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BY
ROBERT M. ROMANCIER

REPORT NUMBER 16
GEORGIA FOREST RESEARCH COUNCIL
MACON, GEORGIA 1965

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BY
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ASHEVILLE, NORTH CAROLINA

REPORT NUMBER 16
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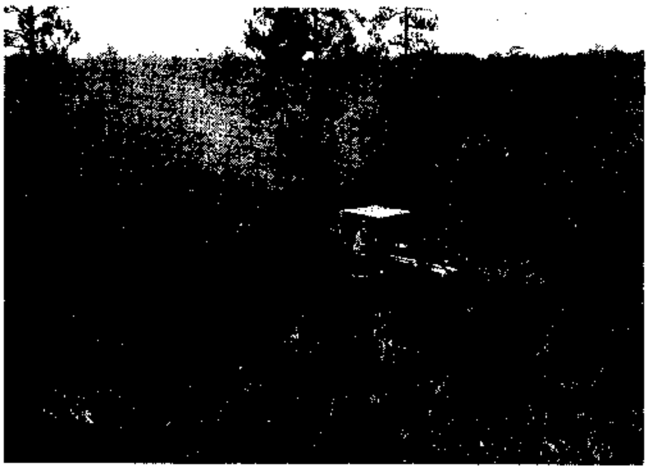
Robert M. Romancier, a native of Springfield, Massachusetts, has degrees in forestry from the University of Massachusetts and Yale University. Since joining the U. S. Forest Service in 1957, he has served at field locations maintained by the Southeastern Forest Experiment Station at Franklin, Virginia, Macon, Georgia, and Charleston, South Carolina. At these centers, Romancier worked primarily in forest management research, especially on problems of pine regeneration and also the uses of fire and chemicals in hardwood control. Early in 1965 Romancier moved to Station headquarters in Asheville, North Carolina, where he is serving as a staff assistant in the Timber Management Research Office.



THE COVER:

Georgia Forestry Commission photo.
The use of tractor-mounted mist blowers is one of the latest and most popular techniques in the application of herbicides for woody plant control in the Southeastern United States.

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FOREWORD

This paper is intended to serve as a source of reference and as a guide to foresters and landowners who want information about 2,4-D, 2,4,5-T, and certain related chemicals. The scope is primarily limited to these herbicides as they relate to control of woody plants growing in the southeastern United States. Properly used, these recently synthesized herbicides will control many of the woody plant species found in the southeast, at reasonable costs, and with far greater safety than some of the earlier chemicals.

ACKNOWLEDGMENTS

Many people have assisted in the preparation of this paper. I wish especially to thank O. Gordon Langdon of the Southeastern Forest Experiment Station for his many useful suggestions and hours of discussion, and also E. V. Brender of the same Station who made many contributions in the early phases of this publication. Several reviewers gave sound advice: W. E. McQuilkin of the Northeastern Forest Experiment Station, John L. Arend of the Lake States Forest Experiment Station, Jack Stubbs of the Southeastern Station, and John H. Kirch of Amchem Products, Inc. Mason C. Carter, Auburn University, was especially helpful with the sections on organic chemistry.

2, 4-D, 2, 4, 5-T, AND RELATED CHEMICALS FOR WOODY PLANT CONTROL IN THE SOUTHEASTERN UNITED STATES

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THE PROBLEM AND THE ROLE OF 2,4-D AND 2,4,5-T

The control of weeds has been a problem ever since man first learned to cultivate plants. Some weeds compete with desirable plants for space, water, or nutrients; others poison man's livestock, irritate allergies, spread plant diseases, or in other ways interfere with the most effective utilization of this productive earth.

Weed control measures are often among the most expensive steps in growing crops for food or fiber. In the never ending struggle against weeds, man has used many methods of control. He has used his bare hands to pull weeds out of the ground, he has used a hoe or fashioned many mechanical tools to act as hoes, he has used fire, he has introduced insect enemies of plants, he has encouraged domestic animals to eat the weeds, he has flooded with water. And he has used chemicals.

Chemicals are not new to the field of plant control, for we know salt was used to sterilize fields in Biblical days. In more recent times, sodium arsenite and ammonium sulfamate (ammate) have been used to kill woody plants, but the arsenite is dangerous, most forms of ammonium sulfamate are corrosive to metal, and neither is selective—they kill or affect whatever they contact. There has been a definite need for a selective, low-cost herbicide.

Two chemicals, 2,4-D and 2,4,5-T, were first synthesized in the early 1940's *(167)*. The first developed, 2,4-D (2,4-dichlorophenoxyacetic acid), was initially found to be a plant growth regulator *(235)*. The development of 2,4,5-T (2,4,5-trichlorophenoxyacetic acid) followed closely. In 1944, after successful field trials, Hamner and Tukey *(73)* announced that 2,4-D and 2,4,5-T were selective herbicides.[1] Wartime secrecy had been imposed when it was thought that these herbicides might be used to kill enemy crops. A more complete account of the discovery of 2,4-D and 2,4,5-T and their uses has been written by Freed *(63)*.

Since 1944, continuous advances in chemical formulations, knowledge of the specific action or actions of these herbicides, and new application methods and equipment have been made. Preparations and techniques of the 1940's and 1950's have been superseded, and results have been bettered. Scientists have given us insight into the action of these chemicals, so that we now know something of why they work and how to use them more efficiently and effectively.

THE GENERAL NATURE AND ACTION OF 2,4-D AND 2,4,5-T

These chemicals are in the organic chlorophenoxy (or simply phenoxy) group. They are nonflammable, nonexplosive, and noncorrosive. They are considered selective, in that some plants are more susceptible than others to these substances. And they are translocated herbicides, which means they travel within the plant, rather than acting only where they are applied. They are usually effective in very low concentrations.

2,4-D and 2,4,5-T are auxins or growth regulators which in some ways act like plant hormones *(43, 143)*, but they disrupt the normal cell and plant life processes. Unfortunately, much of the basic research into the action of the phenoxy herbicides has not been on the woody plant group, but rather on tomatoes, beans, oats, and morning glories, so it is often risky to apply the findings of such studies to maples, pines, or oaks. Additionally, almost every study has been based on foliar application, with little attention given to cut surface, dormant season, or soil application.

Certain conditions and observations, however, are basic to all plants. Thus, some references cited here are based on nonwoody plants, such as oats, or unfamiliar tree species, such as California blue oak, rather than on woody weed species found in southeastern forests.

There are many obstacles or variables affecting the performance of a translocated herbicide. Shaw *et al.* *(188)* graphically illustrated some of these obstacles in the following diagram (Figure 1). Freed *(63)* has estimated that less than 40 percent of the applied chemical finds its way into the plant to become effective.

For a translocated herbicide to have a potentially lethal effect on a plant: (1) the herbicide must penetrate or be absorbed into the plant, (2) it must move through the plant, generally in the phloem, and (3) it must have a toxic reaction with the cells and tissues of the plant *(29, 108)*.

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[1] *Some confusion in terms exists. Properly, an herbicide will kill herbs—plants that annually die back to the ground and have no woody stem. Silvicides and arboricides kill tree species, and phytocides kill all plant species. However, since the term "herbicide" has been used by almost all writers to describe a chemical killing woody plants, herbicide will be used in that context throughout this paper.*

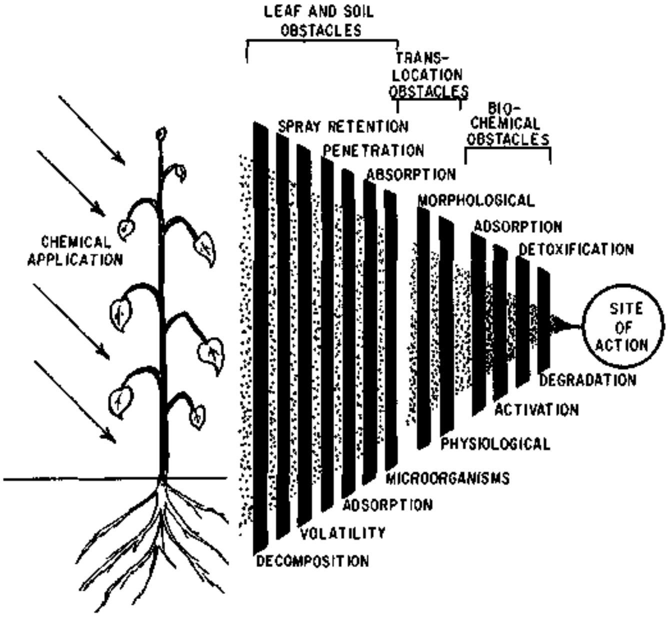

Figure 1. Obstacles which determine the concentration of toxic material at the site of action (188).

PENETRATION AND ABSORPTION

Studies on how the phenoxys get into plants have mostly been based on foliar entry. The shape, position, density, surface, and margins of a leaf all influence the foliar distribution, retention, and uptake of herbicides.[2] The main obstacle to foliar penetration is the cuticle, a waxy layer which acts to retain moisture in the leaf, and which is found in varying thickness over most of the leaf surface.

The cuticle is a barrier to the penetration of any water-soluble material, and a thick cuticle is a greater barrier than a thin one. Thus young leaves, which have very thin cuticles, are more easily penetrated by herbicides in water emulsions than are older leaves.

Minute openings (stomata) in the leaf are usually open at the time of spraying *(47, 176)*, depending on humidity and moisture relations. While most penetration is through the cuticle, a certain amount of stomatal penetration probably takes place *(90, 98)*. Penetration is reportedly more rapid in plants with stomata on both upper and lower leaf surfaces than in plants with stomata only on lower leaf surfaces *(108)*, and Walker *(219)* reported that lower leaf surfaces absorbed more 2,4,5-T than upper surfaces, which he related either to a thinner cuticle or more stomata on the lower surfaces. Absorption and translocation increase with rises in temperature and humidity, possibly because of stomatal opening *(150)*.

It is possible that oil sprays can easily enter open stomata, but water-based sprays may require the addition of a wetting agent for stomatal entry *(107)*.

Other entry paths in the leaf are the phloem cells found on the underside of many leaves, modified epidermal cells overlying the veins, through cracks in the cuticle, or through the cuticle in areas where it is stretched by expansion of the underlying layers *(216)*. The acidity or pH (see glossary) of the herbicidal mixture is also important. Kirch *(93)* reported maximum penetration and translocation at a pH of 5.0 or less. Little occurs above 6.0 *(216)*.

Absorption is generally greater in the light than in the dark *(49)*.

The material of the stem is usually suberized (corky) and resists penetration by water or water-borne herbicides. For this reason, herbicides applied as basal sprays are not diluted with water, but with light oils which facilitate penetration *(47, 176)*. Bark sprays enter not only through the bark itself, but also through bark fissures and lenticels (see glossary) *(191)*. Herbicides applied to cut surfaces are more rapidly taken up by the sapwood; movement into the dry heartwood is much slower *(107)*.

TRANSLOCATION

Translocation, the movement of materials within and throughout a plant, is a complex subject with some apparent contradictions.

The usual herbicide pathways in a plant are upward in the xylem and downward in the phloem *(10, 232)*, although there may be some reversals *(77, 176)*. Under usual conditions, phloem transport is greater and more important by far than xylem movement. Xylem movement of foliar-applied herbicides is usually restricted to the foliage, from treated to untreated leaves, not downward *(41)*. Of considerable importance is the fact that there is very little lateral or sideways movement of herbicide in a stem *(32, 176)*. Thus, close spacing is usually necessary for satisfactory results with tree injectors.

As a movement process, translocation is relatively rapid at times, and very slow at others. Many environmental and physiological factors influence translocation *(10)*. Working with blackjack oak,[3] Basler *(10)* found that both the absorption and translocation of radioactive 2,4,5-T (tagged with C^{14}) was high in the early spring, low in the early summer, and increased some in the fall. Basler also noted that leaf respiration followed the same curve as absorption and translocation. In mesquite, maximum translocation occurs when the total sugar content of the roots is building up at a rapid rate after the low level attending full leaf development *(62)*.

Yet translocation is not completely predictable. Some researchers have failed to find any relationship between carbohydrates stored in the roots and either the susceptibility to herbicides or the development of sprouts after the stem is cut *(208, 224)*. Generally it can be said that herbicides applied to immature leaves which are still importing foods from more mature parts are not translocated out of that leaf *(45, 46)*.

Some of the observed contradictions in translocation may be the result of the environmental conditions of the studies. Translocation rates increase with

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[2]*Shaw, W. C. Advances in chemical weed control research. Paper presented at the Beltwide Cotton Production-Mechanization Conference, Greenville, S. C., Jan. 11-13. 1961. (Mimeographed.)*

[3]*Scientific names for all species mentioned in this paper will be found in the appendix.*

increases in light intensity *(110)*, and are most rapid at high light levels *(41, 230)*. Temperature also affects translocation. Foliar sprays, if applied during periods of high temperature and low humidity, when the plant is losing more water than it takes in, will often result in failure *(16)*.

Overly concentrated dosages, which cause contact injury or death to the leaf, defeat the purpose of using a translocated herbicide. If the chemical is not translocated out of the leaf rapidly enough, the herbicide concentration will build up and kill only the leaf *(47)*.

Since the movement of herbicides and foods is usually toward the areas of greatest physiological activity, the herbicide may be diverted to the wrong tissues, such as flowers, fruits, or vegetative shoots *(108)*. Fungal infections may also attract 2,4-D or 2,4,5-T *(107)*. Herbicide sprays applied when fruit or seed is in rapid development are rarely successful *(16, 142)*. Some plants treated toward the end of the growing season may not respond until active growth resumes the following spring *(223)*.

The particular formulation of 2,4-D or 2,4,5-T applied is sometimes credited with influencing translocation, but more probably the specific formulation, such as the ester, is important in the penetration stage *(93, 110)*, but is hydrolized (see glossary) and retained in the leaf while the free or basic acid form is translocated within the plant *(77)*. It is even possible that herbicides applied in one form may be translocated in another form, and cause injury in a third form *(188)*.

Species that form root grafts or root suckers may translocate herbicides applied to one stem through the shared root system, killing stems not directly treated *(83)*. Such injury is called "flashback," but is relatively rare with 2,4-D or 2,4,5-T, and occurs only when strong dosages are applied near the ground line.[4]

DEATH

How does a phenoxy herbicide kill a plant? No one knows, although Leopold *(110)* lists six theories:

1. Respiratory depletion.
2. Cellular proliferation.
3. Formation of toxic materials through abnormal metabolism.
4. Activation of phosphatase system—destructive hydrolysis of high-energy phosphate bonds.
5. Hydrolysis of protein materials in the cell—retard or destroy essential enzymatic activities.
6. Potassium metabolism interference.

An additional possibility is that if the usual role of auxins is to order normal cell divisions, herbicide molecules may bring about disorganized cell divisions, resulting in abnormal growth, derangement of metabolic and physiologic processes, disorganization of form and function of vascular tissues, and ultimately death *(47)*. It is probable that there is more than one lethal action involved, or at least different manifestations of the same action, or even that various species are affected differently.

U. S. Forest Service photo.
Figure 2. A typical response to stem applications of 2,4,5-T is the development of bark splits and perforations noticeable at a considerable distance. Frill treatments, shown here, are often accompanied by a marked swelling above the frill.

The 2,4-D (or 2,4,5-T) molecule itself may be metabolized, and degraded or altered by plants, but it is uncertain whether these metabolic actions are detoxification processes, because it is uncertain if it is 2,4,-D or one of its metabolized forms that is the toxic agent responsible for the changes in a plant, so metabolism could represent either an activation or detoxification mechanism *(188)*.

Often the first sign of injury is curling or twisting of the leaves, technically called epinasty. This is followed by swelling, splitting, and perforations of the bark and browning foliage (Fig. 2). Death may follow the application of the herbicide within a few weeks or months or after several years. Often the slower-acting herbicides and formulations result in a higher final percentage-of-kill.

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[4]McQuilkin, W. E. 1963. Personal communication.

STRUCTURE AND FORMULATIONS OF 2,4-D, 2,4,5-T, AND RELATED COMPOUNDS

STRUCTURE

2,4-D and 2,4,5-T are organic chlorophenoxy compounds belonging to the carboxylic-aromatic group of chemicals. The basic component is benzene (C_6H_6), which has a ring structure (Fig. 3A). Each carbon atom is assigned a number, but in usual diagrams neither the carbons nor the numbers are shown. Removal of one hydrogen atom leaves C_6H_5, a phenyl group or ring. When the phenyl group is attached to an oxygen atom, which in turn is attached to an alkanoic acid group, we have the basic phenoxy model (Fig. 3B), the basis for all forms of 2,4-D, 2,4,5-T, and many other related compounds.

2,4-D

To make 2,4-D, the general phenoxy model is used, and chlorine is substituted for the hydrogen atoms at sites 2 and 4, which explains the use of these numbers in the name (Fig. 3C). The D in the common name represents *di,* or 2 chlorine atoms.

2,4,5-T

The only difference in the organic structure of 2,4-D and 2,4,5-T is that in the 2,4,5-T a third hydrogen, at site 5 in the phenyl ring, has been replaced by a chlorine atom (Fig. 3D). The T in the common name represents *tri,* or 3 chlorine atoms.

OTHERS

Since the discovery of the herbicidal properties of 2,4-D and 2,4,5-T, many analogs (chemically similar herbicides) have been formulated. These include 2-(2,4,5-TP) (commonly called silvex), 2-(2,4-DP), and 4-(2,4-DB). Their organic structures are included in the appendix.

2-(2,4,5-TP)[5] — Silvex, or 2-(2,4,5-trichlorophenoxy) propionic acid, is structurally similar to 2,4,5-T, except that it is a propionic acid (meaning 3 carbon atoms) instead of an acetic acid (2 carbon atoms) *(98)* and is available in a number of formulations.

2-(2,4-DP)[6] — 2-(2,4-dichlorophenoxy) propionic acid is the propionic form of 2,4-D.

4-(2,4-DB)[7] — This butyric formulation, 4-(2,4-dichlorophenoxy) butyric acid, is not toxic to vegetation, but it is still used as an herbicide. Double-talk? No, the explanation is that the susceptible plants (those having an active beta-oxidation system—see glossary) convert the nontoxic 4-(2,4-DB) to 2,4-D in their tissues, bringing about their own deaths. For example, 4-(2,4-DB) has no toxic effect on Douglas-fir, but when the herbicide is ground up with alder leaves, the combination is then toxic to Douglas-fir foliage. The alder leaves convert the 4-(2,4-DB) into the toxic 2,4-D *(172).*

4-(2,4-DB) is a highly selective herbicide that works slower than the more orthodox forms, and is harmless if applied to nonsusceptible plants *(47, 188, 217).* The mode of action of 4-(2,4-DB) may be a real clue into the development of herbicides that only affect one genus or one species of plant. Conceivably, understanding

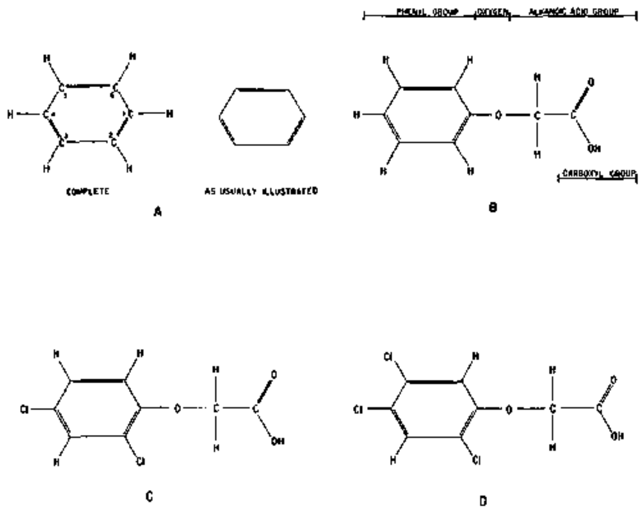

Figure 3. Construction of 2,4-D and 2,4,5-T. A, organic structure of the benzene ring. B, the general phenoxy model. C, 2,4-dichlorophenoxyacetic acid (2,4-D). D, 2,4,5-trichlorophenoxyacetic acid (2,4,5-T).

all the chemical and physiological differences between two species should make it possible to formulate a truly selective herbicide for aerial application that would be toxic, for example, to red maple but not to a sugar maple standing beside it.

At least two other nontoxic herbicides exist; these are 2,4-dichlorophenoxyethylbenzoate and 2-4-dichlorophenoxyethylsulfate (sesone). When applied to the soil, these are converted to 2,4-D either by microbial action or by acid hydrolysis (see glossary) and then taken up by plant roots *(110).* So far these compounds have found no use in practical woody plant control.

Tordon[8] — A new herbicide marketed by the Dow Chemical Company appears to be very effective on a number of species usually considered resistant to 2,4-D or 2,4,5-T. Tordon—4 amino-3,5,6 trichloropicolinic acid—is often diluted with water and used at lower concentrations than 2,4-D or 2,4,5-T, reportedly giving a very high degree of root kill *(222).* It may be applied to foliage or cut stems, or pelletized as a soil treatment.

Additional Herbicides — A host of other herbicides exist, including 2,4-DEP, 4-(2,4,5-TB), 2,3,6-TBA, 4-(MCPB) *(6, 19, 98, 187, 205).* Studies are underway

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[5] *Usually the more simple abbreviation, 2,4,5-TP, is used, but since there is also a 3-(2,4,5-TP), the more specific formula is desirable to avoid confusion.*

[6] *Often simplified to 2,4-DP, but not to be confused with 3-(2,4-DP), a compound not frequently or successfully used in woody plant control.*

[7] *Again, the simple abbreviation, 2,4-DB, can be confusing, because it may also represent at least two other butyric forms that have been tested as herbicides; 2-(2,4-DB) and 3-(2,4-DB), neither of which seems very effective against woody plants.*

[8] *Use of a trade name is for identification purposes only, and does not represent endorsement by the U. S. Department of Agriculture.*

not only to create and use new phenoxy forms, but to combine the forms now available in new ways. Such combinations as 2-(2,4-dichlorophenoxy) ethyl 2,4,5-trichlorophenoxyacetate (more simply 2, 4-D ethyl 2,-4,5-T) offer new experimental possibilities.

FORMULATIONS

2,4-D, 2,4,5-T, and many of the related compounds are available in a number of formulations, which differ in cost, effectiveness, and application requirements. For simplicity, only 2,4-D will be discussed, with the understanding that similar forms of 2,4,5-T are generally available. The various formulations include the acid, simple salts, amine salts, and esters, all of which are created by the substitution or addition of other atoms or molecules for the hydrogen of the carboxyl group. Organic structures of representative salts, amines, and esters are in the appendix.

ACID

The basic form of 2,4-D, the acid, is a whitish crystalline solid that is relatively insoluble in either water or petroleum oils. Although an acid, its acidity is more on the order of vinegar than sulfuric acid. The acid may be applied as a finely ground or colloidal powder, or as a paste with a liquid carrier, but these have very limited usefulness. A more useful formulation, the emulsifiable acid, is made by suspending the 2,4-D acid in water.

SIMPLE SALTS

When the uses of 2,4-D and 2,4,5-T were first being explored, the relatively simple and cheap salt forms, such as ammonium, sodium, lithium, potassium, and calcium were used as foliage sprays. Salts are created by the reaction of the basic acid with an alkali.

The simple salts may be formulated as a dry powder or as a liquid *(47, 98)*. Although these salt forms have generally gone out of usage, some sodium salts are still sold commercially *(182)*.

AMINE SALTS

If the 2,4-D acid is reacted with an organic compound containing an amino group ($-NH_2$), a salt of 2,4-D called an amine is formed. Common amines include alkanoamine, isopropyl and di-isopropyl amines, diethanolamine, triethanolamine, dimethylamine, trimethylamine, triethylamine, dodecylamine, or mixtures of these. The amines come in liquid form and are available as either water soluble or oil soluble.

A spraying hazard is involved when any of the salt formulations are used with a water carrier. Some of the salt molecules dissociate into ions. If the water has a high calcium or magnesium content (hard water), a white precipitate may form that can clog filters and nozzles. This precipitate is difficult if not impossible for plants to absorb. However, water-soluble amines can be sequestered (see glossary) in the laboratory to prevent the formation of a hard water precipitate *(93)*. Oil-soluble amines can generally be used in both oil and oil-water carriers, although some specific formulations are not suitable for combination with water.

The simple and amine salts, and the acid form, all exhibit a low degree of volatility *(133)*.[9] [10] Volatility will be discussed in detail in the section on esters, but low volatility is considered a valuable attribute.

ESTERS

The most commonly used forms of 2,4-D and 2,4,5-T are the esters. These are created by combining the basic acid form with any one of many different alcohols. The result is an oily liquid which is oil soluble but not water soluble. A great many esters have been formulated. Generally these are grouped together as either high volatile or low volatile, depending on how readily they go into the vapor or gaseous phase from the liquid phase in which they are applied.

The nomenclature of the various esters is sometimes confusing because some manufacturers and some reporters have disregarded standard chemical nomenclature procedures. In many cases the manufacturing process, and not the chemical, is patented, and the manufacturer need not say (and may even not know) what the exact formula is. In an attempt to clarify some of this confusion, many of the various esters and their synonyms are presented in the following list, along with some explanatory notes.

High volatile esters

Amyl = n-Amyl = Pentyl[11]
Butyl = n-Butyl
Ethyl
Isoamyl
Isobutyl
Isopropyl
Methyl
Propyl

Low volatile esters

*Butoxy ethanol
Butoxy ethanol propanol
Butoxy ethoxy propanol = Butoxy ethoxy propyl
Butoxy ethoxy propylene
Butoxy polypropylene glycol = Propylene glycol butyl
Butoxy propyl = Butoxy propanol
Capryl
Ethoxy ethoxy propanol
Ethylene glycol butyl
*Isooctyl
Octyl[12]
Polyethylene glycol
*Propylene glycol butyl ether = Polypropylene glycol butyl
*Tetrahydrofurfuryl
*2-ethyl-hexyl

*Indicates the most commonly used esters.

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[9] *Anonymous. Oil-soluble amines of 2,4-D and 2,4,5-T for the control of woody plants and broadleaf weeds. Amchem Tech. Serv. Data Sheet H-88, 16 pp. 1962. (Mimeographed.)*

[10] *Kirch, John H. The business of controlling woody plants. Paper presented at Western Weed Conf., Las Vegas, Nevada, March 20-22, 13 pp. 1962. (Mimeographed.)*

[11] *Pentyl and amyl are the same ester, and were once considered low volatile.*

[12] *Although Crafts (47) lists octyl as an alkyl ester (generally high volatile), he pointed out that octyl (8 carbons) is a long-chain ester. The decyl ester is similarly a long-chain alkyl ester.*

Often the effectiveness or usefulness of an ester is related to its volatility. Volatility is important because it indicates the ease with which an applied herbicide moves into the vapor form, and through the air from the site of application to another area. These vapors may be deposited on a susceptible plant, and in sufficient amounts will cause injury or death just as if purposely applied to that plant. This vapor movement can occur for several days or even weeks after application (Fig. 4). Vaporization increases as temperatures increase.

While there is no single scale or accepted standard for determining volatility, there are several laboratory methods, usually based on stem and leaf epinasty of one or more plant species. One method listed in the Official and Tentative Methods of Analysis of the Association of Official Agricultural Chemists[13] is designed for the ester forms and utilizes tomato plants *(133)*.

Esters with pH values of 3 to 5 (acid) are thought to be more effective for penetration and translocation than the neutral esters (pH 7.0) *(15, 90, 93)*.

CARRIERS, ADDITIVES, AND CONCENTRATIONS

Unfortunately, choosing the best herbicide and the best formulation is not enough. The carrier used can often decide the success or failure of a treatment. Some additives will markedly enhance the toxic effects, and use of the proper concentration can also determine treatment effectiveness, since too little active herbicide necessitates re-treatment and too much is a waste of money and may cause contact injury to the foliage or stem.

CARRIERS

Carriers are used to dilute concentrated herbicides so that a small amount can be used to treat uniformly a large area or many stems, and also to increase the herbicides' effectiveness. Inadequate treatments may result from too low a volume of carrier.

Although some individual stem treatments can be made with the undiluted concentrate, carriers are always used for foliar and other broadcast applications. The most common carrier choices are diesel oil, diesel oil-water, and water. The choice depends on the formulation of 2,4-D or 2,4,5-T to be used, the method and season of application, and the species treated. Some formulations are not compatible with oil; others are not compatible with water. Emulsions are naturally less stable than solutions, and require periodic or continuous agitation. Manufacturer's directions, which should always be read carefully and followed, usually list possible recommended carriers and specific mixing directions.

WATER

Water is used with the water-soluble amines, with emulsifiable acids, and often with esters to form emulsions. Early in the growing season, before plant cuticles thicken, water is usually a satisfactory carrier for any suitable herbicides applied as foliage sprays; it is generally unsatisfactory for cut-surface or basal spray methods *(156, 173)*.

OIL-WATER

Oil-water emulsions are often considered better than a straight water carrier, and as effective and cheaper than a straight oil carrier *(62)*. When an herbicide-water emulsion is being prepared, oil is often added when esters are being used. Oil decreases the specific gravity of the ester, making it nearer that of the water, which creates a more stable emulsion *(106)*. An oil-water emulsion is sometimes recommended over an oil solution when susceptible pines will receive some of the spray mixture, for too much oil may damage any pines present *(1, 2, 140)*.

The proportion of oil generally need not be great. Upchurch and Keaton *(215)* suggested the addition of 10 percent diesel oil to 2,4,5-T in water emulsions, and Sutton *(205)* cautioned that too much oil in the mixture might inhibit translocation of the herbicide.

Recent developments in equipment design and in herbicide formulation make possible a new type of oil-water emulsion called the invert, which is an oil-water mixture in which the oil, rather than the water,

Photo by Dr. B. E. Day, Univ. of California.
Figure 4. This cotton plant, located a considerable distance from the spray site, was damaged by vapors alone. The butoxy ethanol ester—a relatively low volatile ester—of 2,4-D caused the injuries.

[13] *Association of Official Agricultural Chemists. 9th edition, p. 47. 1960. (Available at P. O. Box 540, Benj. Franklin Station, Wash. 4, D. C.)*

is on the outside of each droplet; this external oil phase reduces the chance of rain washing the spray from a plant. Invert emulsions can be applied with a mist blower, ground spray equipment, or by airplane *(94, 165)*.

OIL

Oil carriers, despite the higher treatment costs, are popular because the oil lowers the surface tension and increases the wetting ability of the spray. Oils penetrate the plant bark or cuticle much more readily than water does *(119, 135)*. Oils also make possible herbicide movement through nonliving cells, independent of the normal translocation mechanism *(110)*. Oils are especially helpful for late summer foliar treatments, when the waxy cuticles are very thick and evaporation rates high *(27, 48)*. Oils are used for almost all cut-surface treatments, and for basal sprays.

Straight oil carriers may cause burning of pine or hardwood foliage, which is undesirable because burned leaves neither absorb nor translocate phenoxy herbicides. Apparently oil toxicity is related chiefly to the aromatic content of the oil *(128)*, but other factors include sulfur content, viscosity, and specific gravity.[14] To eliminate or minimize the contact-killing effect of an oil carrier, various nonphytotoxic oils are coming into usage. Much undesirable foliage damage to both pines and hardwoods may be avoided by using these oils *(9, 165)*. They do not burn or contact-kill the foliage, so the leaves remain green for several weeks after spraying *(19)*. This allows the plant to function normally for a longer time, resulting in the translocation of more herbicide to the roots.

Some confusion exists over the nomenclature and properties of the oils commonly used as carriers. Although the chemical and physical properties of oils can differ between manufacturers, and even between batches, some approximations can be made, based on data from the Pure, Gulf, and Texaco Oil companies:

Trade name	*Common name*	*Weight per gallon (Lbs.)*	*Flash point (Degrees F.)*
#1 Fuel oil	Kerosene	6.6	120
#2 Fuel oil	Diesel	7.4	150
*Mineral seal oil	Refined kerosene	6.8	225

**Mineral seal oil is the most commonly used non-phytotoxic oil.*

The flash point shows that kerosene is the most flammable of the three oils, followed by diesel oil and mineral seal oil. Kerosene is also the most volatile, diesel oil is intermediate, and the mineral seal oil least volatile. Mineral seal oil will remain in liquid form on the foliage longer than the other two oils.

ADDITIVES

An additive is any material added to an herbicide to increase its effectiveness. There are many types for many purposes, and the effects of some additives differ according to the formulation with which they are used. Some additives, such as emulsifiers and cosolvents, are incorporated into the concentration before it is sold; others must be added by the ultimate user. Additives include: stickers, humectants, deposit builders, penetrants, surfactants (wetting agents), and spreaders. Sometimes two or more additives act to give the same results, which causes some confusion in terminology.

Surfactants, or surface-active agents, may increase, decrease, or not affect herbicidal activity, and may themselves be phytotoxic or growth stimulating. Surfactants may alter the permeability of plant tissues to a herbicide, or may reduce spray volatility *(81, 206)*. The proper surfactant may increase herbicidal activity on one species and not affect another *(86)*. This would be the case when species susceptibility or herbicide selectivity is based on selective foliar absorption *(98)*. The use of a surfactant in a spray applied to very hairy or pubescent leaves should increase effectiveness, but too much wetting agent can cause excessive runoff, wasting some of the spray *(6)*.

Wetting agents have given improved kills with amines and esters of 2,4,5-T and 2,4-D *(37, 69, 190)*. Deposit builders increase the spray load on a surface, but may clog the stomata and thereby reduce penetration. Humectants aid penetration and absorption by preventing too-rapid drying of the spray on the plant. Spreaders serve to assure a more uniform coating of spray on a surface, and stickers cause the spray to adhere to a surface. Penetrants facilitate entry of herbicides into the plant, particularly the amine formulations *(93)*. Esters are naturally oily, and this oiliness aids in wetting and acts as a cuticular and stomatal penetrant *(84)*.

Other additives have been tested. Pentachlorophenol was added to an ester of 2,4,5-T used as a foliage spray, but the combination was no more effective than the ester alone *(69)*. Currier and Dybing *(49)* found silicone oils unsatisfactory. Ethanol improved the absorption of the 2,4-D acid, but not of the amine salt, whereas urea increased the rate and total absorption of 2,4-D. Urea and sucrose have been useful in reducing foliar damage *(68)*.

A different kind of additive from those discussed so far is the marker. It is used to indicate the areas and plants that have been treated and those missed. Markers are especially helpful when no identifying wound is left on the plant; thus, broadcast and basal sprays often include a marker. For water-based sprays, boron red dye has been used with ester forms *(80)*, or superfine wood flour or titanium dioxide *(149)*. For oil solutions, ½ to ¾ pounds of para red per 100 gallons of spray has been used successfully *(173)*.

CONCENTRATIONS

The proper strength or concentration of herbicide is primarily decided by the method of application, treatment objectives, and the material to be treated. The formulation used, season of the year, weather, equipment, cost, and other variables also affect the decision. The most suitable concentration for a given set of circumstances is best determined by experimenting with several concentrations under actual work conditions.

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[14]Romancier, Robert M., and Harms, William R. The relative phytotoxicity of various oils to pine and hardwood foliage. 1963. (Unpublished data on file at the Southeastern Forest Experiment Station, Charleston, S. C.)

Commercial herbicides are usually formulated at from 2 to 6 pounds acid equivalent (AE) per gallon, with 4 pounds acid per gallon the most common.

Generally speaking, a more concentrated mixture is needed for dormant season application than for growing season application. More rapid kills also usually follow use of high concentrations *(91, 185)*. However, overly concentrated mixtures, to the order of 50 pounds acid per hundred gallons of the mixture of herbicide and carrier (AHG), may be less effective than very dilute ones, and are certainly more expensive *(20, 125)*. Applying too much active herbicide per acre or per hundred gallons of mixture may result in contact damage and little or no translocation, giving at best only a top-kill and resulting in heavy sprout activity. Though acting slower, low concentrations may give as good end results as high concentrations.

When undiluted concentrates are used, such as the injection application of full strength amines, the amount applied per injection and the spacing is an expression of concentration. Related to spacing is the height on the stem where the frill, basal spray, or injection is made. This too reflects concentration. Treatments made low on the tree are most effective because the distance to the roots is shorter. Low treatments involve a greater circumference than those made at a higher level where the tree is smaller. Thus, more of the herbicidal mixture is applied *per tree* in low treatments than in those made higher up on the stem. A brief survey of some typical concentration rates, by method, will illustrate general practice (table 1).

APPLICATION

The application of 2,4-D and 2,4,5-T can be made by many kinds of equipment, but before attempting to choose any particular piece of equipment the various methods and techniques should be understood, and the reasons for selecting a particular method known.

METHODS

The methods used depend on the area to be treated and the purpose for treating. If a complete treatment of all the stems present is desired, a broadcast treatment is called for. Or the treatment may be selective, reserving some stems from treatment, so an individual stem treatment would be used. Often more than one type of equipment or method may be necessary, as with a multi-storied stand of many unwanted species, or where large and small stems are intermingled. Often re-treatments are necessary 1 or 2 years after the initial treatment.

BROADCAST TREATMENT

Broadcast treatments would probably be prescribed for uniform stands covering large areas, or for control of an understory layer of hardwoods, or in some cases when individual stem treatments would be too expensive. Mist blowing, aerial application, and ground spraying not directed to individual stems all fall into the category of broadcast treatment.

High Volume Spraying — One of the earliest methods used, a high pressure spray system is usually mounted on a truck or jeep, and applies water or oil-water emulsions of 2,4-D or 2,4,5-T through one or more hose lines, or through fixed spray guns attached to the spray rig or powering vehicle (Fig. 5). Application rates may be in the order of 200 gallons per acre or even more.

Although this method generally gives a good level of control, it is expensive, time-consuming, and limited in that only areas accessible to the heavy spray rig and its hose lines can be treated. The large volumes of carrier needed can create a supply problem. Aerial spraying, mist blowing, and individual stem treatments are replacing high volume ground spraying for most applications.

A high volume ground spraying use that will probably continue is the treating of roadside and right-of-way brush and tree species. Spraying usually reduces mowing and brush control costs *(136)* and can often be done from moving vehicles. Rail-mounted sprayers, used to maintain railroad rights-of-way and to keep the ballast free of weeds, are likely to continue in use for some time.

TABLE 1. SOME CONCENTRATIONS OF 2,4,5-T COMMONLY USED, BY METHOD OF APPLICATION

Method	*Unit of application*	*Usual rate*	*Range*
		Pounds AE 2,4,5-T	
Aerial	Acre	2	1-6
Mist blower (foliage)	Acre	2	1-4
Mist blower (dormant)	Acre	[1]5	2-8
High volume	Acre	[2]7½	6-9
High volume	AHG	6	4-12
Basal spray	AHG	16	8-20
Stump spray	AHG	16	16-20
Injection	AHG	[3]20	8-44
Frill	AHG	8	4-20

[1]Only two rates reported; 2 and 8 pounds AE per acre.
[2]Only two rates reported; 6 and 9 pounds AE per acre.
[3]Rate depends on season; often less than 20 in summer, over 20 in winter.

Aerial Spraying — Herbicide application by airplane or helicopter is one of the most popular methods used today (Figures 6 and 7). Aerial spraying offers reasonably cheap control of large areas supporting susceptible or semi-resistant species. Stands and forests can be treated very quickly, and many areas not easily accessible to ground treatment can be readily reached by air.

Aerial spraying is most often done to treat brush or trees that are overtopping pine regeneration, to prepare a site for planting, to bring about stand conversion, and to foster forage production. Aerial spraying has also been useful in creating conditions favorable for wildlife *(174)*. When a two-storied stand of unwanted species is to be treated, a single treatment usually affects only the overstory; a repeat spray, 1 or 2 years after the first, will then be able to reach the understory *(9, 78)*.

Drift is a particular hazard when aerial spraying, and there also may be circumstances when aerial spraying will kill more trees than is desirable, resulting in a loss of valuable pine or hardwood timber species *(174)*. Killing hardwood trees when there are no pines to take over the site can lead to the development of a brush field, which is even less desirable than the hardwood tree species it replaces.

Almost all applications are made during the growing season, but dormant budbreak spraying has also been successful *(95)*.

Helicopters and fixed-wing aircraft are both used for aerial spray applications. Fixed-wing planes, with their lower operating costs, generally lower capital investment per pound of payload, and larger load capacities, are used to treat large areas and those with regular, easily identified boundaries. Helicopters, with their inherent maneuverability, are better suited for treating smaller or irregularly shaped areas, for right-of-way spraying, or for use in areas lacking runways and airstrips. Additionally, the downdraft created by the helicopter rotors forces some of the spray particles down through the upper leaf canopy, improving spray coverage *(181, 207)*, although even with this downdraft the treatment may not give a satisfactory kill of multi-storied stands *(21)*.

U. S. Forest Service photo.
Figure 5. Ground spray equipment can apply high volumes of herbicides to roadsides and rights-of-way.

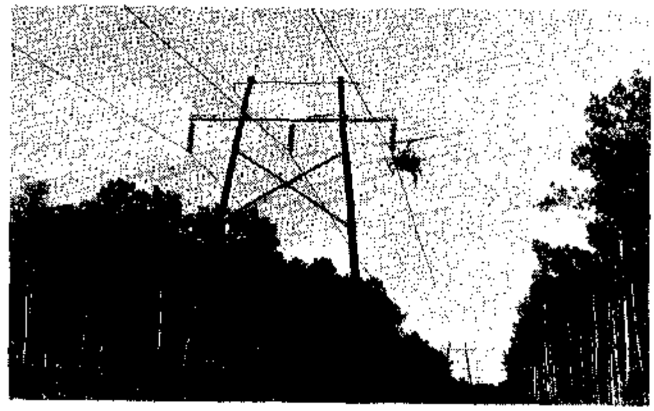


Photo by Stull Chemical Co., San Antonio, Texas.
Figure 6. The helicopter is particularly suited for controlling right-of-way vegetation. A day's flying means many miles of treated power, telephone, or gas lines.

Photo by Stull Chemical Co., San Antonio, Texas.
Figure 7. Aerial application of herbicides permits rapid, uniform treatment of large areas. Areas inaccessible by land are easily treated from the air.

Marking the areas and strips to be treated is often costly and difficult, but necessary. Balloons, long poles, smoke bombs, fluorescent sheets, mirrors, dust blown through mist blowers, and tinfoil are among the materials used. Deadened trees seem to be the most popular single method, and locating them ensures at least a minimal degree of familiarity with the area to be treated. After trees are deadened, several weeks should be allowed for the tops to turn color before spray flights are started. The use of aerial photographs combined with ground inspection to locate definite areas for treatment is a sound prespraying step *(147)*.

When contracting aerial spraying, it is important to know and understand any applicable state and Federal laws, to employ licensed pilots and aircraft, and to have a fully-understood contract fixing such items as bonding, maintenance records, coverage, drift, application rates, mixing techniques, weather conditions, legal responsibility, and so on *(210, 212)*. There is a Federal Aviation Agency regulation prohibiting the aerial application of dust forms of any hormone-type herbicide. Each state may also have herbicide regulations. Liability insurance to protect the landowner, even though he contracts the spraying, is a wise investment *(209)*.

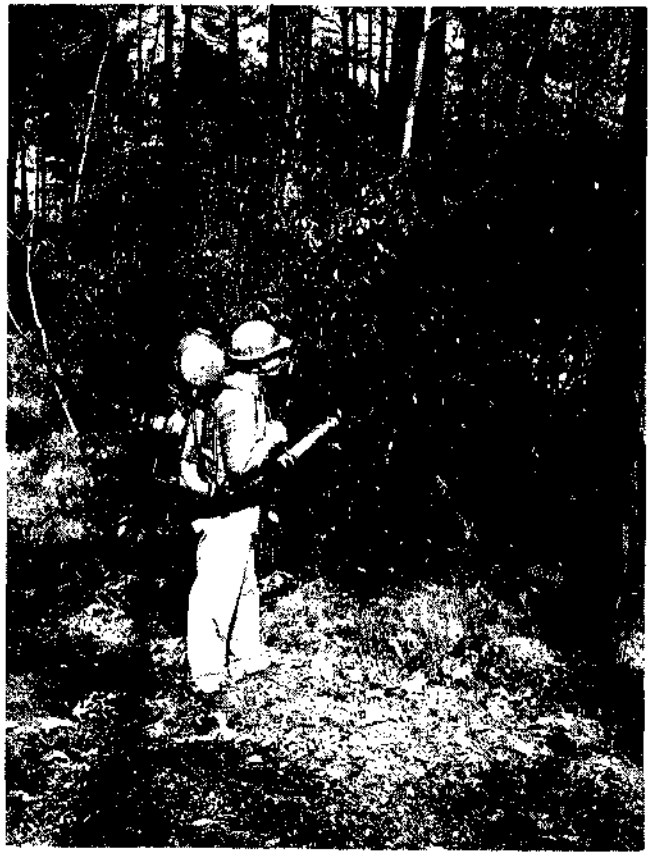
Mist Blowing — Applying herbicides by mist blower is one of the latest and most popular of the current techniques (Fig. 8). Mist blowers are already considered valuable tools in the field of woody plant control, and have a good deal of potential. As with other broadcast or area methods, however, mist blowing is usually less effective and less expensive than an individual stem treatment.

Two sizes of mist blowers are available. The portable size costs approximately $300, and is carried and used by one man; a larger unit costing about $800 is for installation on a tractor or truck.

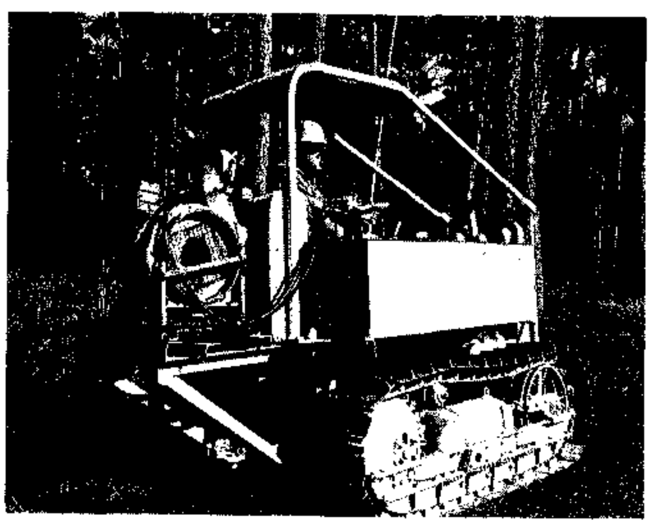
With a portable (back-pack) mist blower it is possible to thoroughly treat individual clumps or stems, avoiding nearby pines or desirable hardwoods. Misting may be done on areas that are small or irregular in shape, and small stands of good hardwoods can be left to grow amid treated areas of weed hardwoods *(120)*. It is also possible to treat hardwood brush under a pine or valuable hardwood overstory with no damage to that overstory, a situation where aerial spraying could not be successful. Mist blowers seem best suited for understory control because their effective range is quite limited; the portable or back-pack machines have a working vertical range of 15 to 20 feet *(74, 120)*. Maximum horizontal distances are usually somewhat greater. Tractor- or truck-mounted mist blowers have a greater range than the portable models (Fig. 9). Vertical reach is probably 30 to 40 feet for the average machine, although 55- to 60-foot heights have been claimed *(193)*. The effective lateral distance is 30 to 50 feet *(78, 168)*.

Some previously successful treatments furnish guidelines (table 2). Where drift is a problem, a greater volume of spray may be applied per acre in a heavier or coarser mist, but with the same acid equivalent *(78)*. A droplet size of 50 to 90 microns (μ) (see glossary) is generally recommended for normal application *(26, 168)*.

Marking treatment areas or strips may be necessary. McNewman *et al. (134)* used plastic flagging; MacConnell and Bond *(120)* recommended toilet paper.



U. S. Forest Service photo.
Figure 8. The portable mist blower is a recent tool with much potential. Here a rhododendron clump is being treated with an oil-water emulsion of low volatile esters of 2,4,5-T at the rate of 2 pounds acid equivalent per acre.



U. S. Forest Service photo.
Figure 9. The tractor-mounted mist blower has become a popular silvicultural tool in the southeast. It will travel almost anywhere and can effectively treat trees 30 to 40 feet high.

TABLE 2. VARIOUS SUCCESSFUL MIST BLOWER APPLICATIONS OF 2,4,5-T

Formulation	*Carrier*	*Concentration*		*Remarks*	*Reporter*
		AE	*Total mix*		
		— *Per acre* —			
Ester	Oil or oil-water	1	2.5-5.0	For small trees	MacConnell & Bond *(120)*
(1)	Oil	8	22.0	Dormant season	Seelbach *(185)*
Ester	Oil	2-8	10-20	Dormant budbreak	Kirch *et al. (95)*
Acid[2]	Water	4	5	Little pine damage	Starr *(200)*
Ester	Oil-water	2	5	Tractor applied	Hill *(78)*
Ester	Oil and/or water	1-2	3-5	Tractor applied	Smiley & Burns *(192)*
Ester	Oil-water	2	3	Good when stems numerous	Smith *(193)*; Hill *(78)*
(1)	Oil-water	2	3-5	Lower volume easier on pine	Kirch *(90)*
Ester	Oil-water	2	9-15	For < 3″ d.b.h.	Haney *(74)*

[1]*Formulation not given.*
[2]*Emulsifiable acid.*

U. S. Forest Service photo.
Figure 10. Large, rough hardwoods take up valuable growing space. Trees this size generally require individual stem treatments, such as frilling or injection.

INDIVIDUAL STEM TREATMENT

Single stem treatments, such as injection, frilling, or basal spraying, are truly selective and are usually more effective than broadcast treatments. Although they can usually be used in close proximity to susceptible crops or other plants, they are also more expensive if many stems per acre must be treated. The particular method of treatment depends primarily on the size and number of stems to be treated. Basal spraying is most suitable for relatively small stems; large stems may be injected if numerous or frilled if scarce (Fig. 10).

Injection — Injection is the insertion of herbicides into low cuts around the base of a tree with a special tool (Fig. 11). Several types of injectors are available. The oldest one, the Cornell tool, discharges a preset amount of the herbicidal mixture a split-second after the cutting head of the tool is driven into a stem. The dosage cannot be conveniently changed from tree to tree, so the more resistant tree species are given wounds closer together than susceptible tree species. Newer injectors have hand control levers to control release and dosage of herbicide discharge. In the newest injector, the volume discharge is much less than with the earlier tools. This change permits the injection of undiluted concentrates. Changing the amount of concentrate to be delivered per stroke requires only a quick external adjustment with a wrench. For easier application, it may be necessary to dilute the viscous amines slightly *(76)*. With a preset discharge rate, the spacing of injection cuts and the working of the lever determine the amount of mixture introduced into the tree. Because there is little lateral transfer of herbicides, close spacing is more effective but more costly than wide spacing. Experience with the chosen herbicidal mixture will determine the best spacing for a given species and size class.

Injection is usually a very successful method for killing a tree, but technique is important and can make or break the success of the treatment. Jab wounds should not be too far apart, and each wound must receive an adequate amount of herbicide. Common errors include failure to shape wounds to retain the fluid and placement of injections too high on the stem. Injections are most effective when made just above the root collar. When correctly used, an injector is more effective than a basal spray on thick-barked trees *(47)*, but some unsuccessful injector treatments have been traced to failure in penetrating thick or tough bark *(22)*. Such failure is a crew or individual training problem, not a deficiency in the method.

Frilling — Frilling, like injection, calls for the mechanical cutting of the bark, but in frilling an ordinary ax is the usual cutting tool, the continuous wound encircles the tree, and the herbicide must be applied as a separate operation (Fig. 12). Properly made, frills are very effective, but for maximum efficiency they must be made just above the root collar zone, not at the usual convenient height of 3 feet or so. The chemical should be applied immediately after the frill is made, and in sufficient quantity to fill the frill. Species that tend to grow over a single frill must be either double frilled, or the frill must be wider than usual.

Power-driven girdlers have been used to prepare a frill surface, even though the groove does not hold an herbicidal mixture as well as a conventional ax-made frill (Fig. 13). In contrast to an ax frill, power girdlers affect only a narrow ring of cambium, so there is a greater chance of the bark growing over or "bridging" the wound *(137)*. Incomplete frills often fail to kill the tree *(32)*.

Because penetration is unnecessary when frills are used, water carriers have been suggested, but most foresters prefer oil solutions *(114, 115, 126)*. Either concentrated or dilute herbicides may be applied *(203, 218)*, although the concentrate may be a poor sprout inhibitor.

Frilling is essentially a treatment for a relatively few large stems per acre. Kirch *(91)* pointed out that if there are more than a few hundred stems per acre to be treated, some other method, such as tree injection, will be more rapid and more economical.

Basal Spraying — Basal spraying is the application of an herbicidal mixture to the otherwise undisturbed lower portion of a woody plant stem or to a cut stump. When small areas or relatively few stems are to be treated, a lever-action 3- or 5-gallon knapsack sprayer is often used (Fig. 14). For larger areas or more stems, power equipment and long hose lines are frequently employed.

Basal spraying is often done in conjunction with a frilling or injection operation. Weed species up to 2 or 3 inches d.b.h. are basal sprayed and larger stems are frilled or injected. Basal spraying is most effective on small trees *(100)*. Root-suckering species, such as black locust, sumac, sassafras, and aspen, are usually effectively controlled by treating not only the base of the tree but also the radial 2 feet or so of soil around the tree *(39)*.

Standing trees are more resistant to a basal treatment than cut stumps, and require a higher concentration or volume of herbicide for satisfactory kill *(83)*. This resistance relates primarily to the nature of the bark. Thick-barked trees would be better frilled or injected than basal sprayed *(98, 211)*, because the bark itself would hold (thus waste) a portion of the applied herbi-

U. S. Forest Service photo.
Figure 11. The injector gives excellent control when wounds are made close enough together and low on the tree. Here, 2,4,5-T at 20 pounds acid equivalent per 100 gallons of diesel oil is used to deaden a post oak.

U. S. Forest Service photo.
Figure 12. When relatively few trees are frilled, the herbicide solution can be applied from a glass jug. Usually a knapsack sprayer is used. The customary mixture is an ester of 2,4,5-T at 8 to 12 pounds acid in enough diesel oil to make 100 gallons. The frill should be completely filled with the solution.

U. S. Forest Service photo.
Figure 13. A power girdler being used to girdle a cull hardwood. Either dilute or concentrated herbicides may be applied to the cut surface to prevent sprouting.

U. S. Forest Service photo.
Figure 14. For small or multiple stems, a diesel-oil solution of 2,4,5-T esters applied as a drenching basal spray is usually the most effective method of control. A 5-gallon knapsack sprayer is commonly used.

U. S. Forest Service photo.
Figure 15. A 3-inch sweetgum cut in December and photographed in mid-May when the sprouts were about 6 weeks old.

cide if it is sprayed on. Yet in some cases basal spraying standing trees is more effective than treating stumps, because spraying the stump area before a tree is cut means that none will be missed or skipped and no dirt or sawdust will interfere with the proper chemical action *(79, 111)*.

A minimum waiting period of two weeks (preferably much longer) after spraying and before logging is desirable so that the herbicide may be effective on the dormant buds before the tree is cut. Good results have been reported when stump spraying was delayed up to a year after cutting *(122)*, but the best results are obtained from spraying soon after cutting (Figures 15 and 16).

Because undisturbed bark must be penetrated, water carriers would not be satisfactory; only oils are used as carriers for basal sprays. Additives to aid penetration may be used, but are not usually needed. The most important consideration is to apply enough herbicide in the right place. The solution should be applied so that it soaks down to the root collar zone, where the dormant buds are located *(77, 160, 231)*. Spray until run-off is the general rule.

Basal painting is similar to basal spraying. An ordinary wide paintbrush is used on smooth-barked species to apply an oil solution of 2,4,5-T. The painting is done in early summer and is effective on beech but not as satisfactory on red maple *(145)*. Even more unusual is the use of an herbicidal paste, applied to individual stems standing next to or intermingled with stems of desirable species. A small amount of 2,4-D or 2,4,5-T is combined with vaseline or vegetable shortening to form a paste, which is then applied by hand with

U. S. Forest Service photo.
Figure 16. This 3-inch sweetgum was also cut in December, but the stump was then basal sprayed with a solution of 2,4,5-T and fuel oil. No sprouts have appeared by mid-May.

rubber gloves or a brush *(127)*. This method is obviously too expensive for woods forestry, but might be useful under certain conditions. Basal spraying has also been suggested to prepare standing pulpwood trees for debarking *(191)* but this would be costly.

SOIL TREATMENTS

The application of granulated or pelletized 2,4-D or 2,4,5-T to the soil has generally been unsuccessful. The phytotoxic effect is erratic, and depends on weather, soil type, and micro-organism action *(47, 154)*. After Darrow and Haas *(51)* tried esters of 2,4-D, 2,4,5-T, 2-(2,4,5-TP), and a borate-2,4-D mixture in Texas for brush control, they concluded that such forms were generally ineffective at economically feasible rates. Because pellets must be applied to an area, even an area *around* a particular stem, rather than to a specific unwanted plant, desirable plants may be damaged if their roots extend into the zone of treatment *(92)*.

COMBINATION TREATMENTS

It is a rare forest acre that supports trees or bushes all of the same species and size. Some species or size groups are more resistant to one manner of control than to another. For example, a tree resistant to foliage sprays may succumb easily to injection methods. The limitations and advantages of the various described methods must be weighed to select a proper combination to satisfy objectives in woody plant control.

Several combinations have already been suggested, such as injection of overstory trees coupled with misting or aerial spraying of the understory, or the basal spraying of small stems and the frilling of larger ones. The application of 2,4,5-T to frills made by a power girdler is a combination of a mechanical and a chemical treatment. In many cases, stems are cut or crushed, allowed to sprout, and then the sprouts are sprayed with an herbicide *(58, 96, 218)*. An alternate may be used too, with the brush sprayed and then cut or mechanically cleared *(181)*. Dense stands might be foliage sprayed by air, with a basal spray follow-up the next year *(211)*.

One treatment which has not been mentioned—fire—is well suited for combination with one or more of the less spectacular methods of weed tree control. A stand can be prescribe burned to improve access and to top-kill many small hardwood stems. The sprouts can then be treated the next year by foliar or basal sprays while the larger stems are injected or frilled *(35, 40, 116)*, or the treatment order can be reversed. Sweetbay-gallberry stands have been aerial sprayed first, and although this only killed the sweetbay, it opened up the stand and provided fuel for a prescribed fire which killed the aerial portion of the gallberry *(207)*. Both aerial spraying and injection treatments have been followed up with fires in preparing sites for direct seeding.[15]

In discussing fire and chemical control of inferior trees in the management of loblolly pine, Chaiken *(36)* stated that:

> *"Even though single prescribed fires reduce only the size of the stem of inferior species, and seldom the number, they usually exert sufficient control and encourage the regeneration of loblolly pine. Burning is cheaper than spraying foliage. Both size and number of competing stems can be reduced by some mechanical means, such as disking, at a greater cost than prescribed fire but still cheaper than [high volume] foliage sprays. . . . The forester can get just about as much control as he is willing to pay for."*

EFFECTIVENESS OF THE PHENOXY HERBICIDES

There are many variables, often interrelated, that affect the success or failure of any control program. The purpose of this section is to provide recommendations and to cite actual results as they relate to specific formulations of the phenoxy herbicides.

2,4-D

ACIDS

The acid forms of 2,4-D are rarely used in the applied control of forest tree species.

SIMPLE SALTS

The various salt forms of 2,4-D are seldom used and have been supplanted by the amine and ester formulations.

AMINES

The effectiveness of the amines of 2,4-D varies greatly, depending on the kind of treatment and the concentration used.

Foliage treatment. — Amines of 2,4-D applied to foliage are not very popular, but are useful in certain situations. Several tree species are more susceptible to 2,4-D than 2,4,5-T, such as the pines and most other conifers, alder, hazel, birch, cottonwood, and willow. If it were desirable to control these species, and they were growing close to crops or desirable trees that would be harmed by the volatile vapors of the ester forms, a dilute foliar treatment of water- or oil-soluble amines could be used. For better penetration, amines applied after late spring should probably be the oil-soluble forms. Inverted amines are reportedly less effective than normal amines.[16]

Individual stem treatment. — 2,4-D amines are not used for basal sprays, because they do not penetrate bark well. Diluted amines applied in frills or by injector are usually inferior to diluted ester forms *(104)*. However, the undiluted amines of 2,4-D applied as cut stem treatments (frill, injector, cut-stump spray), have been very effective. 2,4-D amines appear as effective as those of 2,4,5-T, and result in fewer sprouts *(88, 105)*. Westing *(225)* frilled red and white oaks with undiluted formulations and found the 2,4-D amine superior to the 2,4,5-T ester or amine, which in turn was superior to the 2,4-D ester. Because no carrier is needed, the concentrates are easier and often cheaper to use.

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[15] *Hatchell, G. E. Methods of seeding and releasing loblolly pine on scrub hardwood areas. 1963. (Unpublished data on file at the Southern Forest Experiment Station, Alexandria, Louisiana.)*

[16] *Peevy, F. A. An evaluation of the invert formulation of 2,4,5-T ester, 2,4,5-T amine and oil soluble 2,4,5-T amine for control of blackjack oak. 1963. (Unpublished data on file at the Southern Forest Experiment Station, Alexandria, Louisiana.)*

ESTERS

The ester forms of 2,4-D are generally considered only satisfactory for foliar application on the species more resistant to 2,4,5-T than to 2,4-D, and are seldom used by themselves. However, they have often been combined with the esters of 2,4,5-T to give single-application control over a large number of intermixed species. These combinations, 2,4-D/2,4,5-T, are prepared either by the applicator or ready-mixed by the chemical industry. Crafts *(47)* expressed the philosophy, saying that a mixture broadened the spectrum of the weed population controlled. Much of the right-of-way spraying done in this country employs 2,4-D/2,4,5-T mixtures *(18, 82)*. Borger *(17)* indirectly suggests that 2,4-D in such a combination is most useful against some of the pioneer vegetation, and that 2,4,5-T may better control the later successional (climax) species. There is little evidence to date that 2,4-D/2,4,5-T is more effective under most forest conditions than either is alone.[17] The effect of 2,4,5-T is the same by itself or when mixed with 2,4-D on all species resistant to 2,4-D, and pines are more likely to be injured by 2,4-D/2,4,5-T than by 2,4,5-T alone *(24, 43)*.

2,4,5-T

ACIDS

The emulsifiable acids of 2,4,5-T are used occasionally for foliar application, but they may be harder on pines than the esters *(2)*. Starr *(198)* reported the emulsifiable acid more effective than amines and as effective as low volatile esters on sweetgum, post oak, blackjack oak, and hickory. The acid was also more damaging to pine. Farrar *(61)* stated that the acid was less effective than a low volatile ester but similar in results to an oil-soluble amine on Alabama hardwoods, with no difference in pine seedling damage.

A single reference to the use of acids on cut surfaces indicated that 2,4,5-T acids were inferior to the esters for killing persimmon *(124)*.

SIMPLE SALTS

The salts of 2,4,5-T are not commonly used.

AMINES

Foliage treatment. — Some 2,4,5-T amine foliar sprays have given fair results[18] *(90)*, but were slower acting than the esters *(123, 234)* and in most cases less effective *(59, 61, 163, 208)*. Oil-soluble forms are necessary after leaf cuticles thicken. Amines are less volatile than the esters, and can be used where vaporization would be a hazard.

Individual stem treatment. — Amines are not used for basal sprays, but are effective in most of the cut-surface methods. Although there have been a few recommendations for using diluted 2,4,5-T amines[19] *(199, 214)*, 2,4,5-T has not proved superior to 2,4-D for cut-surface application, though it may give faster kills *(47, 109)*. For undiluted use, most researchers have found little difference in final effectiveness between 2,4-D and 2,4,5-T amines *(105, 159)*, although Day *(53)* reported 2,4,5-T amines more effective on red maple than 2,4-D amines. For hard-to-kill southern hardwood species, 1 milliliter (see glossary) of undiluted 2,4,5-T amine injected at 3-inch spacings (edge-to-edge) or ½ milliliter (ml.) of undiluted 2,4-D amine injected at 1-inch spacings is both effective and economical *(159)*.

ESTERS

The esters of 2,4,5-T are the phenoxy work horses in the control of undesirable trees. They are used in every method of application and serve as standards for comparison with all other formulations.

In selecting an ester for use, will a high volatile or a low volatile form be more suitable? When applied to foliage, the heavier (low volatile) esters are slower acting than the light (high volatile) esters, and seem to cause less contact injury. They also remain in a liquid state on the leaves much longer than the high volatile esters, and consequently more molecules move into the plant over a longer period of time. With these advantages, low volatile esters are carried deeper into the root system and are more effective than the high volatile esters *(47)*. High volatile esters are less soluble in oil and more difficult to work with than low volatile esters *(44, 202)*, and low volatile esters can be successfully applied earlier in the season than high volatile esters *(230)*. In general, the low volatile esters give more consistent kills than the high volatile esters *(62, 132)*.

When applied to the bark of young stems, low volatile esters performed better than high volatile esters, partly because the low volatile esters evaporate less as the formulation penetrates to the living cells *(182)*. In a comparison of amyl (high volatile) and propylene glycol butyl ether (low volatile) esters basal sprayed onto 240 small sweetgums, Davis *(25)* found after 2 years a 3 to 6 percent greater mortality where the low volatile ester had been used. Isopropyl (high volatile) is considered inferior to the low volatile esters for foliar application *(106, 125)*.

Continued usage of the high volatile esters is probable, however, especially in the absence of susceptible desirable vegetation, because high volatile forms are cheaper than low volatile forms and will usually give satisfactory results, especially in cut-surface treatments.

The usefulness of particular esters has been studied by several men. The butoxy ethanol esters may be more effective on hardwoods than the isooctyl, but the isooctyl is preferred when damage to pines must be minimized *(31, 100, 113)*. In describing the unpublished work of Krygier, Dahms *(50)* reported the butoxy ethanol esters of 2,4,5-T more damaging to some conifers than the propylene glycol butyl ether esters, but Newton *(148)* found no significant differences between these forms on conifers. For basal spraying oaks and hickories, the butoxy ethanol may be more effective than the isooctyl, propylene glycol butyl ether ester, or pentyl esters *(100)*.

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[17] Arend, John L., and Roe, Eugene I. How to release conifers in the Lake States with chemicals. 31 pp. 1960. (Preprint publication of the U. S. Forest Service, Lake States Forest Experiment Station.) (Mimeographed.)

[18] Anonymous. Oil-soluble amines of 2,4-D and 2,4,5-T for the control of woody plants and broadleaf leaves. Amchem Tech. Serv. Data Sheet H-88, 16 pp. 1962. (Mimeographed.)

[19] Arend, John L., and Roe, Eugene I. 1960. op. cit.

It may be that specific esters will eventually be prescribed for each species or species group, method of treatment, or site condition. Borger *(16)* recommended using the isooctyl esters where acid swamp soils are encountered (pH 3.5 to pH 5.0), and preferred the propylene glycol butyl ether esters on slightly acid to alkaline soils.

The esters of 2,4,5-T are used for all kinds of foliar treatments; high volume, mist, and aerial, as well as for dormant season broadcast spraying. Sometimes they are combined with the esters of 2,4-D.

Foliage treatment. — Esters are always diluted for foliar application, and applied with an oil, oil-water, or water carrier. Generally, water as a carrier is only suitable in spring and early summer spraying. Later spraying is done with oil-water or oil carriers, which can better penetrate the leaf cuticle. Low volatile esters are most commonly used. When invert emulsions are used to reduce drifting, the ester forms are preferable to the amine forms unless a volatility hazard also exists.

Individual stem treatment. — Frill, injection, and basal spray applications all commonly are made with 2,4,5-T esters. Oil carriers are used, and there is little justification for using undiluted esters *(104, 105)*. Invert forms are not often used on individual stems, but might be satisfactory as basal sprays because of their resistance to moisture and slow rate of emulsion breakdown *(94)*.

OTHERS

2-(2,4,5-TP)

Silvex, the propionic form of 2,4,5-T, is ordinarily available in the ester and amine forms. For foliage sprays, the esters are used with some success, depending on the species being treated. It has been prescribed for use on oaks and maples *(42, 56)*, and is sometimes superior to 2,4,5-T *(9)*, often as effective *(3, 144, 177)*, but also often less effective *(129, 153, 163)*. Silvex is considered more toxic to pines than 2,4,5-T *(9, 93)*.

For individual stems, 2-(2,4,5-TP) is used in both ester and amine forms. Peevy *(157)* frilled blackjack oaks and found that diluted silvex amines were equal to diluted 2,4,5-T esters in top kill and better than 2,4,5-T esters in total kill. Silvex esters diluted in oil for injection or basal or cut-stump sprays are less effective than 2,4,5-T esters *(205)*. Concentrated silvex amines have given good kills *(105)*.

2-(2,4-DP)

The propionic form of 2,4-D is effective for foliar application only in the ester form. Peevy and Burns *(163)* reported that blackjack oak sprouts were treated with the following formulations at the rate of 4 pounds AHG water per acre:

Herbicide	*Complete kill (Percent)*	*Top kill (Percent)*
2-(2,4-DP) amine	35	55
2-(2,4-DP) ester	62	70
2-(2,4,5-TP) amine	47	60
2,4,5-T ester	65	78

The amines are much less effective than 2,4,5-T or silvex esters *(56, 163)*.

For individual stem application, the dilute esters of 2-(2,4-DP) have given some very good results when applied to frills (table 3) and cut stumps *(157)*. Concentrated or dilute amines are not very effective *(105, 159)*.

4-(2,4-DB)

This butyric formulation has not been used very often. It is relatively poor for foliar application *(56, 157)*, but diluted (8 and 16 pounds AHG carrier) amines and esters have given near 100 percent top kill of blackjack oak as basal sprays, with total (root) kill ranging from 23 to 50 percent *(157)*.

TORDON

Recently developed, Tordon has given better results than 2,4-D or 2,4,5-T at lower concentrations as a foliage spray on red and white oaks, ash, willow, birch, hickory, and several other species. Combined with 2,4-D (0.7 lb. Tordon and 2 lbs. 2,4-D in 100 gallons water) Tordon gave better control of sweetgum than 2,4,5-T at 4 lbs. AHG. Tordon was also effective on conifers and root-suckering hardwood species *(184)*. Basal injections of red and white oaks also suggest undiluted Tordon is superior to undiluted 2,4,5-T amines *(214)*. Applied with tree injectors, Tordon was superior to larger amounts of more concentrated 2,4,5-T amines *(221)*. Tordon in water at 0.7 to 5.8 pounds AHG in frills was more effective on white oaks than 2,4,5-T esters in fuel oil at 4 and 8 pounds AHG.

TABLE 3. EFFECTS OF VARIOUS HERBICIDE FORMULATIONS APPLIED TO FRILLS ON 3- TO 10-INCH D.B.H. BLACKJACK OAKS (AFTER PEEVY (157))

Herbicide	*Concentration*	*Total kill*	*Top kill*
	AHG[1]	- - *Percent* - -	
2,4,5-T ester	8	42	100
2,4,5-T ester	16	44	100
2-(2,4,5-TP) amine	8	57	100
2-(2,4,5-TP) amine	16	57	100
2-(2,4-DP) amine	8	39	100
2-(2,4-DP) amine	16	27	100
2-(2,4-DP) ester	8	65	100
2-(2,4-DP) ester	16	63	100

[1]*Carrier was diesel oil for esters and water for amines.*

Granules and pellets applied to the soil gave good results in Dow Chemical Company field tests at 6, 7.5, and 8.5 pounds active ingredient per acre, controlling dogwood, maple, sweetgum, hickory, and others. Soil type, rainfall, and season all materially affect treatment success of such soil treatments, because Tordon is readily leached from the soil. Pellets broadcast over a recently clear-cut area gave good stump control of most species at 6.0 pounds active ingredient per acre *(229)*.

CHOOSING THE MOST SUITABLE CHEMICAL, FORMULATION, AND METHOD

Many things should be weighed in planning a treatment program, with the reason for treatment firmly in mind. The hazards of spray drift and of vaporization should be understood. Differences in the plants to be treated, as well as environmental factors, can have a decided effect on the results of an herbicide. Cost is not always mentioned, but it is important because almost any level of control is available at a price.

DRIFT

Drift and volatility are often confused. They are alike in that both are undesirable. Both may result in unwanted damage to vegetation, and both are forms of movement of the herbicide away from the area being treated, reducing the concentration or treatment level.

Drift, however, occurs only at the time of spraying and is the air current-borne movement of spray droplets (carrier and herbicide) at the time of application. Drift can be a problem with any formulation (acid, salt, or ester), but volatility is mainly an ester hazard.

Drift damage may not be strictly local. Cotton, a very susceptible crop, has been often damaged 3, 4, or 5 miles away from where 2,4-D or 2,4,5-T is being applied. One field 35 miles away was reported damaged, though such instances are rare *(60)*. Shelterbelt plantings adjacent to fields treated with 2,4-D have been affected *(166)*.

Volatility can largely be controlled by using low volatile esters, by switching to amines when temperatures are very high, or by using individual stem rather than broadcast methods. Drift control, however, calls for different measures, such as not spraying near susceptible crops, or when winds are toward these crops from the treatment area. Broadcast spraying should be avoided in dead calms when spray particles may become suspended in the air, or when the air is turbulent. Concentrations should be reduced when spraying near susceptible crops such as cotton, peas, or tomatoes *(7, 233)*.

A major portion of the drift problem can often be controlled by the proper use of the right equipment. For example, when the drift hazard is present, use of a knapsack sprayer instead of a mist blower is one way of reducing the hazard *(169)*. Nozzles and pressures should be such that large droplets are produced.

Invert emulsions have a large droplet size and are less affected by drift than the conventional oil- or water-based sprays. The inverts may have consistencies ranging from that of buttermilk to that of mayonnaise, depending on the additives used. Both amine and ester forms have been used in invert emulsions.

In addition to invert emulsions for drift control, particulate sprays have been developed that can be poured, pumped, and sprayed like liquids but which are particles of water-swellable polymers in water. They are best described as granular liquids. They appear to be as effective as conventional sprays, and drift even less than the inverts *(186)*.

Inverts and particulate sprays are low-drift, rather than no-drift, formulations. Droplets or particles are several times larger and more stable than those from regular spray mixtures *(66, 94, 186)*. The volatility hazard still exists.

DROPLET SIZE AND DISTRIBUTION

It may seem odd that the physical size of a spray droplet can have some influence on the effectiveness of a treatment, but it does. Droplet size is important from two standpoints; movement through the air, and action on the plant surface.

Drift of a spray droplet is ordinarily undesirable, and the smaller the droplet the more it is likely to drift. Coarse droplets, about 500μ or larger, drift little and are as effective as droplets of 100μ *(62, 84)*. Too small droplets may remain in the air and drift off.

Oil solutions produce the smallest droplets. These are more effective than larger droplets in penetrating layers of leaves, but are most subject to drift. Droplets formed by oil-water emulsions are somewhat larger, and those from water carriers are larger still. Inverts and particulate sprays form the largest droplets *(75)*. Burns *(23, 24)* cautioned that too-large droplets applied by aircraft may give poor coverage and may be stopped by any overstory present, while fog-like mists cover everything to the ground but may give spotty results because of excessive drifting. Large droplets will remain in a liquid state longer than small ones. Where absorption is a major factor, as with the water-soluble amines, the larger droplets would be more effective *(13)*.

Droplet distribution on the leaves can also be important. Of course, adequate coverage is necessary, but some untreated areas are needed too, because the area surrounding each droplet on a leaf produces the carbohydrates needed for translocation *(13, 84)*.

SPECIES

Among the woody plants there is a great variety of response to the phenoxy herbicides. In fact, a single species may sometimes exhibit a wide range of response, even to the same treatment *(35, 100)*. Because these are selective herbicides, such differences are important. The manner in which a species reacts to a given set of environmental or site factors can also affect its response to herbicides.

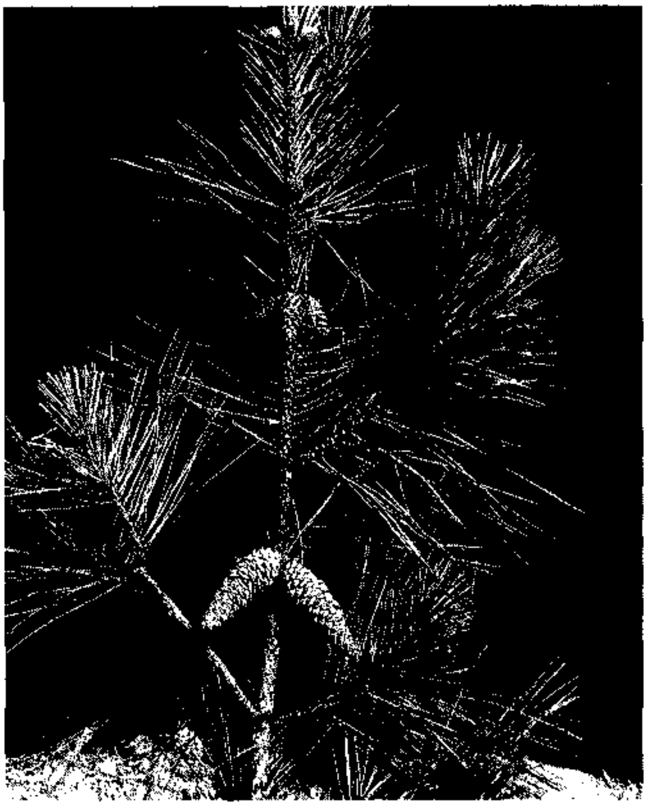
Researchers, probably as a reflection of their individual interests, problem species, and application techniques, may differ considerably in reporting treatment response. A 100 percent total kill, or heavy sprouting following treatment, may matter little or greatly to the experimenter or forest manager, and could materially influence his appraisal of the tested herbicide.

An attempt to draw together some reports of species susceptibility to 2,4-D and 2,4,5-T may give at least a general guide to this confusing area (table 4). Similar tables are available in various publications for both woody and nonwoody vegetation, and for other chemicals in the chlorophenoxy family, such as 2-(2,4,5-TP) and 4-(2,4-DB). Some sources of additional information are Ahrens *(6)*, Sutton *(205)*, and Walker *(218)*.

HARDWOODS

Hardwoods as a group are the usual targets of an herbicidal program. Some species are relatively easy-to-kill, whereas others require more intensive efforts, particularly when total kill (no sprouting) instead of top kill is desired.

In general, white ash, red maple, hickory, and several members of the red oak family are hard-to-kill with 2,4-D or 2,4,5-T, as are mountain-laurel and rhododendron. Easy-to-kill species are alder, birch, black cherry, blackhaw, cucumbertree, sumac, and yellow-poplar. However, tree species not mentioned are not necessarily intermediate in susceptibility. Many species will resist foliar treatments but die readily when injected or basal sprayed, or vice versa. Sweetgum is such a species, and is readily killed by foliage sprays of 2,4,5-T, but not by injection *(36)*.



U. S. Forest Service photo.

Figure 17. The full effect of herbicides on immature cones and pine flowers is unknown. Damage may result to the early developmental stages from 2,4-D or 2,4,5-T, so caution is advised when spraying areas being naturally regenerated.

Pallas *(151)* investigated the species responses of white ash, red maple, sweetgum, and yellow-poplar to foliar sprays of 2,4-D and 2,4,5-T. His findings were not complete, but indicated that (1) white ash has poor foliar absorption of 2,4,5-T, (2) the resistance of red maple, sweetgum, and yellow-poplar to 2,4-D is probably related to the production of an unknown chemical in the plants, and (3) the reason for red maple's resistance to 2,4,5-T is unknown, but is not the result of poor absorption or translocation.

Possibly some species differences can be related to wood anatomy. Ring-porous species[20] were far more susceptible to simple girdling than diffuse-porous species[21] in a Georgia study. The respective survival averages, based on percent of trees with living crowns 2 and 3 years after girdling, were 7 percent for ring-porous and 70 percent for diffuse-porous. This might suggest that under certain circumstances only diffuse-porous trees would need herbicide treatment following girdling *(226)*.

CONIFERS

It is often said that pines are resistant to phenoxy herbicides, but this is a generalization at best *(140, 141, 218)*. 2,4-D is more toxic to most conifers, pines included, than 2,4,5-T. During most times of year, 1 to 2 pounds AE of 2,4-D/2,4,5-T, or 3 pounds AE of 2,4,5-T will not permanently damage most conifers *(24, 85, 130)*. Among the southern pines, loblolly is the most susceptible, longleaf the most resistant, and slash intermediate *(140, 141)*.

Different formulations will have differing effects; to repeat, Little *(113)* preferred the isooctyl esters of 2,4,5-T over the butoxy ethanol esters in order to avoid pine damage. Oil carriers are more phytotoxic to pine than water carriers. One unfortunate experience illustrates this point. Cantelou *(30)* reported the results of misting seedling and sapling pine-hardwood stands in Alabama and Mississippi with 2 pounds acid equivalent of 2,4,5-T in straight diesel oil at 3 to 5 gallons per acre. He achieved a 90 percent stem kill of brush to the ground line, with a minimum of resprouting. The unfortunate thing was that he also killed 85 percent of the natural pine in the 10- to 20-foot height class, as well as underplanted pines. When many desirable pines would suffer from a broadcast treatment, a selective stem method, such as injection or basal spraying or both, might be substituted.

Conifers under a year old are susceptible to phenoxy sprays. Older conifers in the period of rapid height growth are also quite sensitive *(8, 194)*, and the effect is not limited to foliage. Pine cone production has been impaired by aerial spraying of amines and esters of 2,4,5-T, silvex esters, and 2,4-D/2,4,5-T esters; the full extent of such damage is not known *(23, 40)* (Fig. 17). Low concentrations of 2,4-D and 2,4,5-T have inhibited catkin development and delayed pollen release in loblolly and shortleaf pine in Georgia *(68)*.

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[20]*Hickories, and white, post, chestnut, scarlet, and black oaks were tested.*

[21]*Blackgum, red maple, and sourwood.*

TABLE 4. SPECIES SUSCEPTIBILITY, INCLUDING DIFFERENTIAL RESPONSE TO 2,4-D AND 2,4,5-T

Species	Ahrens (6)		Klingman (98)		Anon. (1)	Burns and Box (25)	Kirch (91)	Miller (140)	Walker and Wiant (220)
	2,4-D	2,4,5-T	2,4-D	2,4,5-T					
Alder	S	S	S-I	S			S		
Ash, white	R	S-I	R	I-R		R	R	R	R
Bayberry, southern						I		I	
Beech						I			
Beech, blue						I			
Blackberry	I-R	S			S				
Blackgum			I	I		I	S	S	I
Cherry, black	S	S			S	S	S		
Dogwood	I-R	S-I			S	I		I	I
Elm, American	S-I	S	I	I		I			
Elm, winged	S-I	S	I	I		R			S
Gallberry						R		R	
Grape	S	S				S			
Hackberry						S			
Hawthorn	I	S				R			R
Hickory	I-R	S-I			R	I	S	I	I
Holly						R		R	
Honeysuckle						R			
Hophornbeam									S
Huckleberry						I			
Locust, black	S-I	S	I	S-I		I			
Maple, red	I-R	S-R	I	I	S	R	R	R	I
Maple, silver	I-R	S-R	I	I		I			
Mountain-laurel	I-R						R		
Oak, black								I	R
Oak, blackjack			I-R	I		I		I	
Oak, live						R		R	
Oak, northern red						I		I	
Oak, post			I	S-I	S	S		I	R
Oak, scarlet						I		I	I
Oak, southern red					S	I		I	S
Oak, swamp chestnut								I	
Oak, turkey						I		I	
Oak, water						R	R	I	S
Oak, white			I-R	S-I	R	S		I	R
Oak, willow						I		I	
Persimmon			I-R	I-R		I			I
Pine	I-R	I						R	
Redbud						I			I
Rhododendron	I	S					R		
Sassafras	S				S	S		S	
Sourwood						I			
Sumac	S-I	S				S		S	
Sweetbay						I		I	
Sweetgum			I	S-I	S	S	S	S	R
Sycamore						S			
Walnut, black	I-R	S-I	S	S					
Willow	S-I	S	S	S		S			
Yellow-poplar						S			S

S = Susceptible to 2,4-D or 2,4,5-T, or both.
I = Intermediate in resistance.
R = Resistant.

TIME OF YEAR

Applications made during the growing season are generally most successful, although labor is often more readily available and can work more efficiently in hardwood brush during the fall, winter, and early spring. Obviously, foliage treatments must be applied during the growing season, but stem and stump treatments can be made year-round. Dormant season treatments can be made with little or no concern over drift or volatility, because susceptible crops are generally absent. In addition, some resistant species, such as maple, oak, and pine, may be more easily killed when dormant than during the growing season *(12, 39, 99)*.

The reason commonly advanced for the effectiveness of late spring and early summer treatments is that root reserves of the preceding year have been expended in developing the current year's foliage. As soon as the foliage is mature, it starts to manufacture food and to move this food downward in the plant, storing for next year's growth. This period of maximum downward translocation is generally the best time to treat with herbicides. Late summer or early fall treatments are usually less successful than early summer ones.

TREE SIZE AND CONDITION

Young woody plants are more apt to sprout after herbicide treatment than older individuals. Very young plants are easily killed by herbicides, although relatively little has been written on the effect of age. Stoeckeler *(204)* reported that sprouts 3 to 12 months old of many hardwood species were reduced 90 percent by a single spray of 1 percent 2,4,5-T in water, but that 8-year-old sprouts required foliage and stem sprays for at least 2 consecutive years for good control.

The seasonal stage of growth also may affect results. Foliar sprays applied at 5 stages of leaf and shoot development revealed that different results could be expected if spraying were done before full leaf development, or when the shoots were elongating, or before or after shoots had hardened off for the year *(175)*.

Whether or not little trees are easier to kill than large trees appears to depend primarily on the method used, and secondarily on the species. Although exceptions occur *(141, 220)*, in most hardwood species the larger a stem the harder it is to kill *(12, 34, 161)*. Vigorous trees are harder to kill than less rapidly growing ones *(85, 146)*.

STAND STRUCTURE

Structure very often determines what methods can be used in a control program. Stands with two or more levels to be treated will often require either two different treatments or two applications of the same treatment. Particularly dense stands, especially if composed of resistant species, may not be suitable for treatment or deadening by herbicides. In such a situation, fire or heavy mechanical equipment may be the better choice. Some situations just do not lend themselves to the use of herbicides, at least within normal economic situations. Dense stands will also require greater volumes of carrier, or of carrier and herbicide.

ENVIRONMENTAL FACTORS

SOIL MOISTURE AND SITE CONDITIONS

Soil moisture is important for the success of a translocated herbicide. Although a low or deficient supply of soil water does not affect absorption, it does hinder translocation in hardwoods *(152, 171)*. After summer rains exceeding ½ inch, most hardwoods are very susceptible to herbicides, and pines are quite resistant, giving the forester an edge in controlling one group with a minimum of damage to the other *(139)*. Late summer foliage spraying may give good results if there is a high level of soil moisture *(138, 195)*.

Hardwoods on the better or bottomland soils are harder to kill than those on poor soils *(25, 117)* or on ridges or upper slopes *(25, 163)*. Treated trees are also more likely to sprout if located on good bottomland or cove soils *(137, 155, 224)*. Herbicides are more effective on low site index areas. Aspect may also be a factor as it relates to tree vigor and growth *(218)*.

It has been suggested that herbicidal effectiveness also relates to the presence and amounts of certain chemical elements or compounds on each site *(17)*, and differences in treatment effectiveness have been related to different soil textures *(62)* or different soil reaction *(16)*. Although these variables may exist in a given situation, it is probable that the water relationships are the greatest single site factor to be considered.

WEATHER

It is obviously better not to apply 2,4-D or 2,4,5-T by any method during rainy weather. Wet bark increases runoff of basal sprays, and water moving down a stem will flush out frills or injector cuts. Foliar applications will generally be washed from the leaves, although even a short period between application and rain will normally result in some penetration by the herbicide *(31, 218)*. Stump treatments may be benefited from rains, because the water apparently carries the 2,4-D or 2,4,5-T downward into the stump *(109)*.

High winds make broadcast treatments ineffective or spotty; misting or aerial spraying is usually stopped when wind velocities exceed 5 m.p.h.

High humidities during spraying periods are usually considered beneficial, for they prevent water stress in the plant, delay spray drying, favor stomatal opening, and may increase cuticular permeability *(41, 97, 123)*. The more water-soluble herbicides appear to vary more in effectiveness with variations in relative humidity than the less water-soluble forms do *(107)*. Some successful spraying done in periods of low humidity may be explained by high soil moisture levels at the time *(195)*.

Temperatures must also be considered, and appear interrelated with humidity. Moderately warm, though not excessive, temperatures are usually recommended for optimum spraying conditions *(49, 108, 218)*. Results may be erratic if spraying is done in temperatures over 90°F. *(211)*. High temperatures during times of low humidity, when plant transpiration exceeds water absorption, would reduce herbicidal translocation *(16)* and will rapidly evaporate water carriers.

Temperature may also physically affect the herbicide, because even the low volatile esters start to volatilize above 90°F. *(4)*. When high temperatures are common, amine or acid forms should be used near susceptible desirable plants, or individual stem treatments substituted. Low temperatures will reduce the fluidity of the herbicide. Herbicides should not be applied when the temperature nears freezing; 45° to 50°F. is probably a reasonable minimum temperature limit *(183)*.

LIGHT

Spraying done in sunlight is more effective than that done under shade *(218)*, probably because absorption is greater in light than in dark. At low light levels, photosynthesis, translocation, and food accumulation are slight, and nearly all food produced in the leaves may be retained and used within the leaves *(41, 230)*.

OTHER FACTORS

There are other variables that affect a control program. Treatments can seldom be applied in a truly uniform manner. The herbicide concentrates sometimes differ slightly by batches, and preparation of the spray mixture may introduce other variables. The formulations of different companies can be expected to be somewhat dissimilar, and can give varying results. If an ester emulsion (oil and water) is prepared improperly, a viscous invert may form which is very difficult to apply properly without special equipment. Different carriers will often give different results. Even similar oils, such as kerosene and diesel oil, can produce different levels of control *(119)*.

Dissimilar methods of appraising the results make studies hard to compare; rapid top kill or complete sprout control may be important to researcher A but not to researcher B. A line-transect appraisal may give different results from those obtained by planimetering areas of crown kill on an aerial photograph. And, as already mentioned, some species resist one method but are easily controlled by another.

COST

The expense of any control program is difficult to figure in advance. On-the-spot variables, such as species, density, size, and adjacent lands exert major influences on the method and herbicide chosen. The speed and completeness of kill desired are also important. Fast, 100-percent kills cost more than slower, less complete treatments. The desired degree of kill is an essential part of planning knowledge; setting too high requirements for the job at hand wastes money and labor.

In a general way, large areas of similar stands are most cheaply aerial sprayed, with tractor mounted mist blowers next in economy. Small areas can be economically treated with the back-pack mist blower. Cost is usually figured on a per acre basis. Peevy *(158)* compared the cost of 2,4,5-T foliar treatments applied for *two* or more years to blackjack oak sprouts in Louisiana:

Method	*Concentration per acre*	*Trees dead*	*Cost range per acre*
	(Pounds AE)	*(Percent)*	*(Dollars)*
High volume	2 - 4	65	6.50 - 12.00
Aerial	2 - 3	30	7.50 - 12.00
Mist blower	2	45	6.50 - 8.00

When small or large scattered individuals or clumps are to be treated, individual stem treatments are usually called for. Cost is then figured on the basis of stems treated, or more accurately on diameter-inches treated, based on the d.b.h. of each tree. In another phase of the same study, Peevy *(158)* applied 2,4,5-T as a basal treatment for *two* or more years, and found injection generally cheapest, followed by frilling (table 5). Note that in each case treatments were made for two or more years, which greatly increases costs.

Using 2,4-D amines undiluted at 1 ml. at 3-inch intervals (edge-to-edge) gives good results and costs 0.19 cent per inch of trunk diameter (table 6). In comparison, the fairly common treatment of 5 ml. 2,4,5-T esters in diesel oil (1:10, or about 37 pounds AHG) inserted at 1-inch intervals costs about 0.36 cent per inch of trunk diameter.

A refinement of diameter-inches treated is diameter-inches killed, which then reflects effectiveness. Using this scale, Ryker and Minckler *(180)* found low frill treatments (stump height) more effective than injection; even though frilling took twice as long it was three times as effective.

As experience is gained with species, sizes, and seasons of treatment, methods can be tailored for satisfactory results at decreasing cost. For example, the spacing of injector jabs can be widened to 7 or 9 inches for easy-to-kill species, such as blackjack and post oak *(162)*.

Dormant-season treatments may offer some cost advantages. Farm and other labor is often available, and the usefulness of any piece of equipment is increased if it can be used year-round, not just during the growing season.

A 2,4-D formulation costs less than an analagous 2,-4,5-T formulation. In the concentrated forms, the salts

TABLE 5. A COMPARISON OF BASAL TREATMENTS ON BLACKJACK OAK FOR TWO OR MORE CONSECUTIVE YEARS (AFTER PEEVY (158))

Method	*Concentration of 2,4,5-T*	*Herbicide per inch of stem diameter*	*Treated trees dead*	*Average cost range per inch of diameter*
	Pounds AHG oil	*ml.*	*Percent*	*Cent*
Injection	16-20	8	85	0.25 - 0.45
Basal spray	8-16	50	85	.60 - .90
Frill	8-16	20	80	.50 - .75
Stump spray	8-16	20-40	90	.50 - .95

TABLE 6. INJECTION COST PER INCH OF STEM D.B.H. USING UNDILUTED 2,4-D AMINES (PEEVY (161)

Volume per incision (ml.)	*Distance between incisions*			
	1 inch	*3 inches*	*5 inches*	*7 inches*
		Cent		
0.5	0.24	0.14	0.12	0.10
1.0	.32	.19	.16	.13
2.0	.48	.29	.24	.19

are the cheapest, generally followed by the acids, then the amines, then the high volatile esters, with the low volatile esters the most expensive.

SOIL MICROORGANISMS AND RESIDUES

The countless microorganisms in the soil are generally not adversely affected by the phenoxy herbicides *(98)*. In fact, the major factors in the breakdown of 2,4-D residues in the soil are microorganisms *(14, 164)* which may absorb the herbicides and alter or detoxify them[22] *(189)*. These organisms, which include algae, fungi, actinomyces, and bacteria, prefer warm, moist, well-aerated, and fertile soils, and will most rapidly decompose organic herbicides under these conditions. Soil pH affects the kinds and numbers of microorganisms present; bacteria and actinomyces more generally abound in soils with medium to high pH levels, while fungi predominate at pH 5.5 and below (more acid) *(98)*.

Soil bacteria can deactivate 2,4-D, other microorganisms can convert 4-(2,4-DB) to 2,4-D, and microflora can deactivate both forms. Soil microorganisms or acids can hydrolyze 2,4-dichlorophenoxyethylsulfate (sesone) to 2,4-dichlorophenoxyethanol, which may then be oxidized in the soil to 2,4-D *(189)*.

Under usual conditions, 2,4-D is not strongly fixed in the soil; at normal dosages it does not persist in toxic amounts longer than 4 to 6 weeks. In moist soils, 2,4-D was found to be biologically active for only 2 weeks, but in very dry soils it remained active for 1½ years *(142)*. Some of the herbicide is lost by vaporization, some is dispersed to greater depths by tillage, some is deactivated by the effects of sunlight, some may be adsorbed by soil particles, some may be acted upon by soil chemical processes, and some may be taken up by plants. A small amount of the herbicide may be moved downward by leaching, especially in sandy or wet soils or when the formulation is water-soluble *(14, 87)*.

In leaching studies that used 24-inch soil columns, it was found that esters of 2,4-D, 2,4,5-T, and 2-(2,4,5-TP) did not move readily into or through the soil. The salts were more rapidly leached downward, but such movement was still quite limited *(227, 228)*. All water-soluble formulations are not necessarily readily subject to leaching, because they may combine with various soil fractions *(98)*.

Studying just one soil texture—clay—Frissel and Bolt *(65)* reported that the interaction of herbicides differed, depending on the type of clay. Soil adsorption of 2,4-D and 2,4,5-T decreased as the pH increased. The soil electrolytic concentration is considered an important variable in adsorption, as are salt and organic concentrations.

POSSIBLE HARMFUL EFFECTS

MAN

2,4-D and 2,4,5-T have low toxicity. Although spray applications usually leave no toxic residue, a tolerance of 5 parts per million (p.p.m.) has been established on or in apples, citrus fruits, asparagus, pears, and quinces *(5, 118)*. The Federal Insecticide, Fungicide, and Rodenticide Act, as amended in 1959, and the Miller Pesticide Residue Amendment of 1954 to the Federal Food, Drug, and Cosmetics Act are the two Federal laws which directly concern herbicides and their use in forestry.

Some persons may be allergic to the oil used in the herbicidal mixtures, so skin contact should be avoided. Gloves should probably be worn when mixing the chemicals and when mist treatments are used, a respirator is also a desirable piece of safety equipment. The odor or vapors from some formulations may bring on a case of nausea. The Forest Service Health and Safety Code *(213)* cautioned that 2,4-D and 2,4,5-T are mildly poisonous and flammable in an oil base.

Empty herbicide containers should not be discarded where children or adults unfamiliar with the chemicals might find them.

ANIMALS

At the dosages normally used, there seem to be no direct effects on animals *(4, 38, 149)*. This is true whether the animal or bird consumes herbicides with its food or is sprayed itself *(70)*. Massive dosages in the food supply or applied to the skin may prove toxic, but even then some formulations are less toxic than others *(54, 67)*. A veterinarian may incorrectly diagnose animal death as due to herbicides, because accumulations in the body tissue do not necessarily indicate the cause of death *(170)*.

Cold-blooded animals may be injured. Although fish are unharmed at the usual rates of application *(98)*, carp have been killed by 65 p.p.m. of 2,4-D, and 100 p.p.m. was fatal to bream and bass. Again, there is a difference in toxicity, depending on the formulation. Insects and crustaceans may also be affected *(197)*. Mud

[22] *Mitchell, John W. 2,4-D . . . how it kills. Reprint from Agr. Chemicals 3(3). Original not seen. 1948. (Mimeographed.)*

crabs,[23] post-larval and small shrimp, and larval mollusks may all be harmed by low concentrations of the phenoxys, although these herbicides are not usually considered a marine hazard *(28)*.

Some of the toxic effect may be caused by impurities, such as chlorophenol. Another hazard to fish is a depletion of the oxygen level when treated aquatic vegetation decomposes *(11, 67)*, especially since 2,4-D is commonly used to control many aquatic weeds.

Indirect poisoning stemming from the use of herbicides has been suggested. In some plant species, the sugar content in the aerial portions increases 1 to 3 days after spraying with plant hormones, and animals seek out such plants even though they may be of a species generally avoided. The wilted foliage of chokecherry or black cherry, which contains prussic (hydrocyanic) acid, is highly poisonous to animals *(67, 179)*. There may sometimes be an increase of nitrates in plant foliage after spraying with a sublethal dosage of 2,4-D *(179)*. Eating such foliage could prove fatal, although studies made at Cornell University indicate that the diet would have to be almost exclusively such nitrate-rich foliage. Further Cornell studies could relate no animal death to 2,4-D or 2,4,5-T. Instead, suspect deaths were traced to such things as arsenic poisoning, lead poisoning, parasites, foreign objects, etc. No evidence was found that herbicides increased the prussic acid content of the foliage, or that they made poisonous plants more palatable.[24]

It would probably be wise to use an individual stem, rather than broadcast, treatment when using herbicides in an oil carrier on pastured areas. This will avoid undesirable effects from the oil. Species whose foliage is dangerous when wilted, such as black cherry, should be cut, the foliage removed from the reach of ruminants, and the stump treated.

An indirect effect of herbicides that may be either harmful or beneficial is their effect on wildlife food and cover. Effects differ with the treatment, type and extent, and wildlife species considered. Extensive stands of any type are generally considered poor wildlife areas, so treatments that break up such areas are generally beneficial. Often state Game Commissions will use herbicides to create openings in the forest, and may seed these openings to legumes and grasses. As these areas grow up, they are either re-treated or replaced with other clearings *(18, 178)*. Gysel *(71)* reported that right-of-way spraying caused no known adverse effects on birds or animals; rather, a diversity in plant species resulted that provided various density and size classes of vegetation for wildlife.

Deer and rabbits may benefit from an increase in sprouts and often a lower foliage height *(57, 174)*. Ground applications of 2,4-D may be used to top-kill favorite deer browse tree species. This treatment results in a very heavy regrowth of sprouts for deer food *(101, 102)*.

Harmful results may come from broadcast spraying large areas, because desirable wildlife plants are killed along with undesirables *(4, 18)*. When aerial spraying, unsprayed strips should be left to produce wildlife cover and food *(9)*. To some extent, the effect of aerial spraying depends on the forest type. Spraying when an overstory is lacking may reduce the number of desirable stems available for browse *(103)*. Squirrels, deer, turkey, and others are affected by the loss of mast-producing trees *(4)*, and large cull hardwoods, a prime target in Timber Stand Improvement measures, often serve squirrels and raccoons as den trees. Animals have sometimes been reluctant to browse or feed in areas where the vegetation has been sprayed, particularly where an oil carrier has been used *(67, 129)*.

Most hardwood control measures (T.S.I.) are directed toward hardwoods encroaching on pine sites and to controlling the hardwood portion on pine-hardwood sites. Broadcast treatments should generally not be used on hardwood sites. Selective treatments are more suitable to alter species composition or stand structure to favor preferred hardwoods[25] *(38)*.

EVALUATION CONSIDERATIONS

Many of the conflicting reports on the effectiveness of various herbicides, formulations, and carriers depend on the specific formulation, the species treated, and the method used, to name a few of the more important variables. Evaluations should be based on statistically sound sampling methods *(64, 196, 201)*.

No one method may be used to satisfy all objectives and to answer all problems. Some species appear resistant to one kind of treatment but succumb easily to another. The degree of sprouting that can be tolerated may also influence the methods and chemicals chosen. Such things as the type of chemical, carrier, concentration, application method, operational or cost considerations, evaluation techniques, and legal aspects should be carefully thought out *before* field work is started.

Evaluating the effectiveness of a treatment must be done in terms of the owner's or manager's objectives. For example, if heavy sprout development does not hinder the objective, sprouting *should not* play a part in the practical evaluation of the treatment. Sprout mortality or root-kill is probably the best measure of long-time effectiveness of a treatment, but reduction in crown area may be a better estimate of the short-term effectiveness *(72, 125)*. Height changes, stem size, and stem number of the treated species on a plot or acre basis may also be used to determine the results of a treatment.

It may be desirable to appraise results as they affect released trees. Dierauf *(55)* checked an area before mist blowing and found 520 well distributed pines per acre. Half (260) were free-to-grow. After misting treatment he found that 480 seedlings were then free-to-grow. Under some conditions there will be mortality among the trees released. Control plots can give data on

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[23]Mud crabs show irritation to 2,4-D at concentrations of 1 part per billion, and shrimps are considered more susceptible than crabs. Care should be exercised when spraying estuarine or other areas where immature crustaceans may be located.

[24]Anonymous. Brush control tests. U. S. Forest Serv. Region 7, 17 pp. 1953. (Mimeographed.)

[25]Chamberlain, Edward B., Jr. Report to C. W. Watson, Chairman of the Forest Game Committee of the Southeastern Section of the Wildlife Society. 4 pp. 1962. (Mimeographed.)

how much of this mortality is from natural causes and how much from the chemical *(61)*. There are some situations where a reduction of the density of desirable species is essential for successful stand development. Although some individual trees may be killed by an herbicide treatment, often the stand as a whole increases in both diameter and height growth after such a treatment *(121)*.

One other item should be remembered in rating the effects of a treatment. The phenoxy herbicides are essentially slow-acting. Time must be allowed for downward translocation; if the area is burned or mechanically cleared too soon after a treatment, heavy sprouting will develop *(91)*. Valid appraisals of an herbicide's action cannot be made before the second or third growing season after treatment; sprouts developing after a treatment often die in a few years *(33, 124, 185, 231)*. It may take as long as 5 years to determine the final extent of control *(131)*.

GENERAL RECOMMENDATIONS

General recommendations for the use of 2,4-D and 2,4,5-T can be offered if the reader is aware of the many variables involved that will affect any control program, and can select the most suitable method or methods for his particular circumstances. The nature of the formulations, the proper carriers and concentrations, the methods and the many factors contributing to susceptibility must be understood.

In most cases, these recommendations will simply serve as guides from which the individual can derive the most satisfactory techniques for his particular problems. Grouping is by method of application.

HIGH VOLUME SPRAYING

High volume spraying is used primarily for right-of-way and roadside maintenance with power equipment. Vehicle-mounted sprayers result in reduced labor costs over other methods and so the method may be economical in spite of the high chemical costs resulting from the large volumes used. For foliar application, usually 4 to 6 pounds AHG of 2,4,5-T, or 6 to 8 pounds AHG of 2,4-D/2,4,5-T is applied in a water carrier. All foliage is sprayed to runoff. The low volatile esters are most popular, but amines may be substituted for spraying near crops susceptible to phenoxy vapors. Tordon is still experimental but may replace or supplement 2,4-D and 2,4,5-T for this use.

Dormant-season spraying may be tried on species resistant to foliar treatments, or where susceptible annual crops prevent growing-season treatment, but generally an oil carrier is needed for stem penetration, making high volume treatments much more expensive than when a water carrier is used.

AERIAL SPRAYING

Aerial spraying is a foliar treatment suitable for relatively large areas. It is usually not successful to aerially treat a hardwood understory overtopped by desirable species because (1) the desirable overstory will intercept a portion of the spray, and (2) the overstory is likely to be "controlled" or deadened because of this interception. Such results would compound, not cure, troubles. Aerial spraying can be done to release a pine understory or to prepare an area for planting by a temporary reduction in competition of hardwood tree and brush species.

Helicopters or fixed-wing aircraft may be used, depending on the size, shape, and topography of the area. The usual formulation and rate is 2 pounds AE of low volatile esters of 2,4,5-T in an oil or oil-water emulsion (1:8) applied at 3 to 5 gallons per acre, although the prescription may vary widely with species, density, and drift hazard. Where susceptible oaks and maples predominate, silvex may be tried. Post and blackjack oak appear susceptible to 2-(2,4-DP).

Drift is an especial hazard when aerial spraying, and calls for care and close observation of wind characteristics when operating near cropland or other susceptible species.

MIST BLOWING

Mist blowing is a relatively new method of applying herbicides, but is well suited for areas too small or irregular for aerial spraying and when the plants to be sprayed are no taller than the effective height of the mist blower. The maximum height is usually 20 feet for the portable models and 30 to 40 feet for the truck- and tractor-mounted models.

The usual formulation is low volatile esters of 2,4,5-T at 2 pounds AE per acre, applied in diesel oil, or diesel oil-water (1:8) carriers at a total rate of 3 to 5 gallons per acre. Mist blowers, particularly the portable, back-pack ones, permit more selective spraying than does aerial application. Drift is also a problem when mist blowing, although invert emulsions reduce this hazard.

INJECTION

Tree injectors are effective tools for killing woody stems from 1 or 2 inches d.b.h. up to 12 to 15 inches. Just as with the other individual stem treatments, it is more costly and almost always more effective than broadcast spray treatments, but it must be properly done, and enough fluid must be placed in low, properly spaced wounds. Using diluted herbicides, low volatile 2,4,5-T esters at 20 pounds AHG diesel oil, in wounds 2 inches or less apart is a common prescription. Undiluted 2,4-D amines at the rate of 1 ml. in wounds 3 inches or less apart is also generally effective. Winter treatments of resistant species may require higher concentrations or closer spacings of the diluted esters or larger amounts or closer spacings with the undiluted amine treatments.

FRILLING

Frilling is a very effective but relatively expensive way to kill a tree, and is most suitable for a few large trees per acre. Frills should be made as close to the ground line as possible, and must be complete and capable of holding the herbicidal liquid with little or no loss.

The common prescription is 2,4,5-T low volatile esters at 8 to 12 pounds AHG diesel oil, although higher concentrations are often used for winter or resistant-species treatment. If the frill is ax-made, the herbicide solution is usually poured into the frill; if a machine girdler is used, a spray or brush application is more satisfactory.

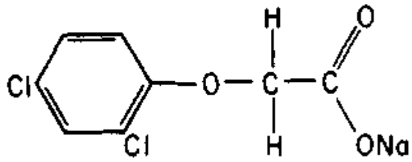
BASAL SPRAYING

Very small stems and thin-barked trees up to a fairly large size (about 12 inches d.b.h.) are best controlled with basal sprays. Esters (low volatile) of 2,4,5-T at 8 to 20 pounds AHG diesel oil are commonly used as basal sprays, and should be applied in a continuous band around the tree or stump base. Emphasis should be on drenching the root collar area: height of spraying need not exceed 1 foot above ground. When spraying cut stumps, the outer 1 to 2 inches of the stump top should be treated, as well as the sides of the stump. A band of soil around stems of root-suckering species should also be drenched for maximum effectiveness.

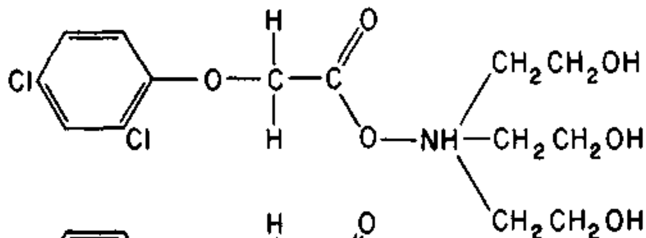
U. S. Forest Service photo.

Once the pine is harvested, the hardwood understory will take control of this productive site unless special control measures are taken. Herbicides offer a method of economical, effective hardwood control.

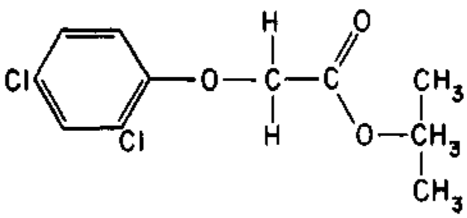
STRUCTURAL DIAGRAMS



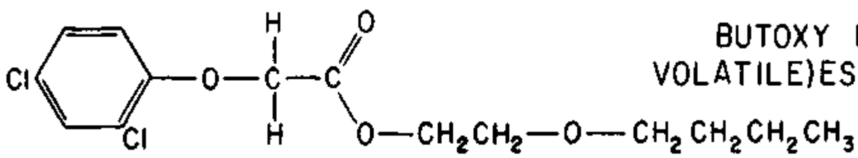
SODIUM SALT OF 2,4-D



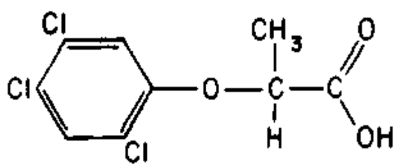
TRIETHANOLAMINE SALT OF 2,4-D



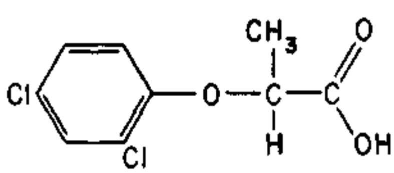
ISOPROPYL (HIGH VOLATILE) ESTER OF 2,4-D



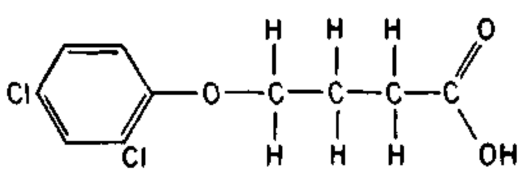
BUTOXY ETHANOL (LOW VOLATILE)ESTER OF 2,4-D



2-(2,4,5-TP) OR SILVEX



2-(2,4-DP)



4-(2,4-DB)

APPENDIX

CARE OF EQUIPMENT

Equipment seems to give service and perform in a direct relationship with the care it receives. The effectiveness of herbicides and modern application equipment can be hampered by fouled tanks, clogged screens, or trash in the lines.

As a general rule, application equipment should be cleaned after each use, no matter what is being applied. This will prolong the life of the equipment as well as lessen the likelihood of poor results. Equipment is easily inspected during cleaning, and leaking valves, split seams, loose nuts or rivets, chemical deterioration, or other weaknesses can be checked.

A good cleaning mixture is a suspension of ¼ pound activated charcoal with ¼ pound of laundry detergent per 10 gallons of water. All systems should be rinsed and flushed with this mixture for several minutes, followed by a flush with clear water.

Household ammonia may be used instead of the charcoal. The first step is a thorough rinse of the equipment; when ester formulations have been used, a prerinse with a small amount of fuel oil is necessary. The rinse should be clear water plus about 1 teaspoon of detergent per gallon. After the rinse is drained out, the equipment (injector, knapsack sprayer, spray tanks) should be filled with an ammonia-water solution (1:99) and allowed to stand for 12 to 24 hours. The final step is a rinse with clear water.[1] Other alkalies, such as trisodium phosphate may be substituted for the ammonia *(5)*.

Metal equipment to be stored should be dried and coated with a light oil. Plastics, as used in portable mist blowers, only need a rinse. Avoid getting any oil on rubber or plastic parts.

Spray equipment should not be used for any other materials after once used with herbicides. Minute amounts of phenoxy herbicides that might remain in even cleaned equipment could prove fatal to susceptible crops. Should it become necessary to use equipment that previously contained herbicides to apply fungicides or insecticides, the equipment must first be checked for the presence of herbicides by spraying a few susceptible plants. If the plants are unharmed after several days, the equipment is clean *(6, 87, 211)*.

COMMON NAME[2]	*SCIENTIFIC NAME*
Alder	*Alnus* spp.
Apple	*Malus* spp.
Ash	*Fraxinus* spp.
Ash, white	*Fraxinus americana* L.
Aspen	*Populus* spp.
Bayberry	*Myrica* spp.
Beech	*Fagus* spp.
Beech, blue	*Carpinus caroliniana* Walt.
Birch	*Betula* spp.
Birch, grey	*Betula populifolia* Marsh.
Birch, red	*Betula nigra* L.
Blackberry	*Rubus* spp.
Blackgum	*Nyssa sylvatica* Marsh.
Blackhaw	*Viburnum prunifolium* L.
Boxelder	*Acer negundo* L.
Catalpa	*Catalpa* spp.
Cherry	*Prunus* spp.
Cherry, black	*Prunus serotina* Ehrh.
Chestnut	*Castanea dentata* (Marsh.) Borkh.
Chokecherry	*Prunus virginiana* L.
Cotton	*Gossypium* spp.
Cucumbertree	*Magnolia acuminata* L.
Dogwood	*Cornus* spp.
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Elder	*Sambucus* spp.
Elm	*Ulmus* spp.

COMMON NAME	*SCIENTIFIC NAME*
Elm, American	*Ulmus americana* L.
Elm, winged	*Ulmus alata* Michx.
Gallberry, large	*Ilex coriacea* (Pursh) Chapm.
Grape	*Vitis* spp.
Hackberry	*Celtis* spp.
Hawthorn	*Crataegus* spp.
Hazel (nut)	*Corylus* spp.
Hercules-club	*Zanthoxylum clava-herculis* L.
Hickory	*Carya* spp.
Holly	*Ilex* spp.
Holly, American	*Ilex opaca* Ait.
Honeysuckle	*Lonicera* spp.
Hophornbeam, eastern	*Ostrya virginiana* (Mill.) K. Koch
Hornbeam, American	*Carpinus caroliniana* Walt.
Huckleberry	*Gaylussacia* spp.
Ironwood	([3])

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[1] *Cleaning solutions should not be dumped into streams or areas that contain desirable vegetation.*

[2] *All common and scientific names in this list were drawn from Check List of Native and Naturalized Trees of the United States (Including Alaska)* (Little 1953) and *Standardized Plant Names* (Kelsey and Dayton 1942).

[3] *See eastern hophornbeam.*

COMMON NAME	SCIENTIFIC NAME
Locust, black	*Robinia pseudoacacia* L.
Maple	*Acer* spp.
Maple, mountain	*Acer spicatum* Lam.
Maple, red	*Acer rubrum* L.
Maple, silver	*Acer saccharinum* L.
Maple, sugar	*Acer saccharum* Marsh.
Mesquite	*Prosopis* spp.
Mountain-laurel	*Kalmia latifolia* L.
Oaks	*Quercus* spp.
Oak, black	*Quercus velutina* Lam.
Oak, blackjack	*Quercus marilandica* Muenchh.
Oak, blue	*Quercus douglasii* Hook. & Arn.
Oak, chestnut	*Quercus prinus* L.
Oak, live	*Quercus virginiana* Mill.
Oak, overcup	*Quercus lyrata* Walt.
Oak, post	*Quercus stellata* Wangenh.
Oak, northern red	*Quercus rubra* L.
Oak, scarlet	*Quercus coccinea* Muenchh.
Oak, southern red	*Quercus falcata* Michx.
Oak, swamp chestnut	*Quercus michauxii* Nutt.
Oak, turkey	*Quercus laevis* Walt.
Oak, water	*Quercus nigra* L.
Oak, white	*Quercus alba* L.
Oak, willow	*Quercus phellos* L.
Osage-orange	*Maclura pomifera* (Raf.) Schneid.
Pecan, bitter	*Carya x lecontei* Little
Persimmon	*Diospyros* spp.
Pine	*Pinus* spp.
Pine, loblolly	*Pinus taeda* L.
Pine, lodgepole	*Pinus contorta* Dougl.
Pine, longleaf	*Pinus palustris* Mill.
Pine, pond	*Pinus serotina* Michx.
Pine, shortleaf	*Pinus echinata* Mill.
Pine, slash	*Pinus elliottii* var. *elliottii* Engelm.
Pine, white	*Pinus strobus* L.
Redbud	*Cercis* spp.
Redcedar, eastern	*Juniperus virginiana* L.
Rhododendron	*Rhododendron* spp.
Sassafras	*Sassafras albidum* (Nutt.) Nees
Saw-palmetto	*Serenoa repens* (Bartr.) Small
Shadbush[4]	*Amelanchier* spp.
Smilax	*Smilax* spp.
Sourwood	*Oxydendrum arboreum* (L.) DC.
Spicebush	*Lindera* spp.
Spruce, white	*Picea glauca* (Moench) Voss
Sumac	*Rhus* spp.
Sweetbay	*Magnolia virginiana* L.
Sweetgum	*Liquidambar styraciflua* L.
Sycamore, American	*Platanus occidentalis* L.
Titi, black[5]	*Cliftonia monophylla* (Lam.) Britton
Titi, white[6]	*Cyrilla racemiflora* L.
Tupelo, black	See blackgum
Viburnum, arrowwood	*Viburnum dentatum* L.
Walnut, black	*Juglans nigra* L.
Waxmyrtle	See bayberry
Willow	*Salix* spp.
Yaupon	*Ilex vomitoria* Ait.
Yellow-poplar	*Liriodendron tulipifera* L.

[4] *Also called serviceberry.*
[5] *Also called buckwheat-tree.*
[6] *Also called swamp cyrilla.*

APPENDIX

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GLOSSARY

acid hydrolysis - The change which takes place when acid reacts with a compound and converts it into two or more compounds.

AE - Acid equivalent. The weight in pounds of the active ingredient or herbicide.

AHG - Acid per hundred gallons. The weight or acid equivalent of active ingredient in enough carrier to make 100 gallons of the mixture.

beta-oxidation - An enzymatic pathway whereby long-chain fatty acids are broken down two carbons at a time. An end product of the beta-oxidation of 4-(2,4-DB) is 2,4-D.

hydrolize - A chemical reaction that breaks down an ester to an acid and an alcohol.

lenticel - A pore or small opening in the stem of a woody plant.

micron (μ) - A metric unit of length equal to $\frac{1}{1000}$ of a millimeter, or $\frac{1}{1,000,000}$ of a meter. 1 inch equals about 25,000μ.

ml. - Milliliters. $\frac{1}{1000}$ of a liter. One liter is equal to 1.06 quarts or 33.81 fluid ounces.

pH - A chemical rating of the acidity or alkalinity of a solution. A pH of 7.0 is neutral; values above 7.0 indicate an alkaline (basic) solution, those below 7.0 indicate an acid solution.

p.p.m. - Parts per million. A measurement of concentration. With herbicides it is better to use pounds of active ingredient per unit volume of solution than p.p.m. or percents based on weight.

sequester - The addition of an organic molecule (chelating agent) which binds metallic ions in an un-ionized state in a solution.

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