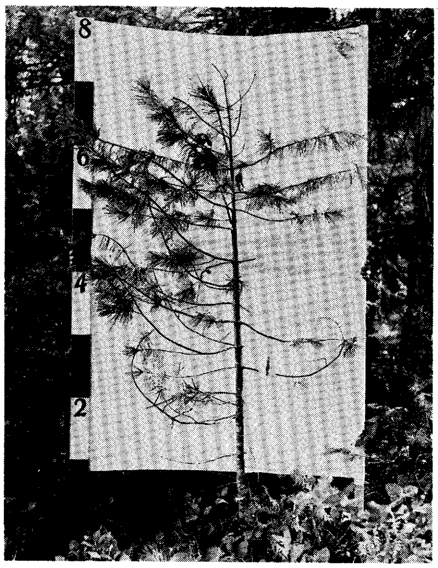


2, 4, 5-T on Sugar Pine

Summer

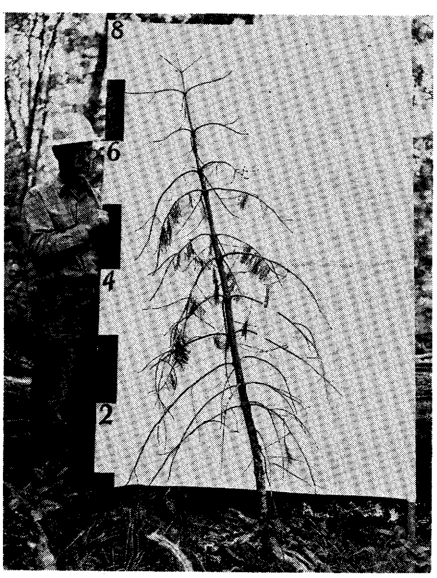
Carrier: Water

2, 4, 5-T was far less toxic than 2, 4-D on sugar pine, but even this herbicide caused an undesirable amount of damage in summer applications. Note healthy appearance of new foliage produced 2 years after spraying.



Carrier: Water plus spreader-sticker

Less damage than from 2, 4-D, but still too much to be tolerated. Results were similar to those obtained with the water carrier above.



Carrier: Emulsion

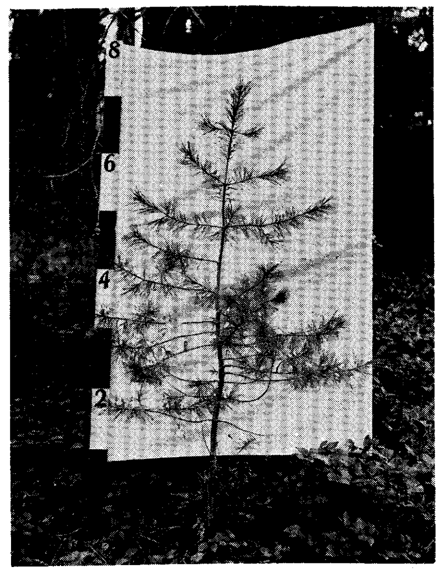
Again, the emulsion carrier caused a pronounced increase in mortality. Three of the five trees were killed; the others severely damaged and defoliated.

2, 4, 5-T on Sugar Pine

Autumn

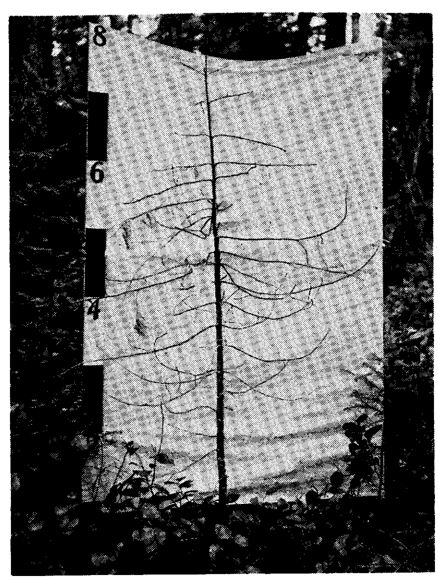
Carrier: Water

No damage was caused by this treatment. As with ponderosa pine, sugar pines showed a pronounced increase in resistance to herbicides in the autumn.



Carrier: Water plus spreader-sticker

Sugar pines were not injured when sprayed with this formulation in October. Compare effect of a similar formulation in midsummer in photo on opposite page.



Carrier: Emulsion

The destructive influence of oil in the carrier persists even in autumn spraying on sugar pine. Three trees were killed by this treatment; two were seriously damaged. In contrast, autumn spraying with 2, 4, 5-T in water carriers caused no damage.

Summary for Sugar Pine

Season.--Seasonal effects of the two herbicides on sugar pine are very much like those on ponderosa pine. Sprays of either herbicide cause an undesirable amount of damage and mortality when applied during the season of active growth. But by early October, sugar pine, like ponderosa pine, showed a definite increase in resistance to the effects of 2, 4-D and 2, 4, 5-T. As in the case of ponderosa pine, these tests do not allow a more precise dating or description of phenology associated with the beginning of this resistant period for sugar pine.

Herbicides.--2, 4, 5-T is slightly less toxic than 2, 4-D on sugar pine in summer, but there is no great difference between effects of the two herbicides in autumn applications. The slight difference in effect of the two herbicides in summer is probably of little value in field application, for both herbicides caused an unacceptable amount of damage in early summer spraying. In autumn, neither herbicide caused much damage when applied in water carriers. Summarizing, the test results indicate that neither chemical is suitable for releasing sugar pines in summer, while 2, 4, 5-T (with its slightly lower toxicity) would be somewhat safer than 2, 4-D in autumn spraying. However, the small amount of damage suffered by trees treated with 2, 4-D in water during autumn indicates that this formulation should also be considered when brush species to be controlled are more susceptible to 2, 4-D than to 2, 4, 5-T.

Carriers.--Use of oil in the carrier drastically increases crown damage and mortality in sugar pine. Unlike ponderosa pine, sugar pine remains susceptible to effects of oil even in autumn when herbicides in emulsion carriers caused high mortality. Only a small amount of damage was incurred from autumn spraying when water carriers were used with either chemical.

Influence of sprays on height growth.--All herbicide-carrier combinations caused damage and mortality and thereby reduced height growth when applied during the growing season. Among the sprayed trees, best growth for the first 2-year period after treatment was found among trees sprayed with 2, 4, 5-T in a water carrier during autumn. Sugar pine also displayed an increased resistance to 2, 4-D in water carriers in autumn, but height growth of trees sprayed with this formulation was significantly less than that of trees sprayed with 2, 4, 5-T in water. Emulsion carriers caused excessive damage and reduced height growth when applied during either season.

RESPONSE OF DOUGLAS-FIR

Douglas-fir, by far the most abundant tree species in southwestern Oregon, is also the species most frequently encountered in brushfields. Excellent stands of Douglas-fir reproduction established under brush cover are common throughout this area, but the trees usually grow slowly due to poor light conditions and competition of the brush overstory for soil moisture and nutrients. Such stands are, perhaps, somewhat more prevalent in the Coast Range than elsewhere. Therefore, a stand of young Douglas-firs near the crest of the Coast Range, 17 miles west of Roseburg, was selected for studying response of Douglas-fir to herbicides.

A cluster of vigorous young trees on a powerline right-of-way was chosen for treatment. The open-grown trees were healthy in appearance (fig. 3), and ranged from 3 to 7 feet in height when sprayed. Only a few large shrubs of brush species were present among the trees, mostly hairy manzanita and golden chinkapin (*Castanopsis chrysophylla*); but western bracken fern (*Pteridium aquilinum* var. *pubescens*) and salal were abundant. There was no overstory of older trees on this plot.

Summer and autumn treatments were used on Douglas-fir. The summer sprays were applied July 2, 1956, and the autumn sprays in the latter half of September. Leader and stem growth was still in progress during the July spraying, but growth had been completed and buds were well developed by the time sprays were applied in September.

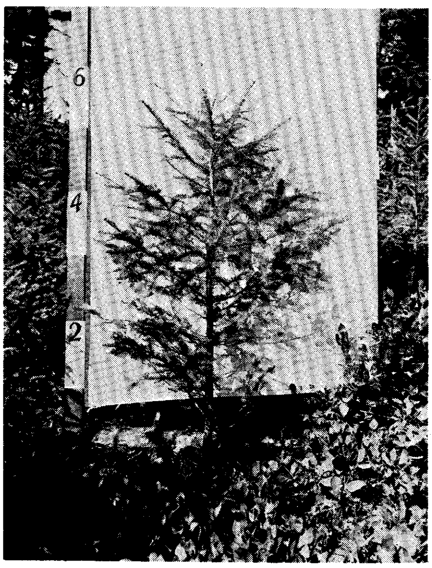
Figure 3.--Typical appearance of untreated Douglas-firs.

2, 4-D on Douglas-fir

Summer

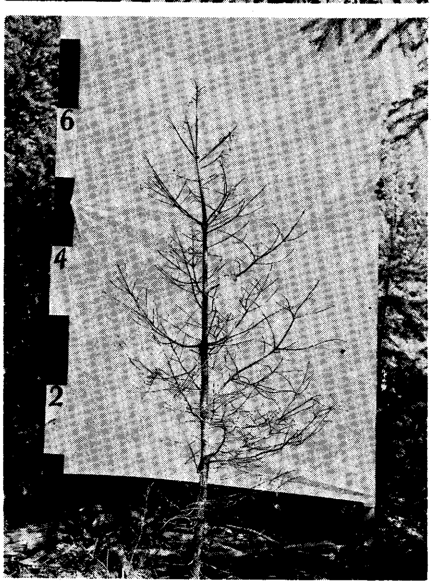
Carrier: Water

Very little damage from this treatment. A negligible amount of defoliation and stem kill occurred. There was some curling of the new growth during year of spraying, but growth in succeeding years was normal, straight, and healthy. Such curling is probably unimportant, for it will be obscured by subsequent growth.



Carrier: Water plus spreader-sticker

A very small amount of defoliation with some kill of stem tips was noted on these trees. Stems curled by the herbicide remain twisted, but later growth is straight and healthy.



Carrier: Emulsion

This was the worst of all treatments on Douglas-fir. Use of oil in the carrier caused a great increase in toxicity, and four of the trees were killed. The remaining tree is severely damaged and probably will not recover.

2, 4-D on Douglas-fir

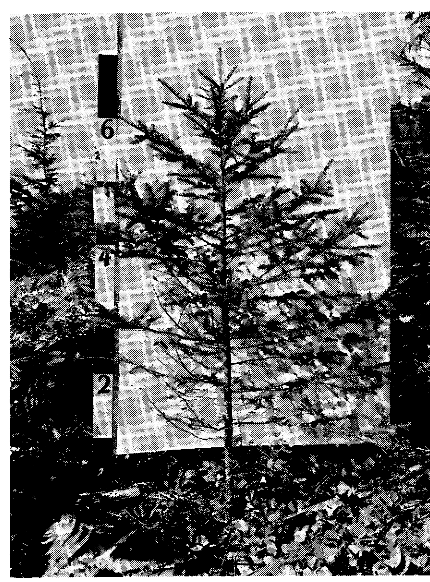
Autumn

Carrier: Water

Almost no noticeable effect from this spray. A small amount of twisting developed in some branches, but no lasting effect. All trees are healthy and normal.

Carrier: Water plus spreader-sticker

These trees healthy and normal in appearance. A minor amount of kill occurred in new growth, but was masked by later growth.



Carrier: Emulsion

Results inconsistent. Most trees showed only light defoliation and little stem kill, but one tree inexplicably suffered severe damage and died. Like the pines, Douglas-fir showed increased resistance to herbicidal sprays in autumn. Compare this tree with average response to similar formulation in summer on opposite page.

2, 4, 5-T on Douglas-fir

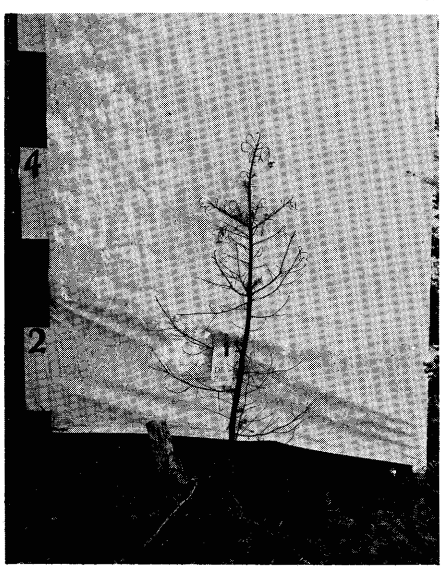
Summer

Carrier: Water

This formulation caused slightly more defoliation and damage than its 2, 4-D counterpart on page 16. Note extensive, permanent curling of stems. But also observe that the 1958 stem growth is straight, normal, and healthy.

Carrier: Water plus spreader-sticker

This treatment caused a moderate amount of defoliation and killed some tender shoots on ends of branches. More damage than from 2, 4-D in a similar carrier, but no trees were killed or severely damaged.



Carrier: Emulsion

Extreme damage resulted from this spray. Although only one tree was killed immediately, the others were so severely damaged and killed back that they will not recover. Note sprigs of new growth on main stem of this severely damaged tree.

2, 4, 5-T on Douglas-fir

Autumn

Carrier: Water

No damage except an extremely small amount of defoliation in older needles. These trees are all healthy and normal in appearance. Note absence of stem curl caused by same treatment in summer (opposing photo on facing page).

Carrier: Water plus spreader-sticker

No damage from this spray. Effects were similar to those in the water carrier above.

Carrier: Emulsion

Only minor damage from this spray. A negligible amount of defoliation and kill of stem tips, but all trees were healthy and normal in appearance 2 years after spraying. Compare with photo on opposite page showing effect of the same treatment in summer.

Summary for Douglas-fir

Season.--Like the pines, Douglas-fir displays increased resistance to 2,4-D and 2,4,5-T in late-season spraying. Summer applications caused varying amounts of damage and mortality, depending on effects of the individual herbicides and carriers. But with all formulations, the amount of damage from autumn application was noticeably less than from the same spray applied in summer. It would be extremely useful to know precisely, by date or phenology, when this increase in resistance first occurs. Since late spring and summer sprays are most effective on brush species, this knowledge might permit selective treatments to kill brush species and release Douglas-fir with a minimum of damage. The present test shows only that this increase in resistance occurs sometime after the end of the growing season, when height growth has ceased and buds have been formed.

Herbicides.--There was no pronounced difference in effect of the two chemicals on Douglas-fir. In summer treatments with water carriers, 2,4-D caused somewhat less damage than 2,4,5-T. When oil was added to the carrier, the effects were reversed--2,4-D killed more trees than 2,4,5-T. The differences observed in these tests, however, are considered too small to be a deciding factor in choosing between the chemicals when they are to be applied in a water carrier. With little difference in effect on the trees, one should use the herbicide most effective on the brush species to be controlled.

Carriers.--Adding oil to the carrier causes a tremendous increase in mortality and damage from summer applications. In autumn, however, Douglas-fir is relatively resistant to the herbicides even in emulsion carriers. Only one tree, which was sprayed with 2,4-D in an emulsion carrier, died after the autumn spray treatments. At the concentration used in this experiment, both herbicides caused only a minor amount of damage when applied in water carriers during the growing season. No damage resulted when the herbicides were applied in water carriers in autumn.

Influence of sprays on height growth.--All spray treatments caused some reduction in height growth during the first 2-year period after spraying, even those treatments where no visible effects of the herbicides were evident. 2,4-D and 2,4,5-T inhibited height growth to similar degrees; neither herbicide was more favorable than the other in this respect. Season of application influenced height growth only when emulsion carriers were used. With water carriers, summer spraying did not inhibit height growth any more than autumn spraying. With emulsion carriers, however, trees sprayed in autumn grew better than trees sprayed in summer.

DISCUSSION

This study has shown that ponderosa pine and sugar pine in southwestern Oregon are damaged less by 2, 4, 5-T than by 2, 4-D, while Douglas-fir appears to be moderately resistant to both herbicides. The results for relative susceptibility of ponderosa pine and Douglas-fir are generally in agreement with observations of investigators in other localities. In eastern Oregon, for example, Dahms[4/] found that ponderosa pine is less susceptible to 2, 4, 5-T than to 2, 4-D, and that this conifer can tolerate twice as much 2, 4, 5-T as 2, 4-D at low concentrations. And in midsummer helicopter applications of 2, 4, 5-T on Ribes spp. in Idaho, DeJarnette (1953) observed that ponderosa pine was much more susceptible to leader damage than Douglas-fir. No information concerning sugar pine was found in the literature.

The inhibitory effect of 2, 4-D and 2, 4, 5-T on height growth of Douglas-fir deserves special consideration, for the prime purpose of aerial spraying to release conifers is to increase growth and survival of the trees. However, in release projects, the degree of growth inhibition exhibited in these tests would probably be more than compensated for by increased growth due to brush control. When conifers are overtopped by a dense brush cover, height growth is slowed, and even survival of the trees is jeopardized. Aerial spraying kills back the brush, allows more light to reach the trees, and reduces brush competition for soil moisture and nutrients. The spray formulation selected should accomplish this objective with a minimum of damage to the conifers. Where release is justified, response of the trees to the more favorable conditions will usually counterbalance the inhibitory effect of the herbicides.

Density of brush and height of trees in relation to brush are important considerations in aerial release projects. If conifers are entirely covered by a dense canopy of brush, only a small amount of spray reaches the trees. In such situations the inhibitory effect of wetting sprays of herbicides observed in this study would be at a minimum while the release effects would be at a maximum. Aerial spraying in such cases would undoubtedly result in a net increase in growth. On the other hand, if conifers are growing among scattered shrubs of brush species and would be directly exposed to the spray, the value of aerial spraying for release would be questionable. The trees would be subjected to the inhibitory effect of the chemical with little or no chance that there would be any compensating effect of release.

Overshadowing the effect of the two herbicides in this study was the pronounced increase in damage and mortality when diesel oil was used in the carrier.

[4/] Dahms, Walter G. Progress report on brush control studies at Deschutes Research Center, 1953 to 1956. 46 pp., illus. 1957. Unpublished report in files of U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta.

This increase in damage and mortality common to all three conifers was not unexpected, but it is unfortunate. Some brush species, such as tanoak (Lithocarpus densiflorus) and canyon live oak (Quercus chrysolepis), are more susceptible to herbicides in emulsion carriers than in water carriers. Use of water carriers to reduce damage to conifers will also reduce the effectiveness of brush control with such species and limit the degree of release obtained for conifer reproduction.

In many ways, oil is a better carrier than water for herbicides. This is partially due to its low surface tension and excellent wetting ability. But in addition, most oil molecules are symmetrical and nonpolar in structure (Crafts, 1950), which aids in penetration of cuticle.

The increased toxicity when diesel oil emulsion was used on conifers is probably due to one or more effects of the diesel oil; for oil: (1) acts as a filming agent (Robbins et al., 1952) due to its low surface tension, (2) improves penetration of cuticle on leaf surfaces as a result of its nonpolar structure, and (3) has a slow-acting toxicity of its own due to its ability to disrupt the lipoid phase of cell membranes (van Overbeek and Blondeau, 1954). Since the toxicant is carried in the oil phase of an emulsion, the oil film spreading over a leaf surface also spreads the toxicant in a thin layer over the leaf surface and brings it into intimate contact with the cuticle. The cuticle itself is oillike in nature, and an oily, nonpolar molecule passes through it more readily than a polar molecule such as water. In penetrating the cuticle, the oil phase of an emulsion may also provide a pathway for rapid movement of a greater portion of the herbicide into cells of the mesophyll and veins, thus increasing the effectiveness of the chemical. The increased damage and mortality of conifer reproduction when oil was used in the carrier may have been due to one or all of the effects of oil described above.

Seasonal changes in susceptibility of conifers to herbicides deserve further investigation, for all three species of conifers exhibit an increased resistance to 2, 4-D and 2, 4, 5-T in autumn. As mentioned earlier, it would be most useful to know precisely when this increase in resistance first occurs. If it develops while brush species are still susceptible to herbicides, we may be able to time our application of sprays to kill brush and release conifers with a minimum of damage.

Concurrent tests on seasonal susceptibility of brush species are also necessary to determine whether brush is still susceptible to herbicides when conifers have become resistant. Evidence indicates that brush species, like conifers, increase in resistance to herbicides as season advances. In eastern Oregon, resistance of pine manzanita (Arctostaphylos parryana var. pinetorum) and snowbrush ceanothus (Ceanothus velutinus) was found to increase abruptly in the latter part of July after stem growth had ceased on manzanita (Dahms, 1955). Small exploratory tests in southwestern Oregon indicate that evergreen brush species in this area also develop an increased resistance to herbicides as season advances, but that the increase in resistance may not be as pronounced as that observed in conifers. Sprays applied as late as November killed brush back to some extent, although the kill did not approach that achieved with similar sprays applied in early summer.

In conifers, this increase in resistance to herbicides may possibly develop soon after height growth is completed and buds are formed. No specific information on this is available concerning Douglas-fir, ponderosa pine, and sugar pine in the Pacific Northwest. But in Michigan, white spruce was not affected by herbicides in emulsion carriers after July 15; while red pine, eastern white pine, Scotch pine, and Norway spruce were not affected after August 1. Jack pine, on the other hand, showed browning of foliage until August 15 (Arend, 1955). Of course, results such as these cannot be interpreted directly in terms of our own conifers. But, when considered in conjunction with results of the present test, this information makes it logical to think that resistance may also develop quite early in the season in our own conifers. If our conifers <u>do</u> become resistant while brush species are still susceptible, proper timing <u>will</u> allow selective spraying to kill brush and release conifers with a minimum of damage.

Phenology was used as a guide in selecting seasons of treatment for conifers in this test. And phenology, subjective as it may be, may prove to be our best indicator of seasonal changes in susceptibility of conifers to herbicides. Stages of growth are a readily evident indication of changes in physiological activity which influence the effect of herbicides in the plant. With at least one brush species, investigators seeking a criterion for seasonal susceptibility to herbicides found phenology a more reliable criterion than quantitative measurements of environmental factors or physiological conditions. Stage of growth, air and soil temperatures, relative humidity, leaf moisture, and the nature and content of carbohydrates in the root xylem were determined in an effort to find a quantitative measure for evaluating susceptibility of velvet mesquite to herbicides (Tschirley and Hull, 1959). Of the factors studied, only stage of growth appeared to be a moderately reliable indicator of susceptibility. The reason for this may be that stage of growth (phenology) reflects not only the individual factors measured in this study but the interaction of these and all other factors of the environment which affect action of herbicides. If an attempt is made to determine when seasonal resistance to herbicides develops in our conifers, an effort should be made to relate this to phenology of the conifers and associated tree and brush species as well.

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