BRUSH CONTROL
Status of Chemical Methods

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The status of chemical brush control is reviewed. Foliage and basal spraying, stump treatment, and frilling with ammonium sulfamate, 2,4-di-, and 2,4,5-trichlorophenoxyacetic acids or derivatives are discussed. Emphasis is placed on a few weaknesses, the aspect most important to future progress. The two most urgent research problems are the effect of the phenoxy compounds or their breakdown products on the dormant buds in the root-stem transition zone and their poor movement into the lateral rhizomes.

HERBICIDE SYMPOSIUM

THE INTRODUCTION of 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) in 1944 has changed the approach to the problem of brush control in this country. Before 1944 most brush control was mechanical; although there was limited use of such chemicals as the chlorates, dinitrocresol compounds, soluble arsenicals, copper sulfate, and ammonium sulfamate (Ammate), these compounds have been replaced by 2,4-D and 2,4,5-T in chemical brush control.

It is estimated that in the United States nearly 4,000,000 pounds of 2,4,5-T were produced last year, all for use in controlling woody plants. As most brush killer formulations contain at least 50% 2,4-D acid equivalent, it is evident that brush killing in this country is consuming many million pounds of these phenoxy acids. The supply has been adequate to meet the demands.

Advantages of 2,4-D and 2,4,5-T

The advantages inherent in 2,4-D and 2,4,5-T gave a tremendous stimulation to the workers in this field and now act as guides in the development and evaluation of new chemicals.

The phenoxy acids are not toxic to humans or wildlife at concentrations used in controlling woody plants. Their selectivity in controlling these plants and broad-leaved weeds without killing grasses is unequaled. This factor is essential in pasture spraying and most desirable on rights of way, where grasses are needed to control erosion and to compete with and suppress reinvading woody seedlings.

Because of their effectiveness at very low concentrations, the phenoxy acids have made possible low-volume airplane spraying. They can be formulated for use in oil or water, and as little as $^{2}/_{3}$ pound of 2,4,5-T acid equivalent in the ester form applied in 4 gallons of carrier per acre controls mesquite (*Prosopis* spp.) (*10*), a woody pest covering some 75,000,000 acres of pasture in the Southwest (*24*).

Even with these desirable properties, the wide acceptance of phenoxy compounds would not be justifiable if it were not for their low cost to the user. The importance of chemical and application costs becomes evident when one considers that often brush must be controlled on land valued as low as $20 per acre.

These millions of pounds of 2,4-D, 2,4,5-T, and ammonium sulfamate are being used, first, on thousands of miles of electric transmission and distribution lines in this country, on which woody plants must be controlled so the plants do not come in contact with the wires, and so the lines are accessible for inspection and repair.

Railroads must control woody plants on their rights of way for maximum vision on curves, to eliminate icy shaded spots, and to encourage the growth of grasses and low-growing cover plants on banks for erosion control.

2,4-D and 2,4,5-T are used widely in clearing brush from range land, and because the effectiveness of 2,4,5-T in controlling mesquite has been proved, well over half a million acres have been sprayed in Texas alone to eliminate the woody pests that decrease the carrying capacity in terms of cattle, seriously compete with the desirable forage plants for water and nutrients, and even make it difficult to find and care for the animals properly. The pasture problem is not sectional, although the Southwest has the largest infested acreage. In the East, the chemicals are used to control thornapple (*Crataegus* spp.), coralberry (*Symphoricarpos orbiculatus*), honeysuckle (*Lonicera* spp.), and many others, while west coast land is troubled with live oak (*Quercus virginiana*), chamise (*Andenostoma* spp.), and manzanita (*Arctostaphylos* spp.).

Foresters are using the growth regulators and ammonium sulfamate to eliminate the undesirable hardwoods from pine forests and the *Ribes* species essential in completing the pine blister rust cycle.

Four major techniques are employed in controlling woody plants chemically—foliage spraying, basal spraying, stump treatment, and frilling.

Foliage Sprays

The foliage spray can be applied with ground equipment using a high volume of solution, or economical low-volume sprays can be applied by airplane. This method is used during the growing season. Best results are obtained after the foliage is fairly mature. Under eastern conditions foliage spraying may be continued for several months, but certain plants, especially in the Southwest, are best treated at very critical times during their growing season. For example, sand sage is most sensitive to 2,4-D over a very short period when the stored food reserves are at their lowest point (*19*), and mesquite response is best when moisture has been adequate during the period before growth starts (*10*).

Three chemicals are being used for foliage sprays—2,4-D, 2,4,5-T, and ammonium sulfamate. Although less selective than the phenoxy compounds, ammonium sulfamate is very effective on many woody plants which resist 2,4-D and 2,4,5-T. Its use is limited to application with ground equipment because of the large volumes of water needed. With the phenoxy compounds relatively small amounts of chemical are needed and, therefore, low-volume airplane application to certain plants is practicable.

The particular chemical used is determined largely by the plant's response. In the case of sand sage (*Salvia eremostachya*) or willow (*Salix* spp.), 2,4-D is most effective, while thornapple and mesquite respond best to 2,4,5-T. When mixed species are present, a combination of 2,4-D and 2,4,5-T or ammonium sulfamate would be indicated, depending on plant sensitivity.

The phenoxy acids are formulated for use on woody plants as "low volatile" esters or as oil-soluble acids. The two most commonly used esters are the propylene glycol butyl ether ester and the butoxyethanol ester. These esters have replaced the short-chain alkyl esters such as butyl, ethyl, isopropyl, and others originally used because they are equal or greater in effectiveness and do not have the same degree of "phytotoxic" volatility.

Chemists may wonder why the vapors given off by the ethyl, butyl, or isopropyl esters are considered harmful. The amount released is small, but it is enough to produce considerable leaf epinasty and stunting in such sensitive crops as tomatoes, grapes, and cotton in the general vicinity of sprayed areas. The esters used today definitely produce less of these symptoms and are termed low volatile esters for want of a better name (*1*, *15*). Several other esters, such as the glycol types (*15*) and tetrahydrofurfural, have been shown to have a similar degree of safety, but before they can be used commercially they must meet formulation requirements and be economically produced.

One of the largest line clearance companies is using acid formulations of 2,4-D and 2,4,5-T in a combination of oil and water. Under field tests, these acid formulations have been even safer than the low volatile esters with respect to vapor damage and equal to the esters in their ability to translocate in the plant. Under arid conditions in California, certain acid formulations have been much more effective in controlling several hard-to-kill plants than has the same acid equivalent formulated as an ester (*21*). This may be explained by the low pH of the acid formulations, which Crafts (*9*), Hamner (*11*), and others have shown to be an important factor in absorption.

Although the acids in oil and the esters seem to be more effective on woody plants because of their apparent ability to penetrate the cuticle of the leaf, experimenters continue to be interested in nontoxic oil foliage sprays of certain amine salts of the phenoxy acids having an affinity for water after entering the plant. Water-soluble esters of the polyethylene glycol type are showing promise under California conditions (*16*) and warrant further study.

Although foliage sprays with present formulations are effective on many woody plants, there are several such as ash (*Fraxinus* spp.), hickory (*Carya* spp.), red maple (*Acer rubrum*), locust (*Robinia* spp.), persimmon (*Diospyros virginiana*), basswood (*Tilia* spp.), beech (*Fagus grandifolia*), and certain oaks (*Quercus* spp.) which do not respond with root suppression or even top kills in some cases. Increasing the amount of acid in the solution often gives poorer instead of improved results. Several research men feel that one answer to the problem may be more frequent applications of the phenoxy acids at lower concentrations. The validity of this approach was very ably demonstrated by McIlvain working with shinnery oak (*Quercus havardi*) in Oklahoma (*18*). Three applications of 1 pound of 2,4-D per acre for three successive years was much more effective than one application of 3 pounds per acre. This approach seems to be effective in treating a plant which can be killed to ground line, and repeat sprays kill the sprouts arising from lateral rhizomes. But the same approach is ineffective on several woody plants such as ash and hickory, where up to four repeat foliage applications have not killed the tops.

Timing Applications

It seems important that foliage sprays of the phenoxy compounds be applied when the stored food supply is lowest (*19*), when the leaves are of medium age (*22*), and when the plants are replenishing their food reserves (*8*).

For most woody plants, sprays can be rather readily timed to take advantage of translocation. However, for plants which replenish their food reserves during a very short period or for short intervals during the growing season, timing is difficult. (Some woody plants growing under arid conditions can be sprayed effectively only when suitable moisture and temperature conditions make them sensitive.)

The extensive root systems of many plants growing under dry southwestern conditions also complicate control. For instance, an 11-month-old mesquite plant with 34 inches of growth above ground had a lateral root spread of 17 feet and a tap root 7 feet deep (*2*). These plants apparently maintain a large amount of stored food, which is a factor in determining the ability of the plant to resprout after the top has been killed.

With many woody plants the phenoxy compound will kill the above-ground portion, but how far the effect of these chemicals extends past the root-stem transition zone in some species is still unknown. Ability to kill these woody plants seems to depend upon such factors as the amount of stored food, the area in which dormant buds are located, the amount of chemical the leaves will absorb and transport, and the sensitivity of the plant to the particular phenoxy compound.

Recently Blair and Fuller, using a radioactive isotope incorporated in a morpholene salt of 2,4-dichloro-5-iodophenoxyacetic acid, noted that in no case did more than 2.5% of the material deposited on the leaves of mesquite seedlings move downward (*5*). This downward movement of the phenoxy acid or its breakdown products in woody plants, particularly when it reaches the root-stem transition zone, needs further investigation and is the most important single problem confronting research workers in this field today.

Use of Additives

To overcome these foliage treatment failures on certain plants, there has been an effort to increase penetration by using various additives with the phenoxy compounds. Tests indicate that the addition of small amounts of oil to the water spray will increase top kill and root suppression on many plants which have not responded to the formulations now used in foliage spraying. Using small amounts of oil in this manner appears to increase penetration and subsequent top kill and root suppression of many plants instead of interfering with translocation as many workers expected. This may be explained by the fact that the present esters of these phenoxy acids are soluble in oil, and extending the oil phase of the formulation not only increases the volume of the active phase in the spray solution, but decreases the concentration of esters in the oil phase. Recent work with oil-water mixtures applied as broadcast basal treatments indicates that increasing the amount of oil in the solution also increases stem penetration (*8*, *10*).

The amount of oil used in the spray solution will vary with species, leaf susceptibility, and stage of growth when treated. Under eastern conditions with mixed species the addition of 10% oil in the water solution has been most effective over the past 2 years (*3*). Tests on the addition of such adjuvants as sodium trichloroacetate and ammonium fluosilicate to the water solutions of 2,4-D and 2,4,5-T to increase top kill and root suppression are most encouraging.

When other chemicals are used with the phenoxy compounds, the most important factor is the amount of chemical used in the spray solution; high rates may produce inhibition rather than activation of the herbicide. Hitchcock has demonstrated that certain chemicals such as indole acetic acid may inhibit the action of phenoxy compounds (*12*). Others, such as trichloroacetic acid, may increase the action of the phenoxy compounds (*23*). Much more work is needed on the use of adjuvants.

Another approach to making foliage sprays more effective on a greater range of species is trial of other growth regulators. 4-chlorophenoxyacetic acid and 2-methyl-4-chlorophenoxyacetic acid possess selective killing properties which have not been fully evaluated on woody plants. Recent work by McCully and Darrow indicating the selective properties of 2-methyl-4-chlorophenoxyacetic acid on white brush (*Lippia ligustrina*) (*17*), and Freed's work on brambles (*Rubus* spp.) (*13*) using the same acid, should encourage more work with this chemical.

To point out the selectivity toward species within the same family, Melander has noted that certain species of barberry are most sensitive to 2-methyl-4-chlorophenoxyacetic acid, while other species respond best to 2,4-D and/or to 2,4,5-T (*20*). There is no way to predict the response to the different phenoxy acids and more field trials are needed to determine the selectivity of 4-chlorophenoxyacetic and 2-methyl-4-chlorophenoxyacetic acids toward plants that are not susceptible to 2,4-D or 2,4,5-T.

Although foliage spraying is the most economical approach to the problem and is very effective on many species, it has some shortcomings. In an effort to overcome the problems of inadequate absorption and translocation of the phenoxy compounds in plants which do not respond to foliage sprays, and to lengthen the spraying season, the basal method has been developed. This method bypasses the foliage and some of the translocation problems by applying the 2,4-D and 2,4,5-T esters of acids in oil to the basal part of the plant covering all the stems from the ground line up 12 to 15 inches.

Basal Sprays

Basal sprays are most frequently used as a follow-up treatment for plants which were not killed by an initial foliage spray, or when most of the plants are known to be resistant to foliage sprays. This technique has the added advantage of being effective at any time during the year. When plants are treated with this method during their dormant period they often leaf out in the spring and then start to die from the growing point back. This method was once considered for use during dormancy only, but 5 years' data have shown it to be equally effective during the growing season (*3*). Red maple may be cited as an exception, because it seems to be affected most when basal application is made just prior to bud swelling (*4*).

When the spray is used during the growing season and applied properly to the basal part of the plant, the leaves continue to function until the chemicals have penetrated the bark or crown of the plant and have been translocated to the growing point, and with certain plants to some extent into the root system.

Basal sprays require higher concentrations of the phenoxy compounds than do foliage sprays. Depending on the plant response, 1 to 2% acid weight of 2,4-D and 2,4,5-T in an oil carrier is needed.

Whether the phenoxy acids are applied as esters, acid, or oil-soluble amines is not nearly as important as the volume of the carrier and the plant area sprayed. Studies conducted with Kauffman indicate that the volume of material applied is the most important single factor (*3, 14*). When a 1.5% by weight concentration of 2,4-D ester in oil was used, about 40 ml. per inch of diameter was necessary to suppress resprouts from the root-stem transition zone. If the concentration was increased but the volume decreased, the results were poor. Coulter has shown that the material must be applied to the basal part of the plant (*7*). Working with oak (*Quercus alba*), he has noted that when the material was applied to the basal 15 inches of stem, the plant was dead through its entire length, but when applied to the terminal 15 inches, kill was limited to the area treated and an average distance of 10 inches below it.

The fact that one must apply the material in rather high volumes, enough to run to ground line, and that the spray must be directed to the base of the plant leads many to question the degree to which the chemical or its breakdown products may be translocating in the root system. It is known that the material applied at the base moves upward and kills the foliage and stems above the point of application. However, workers find that the material must collect at the base of the plant to be effective, indicating that it may primarily inhibit the adventitious buds present in the root-stem transition zone.

Although basal sprays are much more effective than foliage sprays, some species such as locust, aspen, and certain oaks are difficult to eradicate with a single treatment. These plants have the ability to resprout from lateral rhizomes and will resprout in a circle around the treated plant, a good indication that the chemical or its effect is not transported very far in the lateral rhizomes of these species. When these few root-suckering species are encountered, repeating treatment until the food reserves are exhausted is the only course open with the present chemicals.

Experimental basal sprays of an oil-water mixture to reduce the cost of the oil carrier, and experimental broadcast basal sprays on certain species, rather than individual plant treatment, are promising enough to warrant further study.

Stump Treatment

Stump treatment, the third method of using chemicals in brush control, involves the same principles as basal treatment, except that the top of the plant is removed and only the remaining stump is treated with 2,4-D and 2,4,5-T or ammonium sulfamate. Stump treatment is a very practical way of preventing regrowth from cut trees, and is used increasingly where new transmission or distribution lines are being constructed through wooded areas.

This method is effective on stumps of plants which resprout from the root-stem transition zone, but is not as effective on plants which can resprout from dormant buds on lateral rhizomes; this again indicates the poor movement of the phenoxy acids in a horizontal plane and the possibility that the growth regulator acts as an inhibitor of these dormant buds rather than actually killing the plant by translocating throughout the root system.

In treating stumps the growth regulators are sprayed with an oil carrier at concentrations of 1 to 2% acid weight at any time following cutting. As in basal spraying, the material must be applied so heavily to the cut surface and all sides that it runs down and collects at the ground line. Many feel that 2,4,5-T is more effective than 2,4-D when this method is followed, regardless of the sensitivity of the species. Ammonium sulfamate is very effective when applied by using the dry crystals at rates of 0.5 pound per 4 inches of stump diameter.

Frilling

The fourth method used to control woody plants, frilling, is most useful in forest and pasture management where large trees are the problem and may be left standing after they have been killed. This method requires making a frill around the trunk, usually at waist height, with a continuous series of vertical axe cuts, leaving the bark attached at the bottom. A solution of 2,4-D, 2,4,5-T, or ammonium sulfamate is poured into this frill or trough. Ammonium sulfamate is used as dry crystals or as a concentrated solution, while 2,4-D and 2,4,5-T are used in the ester and amine forms. Some workers use the esters in water. Leonard uses 40% amine and notes very little difference between 2,4-D and 2,4,5-T amine when applied to live oak (*16*). When the phenoxy compound is used, it is most important to apply a continuous supply of the material uniformly around the circumference of the tree. Chaiken has found that 2,4,5-T is satisfactory on the white oak and red oak group, beech, hickory, sweet gum, and black gum (*6*). Ammonium sulfamate has been reported effective in frill treatment on nearly all species.

In using the four chemical methods to control woody plants, a thorough knowledge of the plants being treated is essential—the time when food reserves are lowest, the period during which food materials are being transported, the selectivity of the acids toward the plants to be treated, and the area from which the plant can resprout, whether it be from the root-stem transition zone or from dormant buds on lateral rhizomes.

Unsolved Problems

The two most pressing problems needing more research are the effect of the phenoxy compounds or their breakdown products on the dormant buds in the root-stem transition zone (which affects the results of foliage spraying), and the rather poor movement of the phenoxy compounds or their breakdown products into the lateral rhizomes (which affects the results of basal and stump spraying). Unless these problems are solved, repeated spraying until the plant food reserves are exhausted will remain the only choice.

Literature Cited

(1) Allen, W. W., *Proc. Southern Weed Control Conf.*, **1950,** 7–12.
(2) Arend, J. L., *North Central Weed Control Conf., Research Rept.*, **1950,** 231.
(3) Beatty, R. H., *Proc. North Central Weed Control Conf.*, **1950,** 123.
(4) Beatty, R. H., unpublished data.
(5) Blair, B. O., and Fuller, W. H., *Western Weed Control Conf., Research Progress Rept.*, **1952,** 49.
(6) Chaiken, L. E., Southeast Forest Expt. Sta., *Paper* **10** (September 1951).
(7) Coulter, L. L., *Down to Earth*, **7**(**4**), 2–3 (1952).
(8) Crafts, A. S., *Proc. Western Weed Conf.*, **1950,** 61–9.
(9) Crafts, A. S., *Western Weed Control Conf., Research Progress Rept.*, **1952,** 147.
(10) Fisher, C. E., Young, D. W., and Marion, P. T., Texas Agr. Expt. Sta., *Progress Rept.* **1320** (1951).
(11) Hamner, C. L., Lucas, E. H., and Sell, H. M., Mich. Agr. Expt. Sta., *Quart. Bull.*, **29**(**4**), 337–42 (1947).
(12) Hitchcock, A. E., and Zimmerman, P. W., *Contrib. Boyce Thompson Inst.*, **17**(**1**) 35–55 (1952).
(13) Jordan, G. L., and Freed, V. H., *Western Weed Control Conf., Research Progress Rept.*, **1952,** 59–60.
(14) Kauffman, R. I., unpublished data.
(15) King, L. J., and Kramer, J. A., Jr., *Contrib. Boyce Thompson Inst.*, **16**(**6**), 267–78 (1951).
(16) Leonard, O. A., unpublished data.
(17) McCully, W. G., and Darrow, R. A., *North Central Weed Control Conf., Research Rept.*, **1951,** 157.
(18) McIlvain, E. H., *Proc. North Central Weed Control Conf.*, **1951,** 81–4.
(19) McIlvain, E. H., and Savage, D. A., "14-Year Summary of Range Improvement Studies at U. S. Southern Great Plains Field Station," 1951.
(20) Melander, L. W., unpublished data.
(21) Pryor, M. R., unpublished data.
(22) Skoog, Folke, "Plant Growth Substances," Madison, University of Wisconsin Press, 1951.
(23) Wangerin, Robert, and Jacobs, W. A., unpublished data.
(24) Young, D. W., and Fisher, C. E., *Proc. Western Weed Control Conf.*, **1950,** 41–8.

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WEED CONTROL

Pre-emergence Methods

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Pre-emergence weed control refers to the application of the chemical to the soil after the crop has been planted but before it emerges. Although this weed control practice is still in an early stage of development, several chemicals have given outstanding results. Most favorable results have been reported in this type of treatment from 2,4-D, calcium cyanamide, CMU, 2-sec-butyl-4,6-dinitrophenol, sodium 2,4-dichlorophenoxyethyl sulfate, TCA, and chloro IPC. The factors affecting the results of pre-emergence treatments are: the type of weeds present, moisture content of the soil, rainfall, soil pH, soil type, organic matter content, soil temperature, and type of crop.

WEED CONTROL has become a much more important and complicated science since the advent of organic chemical weed killers. With the discovery of new chemicals also came the discovery of new methods of weed control. Although the science of weed control and its widespread practice are relatively new, the use of chemicals to kill weeds dates back a half century or more to such materials as copper salts, iron sulfate, sodium chlorate, sulfuric acid, and sodium arsenite. All these older herbicides, however, were sprayed on weeds and crops after the plants were growing. The application of a chemical as a pre-emergence treatment represents a new method in weed control. This method of selectively controlling weeds in corn was first reported in 1947 (*2*). Pre-emergence in general applies to the application of a chemical after the crop has been planted but before it breaks through the soil.

Pre-emergence treatment has certain advantages over any postemergence treatment. Weed control for the period immediately following emergence of the crop is often a critical factor in keeping the crop weed-free for the remainder of the season. Should unfavorable weather hinder postemergence opera-