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CHEMICAL HERBICIDES AND THEIR USES IN THE SILVICULTURE OF FORESTS OF EASTERN CANADA

by
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PREFACE

This technical note is a review of the information available regarding chemical herbicides and their silvicultural uses, especially in the control of alder birch, hazel, mountain maple, and aspen, in a form that may be of use in studies on the silviculture and ecology of forests in eastern Canada. The work currently being done by other organizations in Canada, especially the Ontario Department of Lands and Forests, should make valuable contributions to the subject when reports become available.

The review is divided into two main parts. The first deals with general aspects of chemical herbicides, and the second with the more important problem species of boreal Ontario and the success achieved in attempts to control them.

The bibliography contains more than 225 useful references.

Chemical Herbicides and Their Uses in the Silviculture of Forests of Eastern Canada

(Project H-103)

by

R. F. Sutton[1]

INTRODUCTION

The use of chemicals to eradicate unwanted woody vegetation is not new, as the method was being developed on quite an extensive scale in India and Australia at least as early as 1915 (Anon. 1917; Allan 1918). However, relatively little progress was made until Templeman and Marmoy (1940) laid the foundation for the development of the chlorinated phenoxyacetic acid herbicides, which became available in the mid-1940's. Since then there has been a remarkable intensification of interest in chemical herbicides and silvicides. Because of rising labour costs, and the very large areas which may benefit from herbicidal treatment, it is likely that the present considerable efforts to improve techniques and to develop even more effective herbicides will continue.

More fundamental and applied research must be done before chemical herbicides can be used generally by the silviculturist with a sufficient degree of finesse. Inconsistent results have been obtained because of imperfect knowledge of (*a*) the physiological effects of the various herbicides, (*b*) the factors affecting their action, and (*c*) the ecology of the species treated. Further research and accumulated experience will progressively reduce and explain apparent anomalies.

Until increased knowledge makes possible the scientific planning of herbicidal programmes, it is advisable before embarking on large-scale operations to carry out small-scale trials to determine the reaction of each problem species to particular herbicidal treatments under well-defined conditions (Stoeckeler and Heinselman 1950). A further word of caution: the reaction of one species to a certain herbicidal treatment is not a guarantee of a similar reaction by another species, even of the same genus (Coulter 1954), since all species of a genus do not react identically, and may react quite differently to particular treatments even under similar conditions.

PART I—GENERAL ASPECTS OF CHEMICAL HERBICIDES

1. Advantages and Disadvantages of Chemical Herbicides

The following indicate, in a general way, some of the major advantages and limitations of herbicidal treatments. Merits and demerits of particular treatments are discussed in subsequent sections.

(*a*) *Advantages*

1. Speed of application. Many techniques which have been used successfully under certain conditions have the value of being expeditious, a major and often decisive advantage in treating large areas.

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2. Relatively low cost. In many instances results have been obtained at a much lower cost than would have been possible had other methods been used to achieve the same success.
3. Applicability to areas difficult to treat from the ground. Aerial spraying is often possible where the terrain makes difficult any form of treatment from the ground. Also, aerial spraying may be able to deal effectively with tall dense brush, the spraying of which from the ground may be impracticable.
4. Saving of man-power.

(*b*) *Disadvantages*

1. Inconsistent results. Present knowledge is often insufficient to enable accurate forecasts to be made of the results of proposed treatments. Faulty techniques may injure desirable species on the treated area.
2. Some techniques are difficult and uneconomic to apply to small irregular areas.
3. Some techniques are less flexible and selective than others. The number and distribution of stems of weed species eradicated can be controlled precisely in methods involving cutting, but such control is impossible when chemical herbicides are applied from the air.
4. Drift and volatilization may damage vegetation outside the area to be treated.
5. The initial expense of equipment may be high.
6. Some chemicals used as herbicides are toxic to animals.
7. Fire danger may be increased temporarily.
8. Most methods leave standing the aerial portion of the treated stems and this may hamper subsequent operations.

2. The Silvicultural Uses of Chemical Herbicides

Chemical herbicides have been used or advocated in the following circumstances.

(*a*) Release of planted conifers from over-topping hardwoods.
(*b*) Pre-planting treatment of brushy sites.
(*c*) Encouragement of conifer reproduction on brushy land.
(*d*) Conversion of low-grade aspen stands to coniferous stands.
(*e*) Creation of conditions favourable to wildlife.
(*f*) Prevention of sprouting by inferior species in stands being regenerated by clear cutting.
(*g*) Prevention of sprouting by all species when more desirable advance growth of seedling origin is abundant.
(*h*) Elimination of an undesirable understory.
(*i*) Elimination of unmerchantable trees left after a commercial cutting.
(*j*) The thinning of dense, stagnating stands of certain conifers e.g. young lodgepole and jack pines.
(*k*) The isolation of trees infected by oak-wilt or other diseases transmitted by root contact.

In general, undesirable species have been hardwoods, and most of the literature refers to problems concerned with the treatment of hardwoods to favour conifers. There are indications, however, that herbicides may become a valuable tool to the silviculturist in the treatment of pure stands of conifers (Atkins 1956a, 1956b; McCormack 1957).

The complete elimination of a species or group of species is seldom desirable or necessary. Usually, it is sufficient to retard undesirable species only just enough to enable the preferred ones to establish a natural ascendency. This can be effected either by damaging a weed species so that recovery will be too slow to interfere materially with desirable species, or by killing a proportion of the weed species. The objectives of herbicidal treatments vary and each case must be assessed on its merits. Consequently, the evaluation of the degree of success achieved by a particular operation depends on the purpose of the treatment. In any event, the economic wisdom of killing more than 90 per cent of the unwanted stems is questionable (Smith *et al* 1954).

Ideally, to keep material costs at a minimum and to secure more uniform results, undesirable woody vegetation should be treated when small and young. Brush spraying, for instance, has been most effective when the brush ranges in height between 3 and 6 feet: adequate coverage of taller plants is difficult, and on smaller ones there may not be enough foliage for effective translocation (Anon. 1954a) of hormonal or translocated herbicides.

If mechanical ground preparation prior to planting is done in conjunction with a herbicide treatment, ground preparation should be delayed for one year or there may be considerable resprouting. Time must be allowed for translocation.

The annual consumption in Canada of esterified hormone-type chemicals alone was already in excess of 2.7 million pounds in 1954, and although a "considerable" proportion of this was used in agriculture, 68,000 acres of brush were treated that year (Suggitt 1956). In 1955, nearly 85,500 acres were treated (Suggitt 1957). The large measure of success achieved with these and other herbicides, despite a dearth of fundamental knowledge, indicates that their use will become increasingly widespread.

3. Methods of Application

There are in common use a number of methods of using herbicides to control woody vegetation. These are listed below and discussed in turn.

(*a*) Foliage spray
(*b*) Basal treatment[2]
(*c*) Poison wound treatment
(*d*) Cut stump treatment
(*e*) Soil sterilization

(*a*) *Foliage spray*

In this method, foliage is covered with finely divided particles of herbicide. It is mainly used in broadcast applications where all the vegetation is sprayed with a selective herbicide to which the desirable species are resistant (Sampson and Schultz 1956).

As undesirable species are generally deciduous, treatment must be given during the period between leaf flushing and leaf fall. It has been found that results vary according to the stage of development of the leaves and the air temperature at the time of application.

Foliage spraying before full leaf expansion, and before products of photosynthesis in excess of current requirements are moving downwards in the phloem,

[2] Sometimes, less correctly, called "dormant treatment".

often gives poor results: this is probably due to ineffectual translocation of herbicide and to temperatures below the optimum. The best results occur from treatment during the period from June to August (Atkins 1956a) and especially in July (Day 1950; Coulter 1954), when food reserves are low and resprouting is at a minimum (Roe 1955).

The toxicity of foliage sprays is considerably less at air temperatures below 50°F. (Anon. 1954a; Atkins 1956), and temperatures of 65°F. or higher have been recommended (Ahlgren *et al* 1951).

They may be applied as "high volume" or as "low volume" sprays. The former are dilute solutions (Sampson and Schultz 1956), from 3000 to 3500 p.p.m.[3], and are usually applied from ground equipment with moderate pump pressure (Anon. 1954a). Concentrations in excess of 3500 p.p.m. are not appreciably more effective (Suggitt 1952). The required volume of solution varies, but a dosage of 100 gallons per acre is usually sufficient. With the same amount of an active herbicide per unit area, high-volume methods have usually given better control than low-volume methods (Zehngraff and von Bargen 1949). The latter are more highly concentrated formulations of herbicides (10500 to 17500 p.p.m.) applied with high pump pressures (Anon. 1954a). Water or oil may be used as the diluent and the dosage may range from 2 gallons per acre to between 30 and 50 gallons per acre (Anon. 1954a). Low volume sprays are usually applied from the air, and are therefore likely to become increasingly popular (Roe 1955).

Certain species, e.g. red maple, appear to be more susceptible to basal and cut stump treatments than to foliage sprays (Beatty 1950).

Spraying during periods of drought or high winds is not recommended (Anon. 1954a).

Sprays of relatively large droplet size (average diameter from 560 to 250 microns) are generally more effective than those of smaller size (down to 30 microns average diameter). The time required for the evaporation of a water diluent may be important in determining the amount of herbicide absorbed by a plant (Rice 1948) in the absence of a hygroscopic agent (Smith 1947) and will partly depend on the droplet size. As the size increases, drip losses become greater (Zehngraff and von Bargen 1949) and there will be an optimum droplet size for each specific treatment.

Absorption into the leaf is primarily by penetration of the cuticle, although some herbicide may enter through stomata (Weintraub *et al* 1954). It may be significantly greater during darkness than in daylight, although different intensities of daylight seem to have no effect on the amount of herbicide (2,4-D, ammonium salt) absorbed (Rice 1948).

(*b*) *Basal treatment*

This method involves the spraying, painting or pouring on of a concentrated solution of the herbicide to the lower parts of the stems of woody plants. It is particularly useful where there are few stems (less than 1,000 per acre (Rudolf 1951)), when foliage spray is dangerous because of drift, or when it is desirable to extend the season of operations. Small trees (basal diameter 3 inches or less) are very susceptible to this method, presumably because of their relatively thin bark.

The essential requisite for successful control of woody species having a tendency to resprout is a drenching of the root collar zone with herbicidal

[3] Parts per million.

formulation (Coulter 1952; Bramble *et al* 1953; McQuilkin 1957). Bramble and his co-workers (1953), working with *Quercus ilicifolia,* found that the only way to prevent resprouting was to soak the root collar thoroughly. Prolific resprouting occurred from trees whose aerial parts had been killed by basal treatment in which wetting of the root collars had been avoided, whereas consistent success was obtained with root collar treatments. Where the root collar was adequately treated, there was no advantage in treating the basal foot or so of stem in addition. Support for these findings has come from McQuilkin (1957) who successfully eradicated scrub oak and prevented resprouting whenever the root collar zone was soaked with herbicide either by run-off from the stem base or by direct application. In contrast, considerable resprouting occurred from stems treated to the point of run-off according to usual practices without "conscious effort" to obtain thorough soaking of the root collar zone.

The importance of the volume of formulation applied per unit area of treated stem base has been stressed frequently (Burbage 1954; Owens and Willard 1954), and high volume rates at low concentrations have been more effective than low volume application of formulation ten times more concentrated (Coulter 1952). These points further support the view that for control of woody species, especially those prone to resprout, it is essential to soak the root collar thoroughly. The success of high volume applications may be attributed to the fact that run-off is enough to do this.

The following table (after Coulter 1952) illustrates the effects of volume and concentration: the values are efficiency ratings ranging from 1.0 (little or no effect) to 5.0 (complete apparent death).

Ml. formulation per inch of circumference	lbs. of acid equivalent per 100 gallons of formulation 4	8	12	16	24	32	40
3 (low volume)	1.5	2.0	2.1	2.2	2.2	2.5	2.8
7 (medium ")	3.2	4.1	3.5	4.9	4.9	4.6	4.9
11 (high ")	4.3	4.5	4.9	5.0	5.0	5.0	5.0

Here, the low concentration of 4 lbs. acid equivalent per 100 gallons of formulation is very effective at the high volume rate of 11.0 ml. per inch of treated stem circumference, but the high concentration of 40 lbs. acid equivalent at the low volume rate of 3.0 ml. per inch is much less effective despite using about three times as much herbicide per tree.

A satisfactory concentration in most cases is 16 lbs. acid equivalent of 2,4,5-T ester in 100 gallons of oil (Anon. 1954a; Jokela and Lorenz 1955), but good results have been obtained with only 8 lbs. acid equivalent (McQuilkin 1957). The concentration needed to effect satisfactory kill at any given dosage rate increases rapidly with stem diameter (Smith *et al* 1954), probably because of increasing bark thickness.

Oil is the usual diluent, being much more satisfactory than water (Anon. 1954a; Sampson and Schultz 1956). All the oil-soluble herbicides may thus be used in basal treatment, and are especially effective in light diesel oil or kerosene since the oils seem to aid penetration through bark to the phloem (Sampson and Schultz 1956). Certain oils alone are useful in treatments of this type, being toxic to the meristematic tissues of epicormic buds of sprouting species.

General agreement has not been reached as to the precise stage of growth at which a tree is most susceptible to basal treatment. In the Lake States, best results followed treatment in the late winter or spring (Coulter 1950; Day 1950; Anon. 1954a), although some control is obtained at any time between early autumn and bud break in the spring (Anon. 1954a). However, as Larsson (1957) points out, this is not true of all species, for the response of silver maple to treatment does not appear to be affected by season of application. Also, hawthorn has been killed by treatment in all months of the year (Waywell 1954), and McQuilkin (1957) states that most hardwood species are susceptible to basal treatment properly applied at any time of year.

Certain species, e.g. red maple, resistant to both foliage sprays and basal treatment, seem to be somewhat more susceptible to the latter.

(c) *Poison wound treatment*

With these treatments the sub-cortical layers are exposed and herbicides applied to the wound. This method has been used for many years and is usually preferable to girdling alone. The latter is slow, expensive and often gives indifferent results.

The poison may either be painted or swabbed on a girdle of the traditional type, poured in a frill, cups or notches cut around the stem, injected by special tools into the stem or inserted as a chemical tab beneath the bark. A frill is a series of contiguous notches around the stem, and to ensure success with intractable species a double frill may be used. Cups and notches are formed by overlapping axe cuts one above the other. Injection methods, as with the Cornell tool (Cope and Spaeth 1931), puncture the stem and deposit therein a quantity of poison. Chemical tabs are inserted between the bark and wood of the stem into a pocket made by a special tool resembling a small bark-peeling spud.

Poison wound treatments, especially the chemical frill type, are particularly useful in the treatment of scattered large stems but results are affected by climate and species. Treatments which do not involve a complete girdling of the stem are usually less effective than those which do. Generally, treatments are most effective if the wound is at the base of the tree.

As penetration of the suberized layers is unnecessary, aqueous solutions may be used, although in some cases an oil solution may be preferable (Arend and Coulter 1952; Anon. 1954b). As yet there is insufficient evidence to recommend one diluent to the exclusion of others. Direct applications of herbicide crystals have been successful. Ammonium sulphamate, sodium arsenite and amine or ester forms of 2,4-D or 2,4,5-T are the herbicides most commonly used, and aqueous solutions of the first two are always prepared when, as is usual, application is to be in liquid form.

Information as to the season at which best results are obtained is conflicting. Other factors appear to exert greater influence than time of year: the time recommended varies from summer or growing season for frills or notches with ammonium sulphamate (Anon. 1954b) to late autumn or dormant season for frills with sodium arsenite (Anon. 1917), but in many cases there has been no consistent seasonal effect (Martin and Jones 1954). Seasonal effect seems to increase in importance with increasing latitude.

There is usually less regrowth from poisoned standing trees of sprouting species than from stumps, herbicidally treated or not. Frills seem to be the most effective treatment in limiting regrowth. Complete inhibition of regrowth has been achieved but knowledge of the conditions required is incomplete.

Concentrations of approximately 10000 p.p.m. of 2,4,5-T in diesel oil for frill treatments and up to 15000 p.p.m. for notches seem to be reasonable for trials, which should precede any large-scale operation. The dosage required is very variable, but probably only 30 to 50 per cent of that required in basal treatments. The concentrations and dosages used in poison wound methods are so varied that the reader is referred to specific examples in Part II of this report for more detail.

(d) *Cut stump treatment*

This method requires cutting of undesirable trees and the application of herbicide to the stump to inhibit regrowth. The maximum effect is obtained if the herbicide is applied within 24 hours after cutting, although satisfactory results have been obtained with delays of up to a month (Anon. 1954b). The herbicide may be sprayed, poured or painted on the stump, or applied in crystalline form. The method is costly because of cutting and the difficulty in locating stumps afterwards. Perfect selection is, of course, possible, and there is no need to use selective herbicides. Cut stump treatment is usually more effective than foliage spray (Rudolf 1951), and may be preferred where brush is more than 6 feet tall and very dense.

Success can be obtained at any season (Martin and Jones 1954; Rudolf 1951; Anon. 1954b). Although excellent results have been obtained by treatment in sub-zero weather, it has been claimed that treatment is most effective during late winter or in spring (Coulter 1950).

Before the introduction of hormone herbicides, the only treatment which seemed to guarantee virtually complete eradication was that of unearthing to expose, then hacking lightly to scar, all the live tissue of the stump and applying a 10 per cent aqueous solution of sodium chlorate, calcium chlorate or ammonium thiocyanate (Bruce 1939; Tryon and Finn 1942).

However, less drastic treatments, making use of herbicides of the hormone type, now give good control in most cases. The formulation should be applied to all cut surfaces and to the bark down to ground level as well as to any exposed roots. The concentration recommended varies between 1 to 5 lbs. (Rudolf 1951) and not more than 18 lbs. (Anon. 1954b) acid equivalent of 2,4,5-T esters in 100 gallons of oil. Similar treatments using ammonium sulphamate at 2 to 9 lbs. per gallon of water or oil also have been successful (Rudolf 1951). It is probable that stump height may have some influence on the concentration necessary for effective control (Anon. 1954c).

Species vary considerably in their susceptibility to stump treatments (Coulter 1954), and where difficulty is anticipated oil diluent should be used rather than water, and the formulation applied in liberal quantities.

(e) *Soil saturation*

This method is non-selective and totally eliminates all vegetation through the application of a persistent toxicant to the soil surface. It has very little use in silviculture.

4. Selectivity of Herbicides

The ability, possessed by certain substances, to affect particular plant species much more than others derives from two main sources. Herbicides with this ability are said to be "selective". The selectivity of herbicides is due sometimes to differences in the structure and growth habits of plants and sometimes to the fact that a substance may be toxic to one plant and not to another.

The basis of true chemical selectivity is thought to lie in the enzyme system of plants. Some plant enzyme systems are capable of breaking down certain fatty acids, and even non-toxic acids can be prepared whose decomposition by a particular enzyme system leads to the formation of toxic substances. In two

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plants, one with an enzyme system of this type and one without, the acid will be toxic to the former and harmless to the latter, quite independently of any differences in plant structure and growth habits. Such an acid is 2,4,5 trichloro phenoxy butyric acid, and indications are that MCPB and 2,4,5-DB owe their weed-killing properties to the fact that susceptible plants possess the appropriate enzymes to convert these substances to MCPA and 2,4-D respectively (Wain 1955).

The herbicides 2,4-D and 2,4,5-T are not truly chemically selective. Any plant can be killed by large enough applications of these chemicals. Selectivity in this case is based on the fact that some plants are more susceptible than others to these substances. It has not yet been demonstrated that enzyme systems are associated with degree of susceptibility in these instances. But in view of the fact that species of the same genus, and morphologically very similar, may exhibit quite widely differing susceptibilities to 2,4-D (Coulter 1954) and similar herbicides, it is likely that enzymes are involved.

Hormone substances promote growth responses in plants when applied in concentrations of only a few p.p.m. in aqueous solution. At higher strengths, up to 0.1 per cent, the effects on a plant can be drastic. Twisting and distortion may occur (Wain 1955), often within 24 hours (Coulter 1950), followed by swelling, and frequently by rupture of the stem. The swelling causes pressures which literally crush many of the vital tissues (Coulter 1950). These effects may cause the death of the plant.

Tolerance of conifers to herbicides

The tolerance of a number of conifers to 2,4-D and 2,4,5-T ester foliage sprays was investigated in Lower Michigan (Anon. 1954d). Red, white, jack and Scots pines and Norway and white spruces, all 15-year-old planted stock, were treated at different times during the summer. The formulations used were 1 and 2 lbs. of acid equivalent in both 2½ and 5 gallons of diluent per acre, the diluent consisting of 1 quart of diesel oil with enough water to make up the required 2½ or 5 gallons of formulation.

The new growth and some old growth of all species was killed or damaged during June and early July by all formulations regardless of concentration and volume per acre. Damage by 2,4-D was greater than that by 2,4,5-T formulations.

There was no apparent effect on white spruce from treatments given after July 15, nor on the other species after August 1 except that jack pine showed some browning of foliage after treatments given as late as August 15th.

In northern Ontario, jack pine was susceptible and spruce and balsam fir were immune to foliage sprays containing 12 Imperial gallons of Brush Bane per 1,000 gallons of water applied at 4.5 gallons (18 lbs. acid equivalent) per acre from hand equipment, and at 1.83 gallons (7.32 lbs. acid equivalent) per acre from powered equipment (Swann 1954).

5. Types of Herbicides

Herbicides may be grouped according to their mode of action into 3 main types; thus:

(*a*) Hormone or growth regulator
(*b*) Contact, translocated
(*c*) Contact, non-translocated

A list of some of the herbicidal chemicals will be found in Appendix 1.

(*a*) *Hormone or growth regulator herbicides*

Hormone herbicides are substances which disrupt cell growth control so that cells enlarge beyond their normal size. Pressures are set up which crush and rupture the affected tissues. Herbicides of this type can gain entry into the plant through any active part (Tam 1947; Rudolf 1951), leaf, stem or root (Dittmer 1954; Wain 1955). Absorption increases with increasing temperature (Tam 1947; Rudolf 1951).

Translocation of the herbicide is associated with the translocation of organic food materials (Mitchell and Brown 1946; Crafts 1953; Mitchell 1954). This explains the poor results obtained by spraying young unfolding leaves: the leaves may be killed, but very little herbicide passes down to the roots which tend to sprout vigorously in those species prone to sprouting.

Boron has accelerated the rate of translocation of photosynthesized materials from leaves to stems (Gauch and Dugger 1953) and its indirect effect in accelerating the translocation of 2,4-D and other hormone herbicides within a tree seems to be more restricted than vertical movement (Gleason and Loomis 1954).

In woody plants the action of hormone herbicides is particularly evident in the cambial area where often a sharp line delimits the black or brown area of dead tissue from the green alive. unaffected parts. Sprouts may arise from the green areas of the cambium (Coulter 1950).

In some plants the sugar content can be shown to have increased 1 to 3 days after treatment with hormone herbicides. Animals may seek out and eat such plants although they are not normally part of their diet. The effect would be drastic if the plant happened to have, like chokecherry, prussic acid in its wilted foliage.

Chlorophenoxyacetic acid formulations may reach untreated areas through:

(i) Drift of particles—minimized by high volume applications (Anon. 1954b),

(ii) Dust blowing from treated plant and soil surfaces,

(iii) Volatilization from treated plant and soil surfaces.

The danger is greatest from (i) and least from (iii) (Barrons 1956), but highly volatile spray chemicals should not be used within 700 feet of susceptible crops.

(1) *The 2,4-D and 2,4,5-T group*

(a) *2,4-Dichlorophenoxyacetic acid*

The compound 2,4-D, in its unformulated state, is white, crystalline and relatively insoluble in water and petroleum oils. But it is soluble in tributyl phosphate which in turn is soluble in the petroleum oils (Ennis *et al* 1946). It is non-corrosive to metals, non-toxic to animals (Sampson and Schultz 1956), and at normal rates it does not significantly reduce the total number of soil organisms (Ahlgren *et al* 1951) although some changes may occur in the proportions of species present. Aerobic organisms appear to be the most sensitive to 2,4-D, which may seriously inhibit their growth; anaerobic organisms may not be affected significantly; some facultative anaerobic organisms may be stimulated (Worth and McCabe 1948). 2,4-D is non-explosive, does not increase fire danger (Ward 1956) and is cheaper to use than most other herbicides.

Many shrubs and trees will sprout after 2,4-D treatment but to a lesser extent than after cutting (Day 1947). Where raspberry is present under a stand of hardwoods, e.g. alder or aspen, that is to be treated herbicidally, the use of

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2,4-D alone, which has little effect on raspberry, may lead to a strong invasion by this species. In such an instance it would be desirable to use a mixture of 2,4-D and 2,4,5-T.

Nearly all germinating seeds are susceptible to 2,4-D (Ahlgren *et al* 1951) and the normal germination of many seeds can be inhibited by concentrations of as low as 1 p.p.m. of 2,4-D acid (Hamner *et al* 1946).

There is considerable evidence that 2,4-D can be decomposed by soil micro organisms. Soil conditions favouring high and active populations of micro organisms seem also to favour rapid decomposition of 2,4-D acid in the soil. High moisture contents result in the most rapid inactivation of 2,4-D acid, but high temperatures, at least up to 70°F., also are favourable (Brown and Mitchell 1948; Jorgensen and Hamner 1948). Inactivation of 2,4-D is quicker when the chemical is mixed with soil than when it merely lies on the soil surface (Jorgensen and Hamner 1948). Autoclaving of soils to kill the micro-organisms significantly reduces the rate of inactivation of 2,4-D (Jorgensen and Hamner 1948), and borates have been used successfully to retard breakdown, by soil micro-organisms, of hormone herbicides of the 2,4-D group (Stone and Rake 1955; Harvey 1956). Leaching also is instrumental in the inactivation of 2,4-D (DeRose 1946; Hanks 1946; Hernandez and Warren 1949). Toxicity is likely to persist longer in alkaline than in acid soils (Kriess 1947; Crafts 1949) although an experiment in Michigan showed that differences in reaction within a sandy soil type did not appreciably affect the rate of loss of toxicity (Jorgensen and Hamner 1948).

Any silvicultural significance of residual, incidental toxicity conferred on forest floors following herbicidal operations has escaped comment in the literature. This is taken to imply that any such residual effect has been negligible silviculturally. The amount of herbicide reaching the forest floor will depend largely on the method of application: only foliage sprays seem capable of depositing herbicide over the forest floor in more than negligible amounts. Normal foliage treatments aim at restricting this wastage of herbicide to a minimum, and it appears that present practices are unlikely to produce soil toxicity pronounced enough to disturb the silviculturist. However, it is stressed that exceedingly low concentrations of chlorophenoxyacetic acid preparations can kill germinating seeds, and this should be borne in mind whenever spraying treatments are contemplated for areas where this type of damage would be undesirable.

Pure 2,4-D acid is seldon used as a herbicide; various derivatives have usually been found to be more suitable. In control of woody vegetation, esters are the most commonly used of the 2,4-D derivatives.

2,4-D esters

Alcohols react with 2,4-D acid to give esters, the ester being identified by the name of the alcohol used in its formation. Esters are neutral substances, the lower members of which are liquids. The esters of 2,4-D commonly used as herbicides are all liquids, soluble in oil, emulsifiable in water, and are non-corrosive to metals. They are more soluble in oil than either the amine salt or acid forms.

The first ester formulations to be used as herbicides were generally the lower alkyl esters, e.g. methyl, ethyl, isopropyl and butyl. These are effective, but have the disadvantage of being quite volatile. Subsequently, less volatile esters, such as propylene glycol butyl ether and butoxy ethanol, were produced. Some of the newer esters are more effective in controlling certain woody plants than were the older, more volatile ones (Anon. 1950a; Rudolf 1951; Mullison *et al* 1951; Crafts 1953).

Esters generally act more quickly than the salts of 2,4-D, and, because of their solubility in oil, penetrate leaves, especially those with a leathery or waxy cuticle, more effectively than either the salts or acid (Coulter 1950; Sampson and Schultz 1956). Formulations of 2,4-D esters are not readily washed off treated plant surfaces by rain. Although the esters penetrate quicker than other 2,4-D substances, their subsequent translocation is slowest (Sampson and Schultz 1956). This applies also to lateral translocation (Gleason and Loomis 1954). The lateral spread of 2,4-D esters is similar at heights of 1 and 3 feet. Lateral movement of 2,4,5-T formulations is usually less than that of the corresponding 2,4-D product, but this difference is less pronounced than the difference between the esters and the amines.

A typical minimum safe storage temperature is 0°F. for the propylene glycol butyl ether ester formulation. If esters which tend to become crystalline at low temperatures are stored below 32°F. they should be agitated thoroughly at room temperature before use (Coulter 1955). It is often difficult to re-dissolve crystallized esters, and oil-water emulsions may coagulate if improperly mixed.

Volatility of esters

The degree of volatility of an ester is relative. Compared to the ethyl ester of 2,4-D, the butyl ester is relatively safe, yet both are commonly classed as highly volatile. Compared to tridecyl ester, butoxy ethyl ester is relatively volatile, although both are generally considered to be in the low volatility class (Warren and Gillies 1953). However, it may be useful to present the following classification of 2,4-D esters, after Marth and Mitchell (1949), Mullison (1953), Warren and Gillies (1953), Baskin and Walker (1953a, 1953b) and others.

2,4-D esters

High volatility	*Low volatility*
methyl	isooctyl
ethyl	butoxy ethyl
isopropyl	tetrahydrofurfuryl
propyl	butoxy propyl
butyl	butoxy ethoxy propyl
isoamyl	ethoxy ithoxy propyl
amyl	propylene glycol butyl ether and
pentyl	other higher alkyl esters

Esters of 2,4,5-T may be rather less volatile than their corresponding 2,4-D analogues (Mullison 1953; Warren and Gillies 1953).

The volatility of eight esters was studied by observing the depression of germination of squash seeds exposed to vapour for 14 days at 100°F. (Mullison 1953). All esters having an aliphatic carbon chain of 5 atoms or fewer showed significantly greater volatility than the others tested. The discontinuity occurred between mixed amyl and nonyl esters in the following series: isopropyl, *sec.* butyl, mixed amyl; nonyl, butoxy ethanol, polypropylene glycol butyl ether, tetrahydrofurfuryl and ethylene glycol mono ester. There were no significant differences in effect between the last five esters of the series.

Warren and Gillies (1953) found a range in vapour pressure of from 11.5 and 10.5 mm. Hg x 10^{-3} for ethyl and isopropyl 2,4-D esters respectively to 0.4 and 1.35 for tridecyl and *n*-heptyl 2,4-D esters. These results agree generally with those of Mullison (1953) above.

The volatility of an ester differs according to the formulation in which it is incorporated, and the same ester in different formulations may show quite widely different resultant volatilities (Warren and Gillies 1953). For instance, an ester of relatively high volatility such as butyl 2,4-D can be formulated so that it is no more volatile than some formulations of butoxy ethyl ester of 2,4-D, which is relatively of low volatility. Marth and Mitchell (1949) found a considerable reduction in volatility of a number of 2,4-D esters when formulated with diesel (boiling range 170° to 335°C.), corn or cottonseed oils, but not with Varsol (B.R. 155° to 200°C.) kerosene (B.R. 180° to 260°C.), motor (S.A.E. 20 or 40) or castor oils. Thus the mode of formulation may be as important as choice of ester in obtaining formulations of low volatility.

The volatility, as measured by depression of germination, of the relatively high volatile esters has been shown to increase with increase of temperature, but temperature did not have appreciable effect on the volatility of relatively low-volatile esters (Mullison 1953).

Summarizing, simple esters, with an aliphatic carbon chain of 5 atoms or fewer, are generally more volatile than more complex esters, but the volatility of an ester may differ markedly between different formulations of that ester.

2,4-D amine salts

Diethanolamine, triethanolamine, isopropanolamine and dimethylamine are amongst the most common of the amine salts of 2,4-D used as herbicides, but they are little used for control of woody plants.

The amine salts are generally available as liquids and are readily mixed in all proportions with water. They are non-volatile (Mullison 1949) but less readily absorbed by leaves than free acid forms (Sampson and Schultz 1956) and act more slowly than the esters, being more comparable in this respect to the ammonium and sodium salts of 2,4-D. However, translocation is more rapid in amines than in esters (Gleason and Loomis 1954). The amine formulations are generally regarded as more selective than the esters (Coulter 1955).

2,4-D ammonium and sodium salts

These are dry powders in the unformulated state and are moderately soluble in water. They are non-volatile, but formulations are affected by rain for several hours after application and take effect more slowly than esters (Rudolf 1951). Precipitation in "hard" water may lead to nozzle clogging (Ahlgren *et al* 1951).

(b) *2,4,5-Trichlorophenoxyacetic acid*

2,4,5-T is closely related to 2,4-D and is similar to it in many respects. Its action is similar to 2,4-D but less selective in that it acts on aspen and other species resistant to 2,4-D, and inhibits root bud development much more than does 2,4-D in certain plants. The specific action of derivatives of 2,4,5-T on many plants tolerant to 2,4-D was noticed quite early (Tam 1947; Barrons and Coulter 1947). Few species are unaffected by 2,4,5-T (Coulter 1955) and most woody species appear to be at least as susceptible to a mixture of 2,4-D and 2,4,5-T as to 2,4-D alone, willow being one established exception (Butler 1950).

Like 2,4-D, 2,4,5-T is white and crystalline. However, the derivatives of 2,4,5-T are generally less soluble in common solvents than the corresponding 2,4-D compounds. There is no great difference in translocation rates between 2,4,5-T and 2,4-D, although the latter tends to be more rapid: this tendency is very much less pronounced than the differences in translocation rates between the esters (slow) and amines (faster) of both 2,4-D and 2,4,5-T (Gleason and Loomis 1954). The rate of translocation is greatest at the full leaf stage, and is favoured by high temperature and low humidity, provided there is no dearth of soil moisture.

Formulations of 2,4,5-T have been superior to those of 2,4-D on most species for basal and stump treatments (Day 1950; Anon. 1954a).

Esters, amines and sodium and ammonium salts of 2,4,5-T are prepared analogously to the 2,4-D series. The most important of these in the control of woody vegetation are undoubtedly the 2,4,5-T esters. Formulations of low-volatile esters have proved to be among the most effective silvicides (Jokela and Lorenz 1955).

(2) *MCP (2-Methyl 4-Chlorophenoxyacetic acid)*

Very similar structurally to 2,4-D, from which it differs in having a methyl group on the second carbon atom where 2,4-D has an atom of chlorine, MCP has been little used in North America until recently, but has had considerable success in parts of Europe, notably Britain. The action of MCP is much like that of 2,4-D, but more highly selective (Fox 1953).

(3) *Propionic compounds*

Up to the present time, these compounds ("Silvex" and "Kuron" are examples) have not been used to any great extent in the control of woody growth, and do not appear likely to oust the 2,4-D and 2,4,5-T compounds from preeminence.

Propionic formulations act slowly relative to those of the 2,4-D group. Leaves treated with propionic compounds may droop and twist soon afterwards, but their death and that of the stem is normally considerably slower than following 2,4-D or 2,4,5-T treatments of otherwise similar nature (Coulter and Gibson 1954). Although initially of slow action, there are indications that any regrowth may be delayed about a year by the use of propionic rather than 2,4-D or 2,4,5-T preparations (Coulter and Gibson 1954). Limited trials have shown "Silvex" to be not particularly efficient in basal and cut-stump treatments.

Further experience may indicate certain advantages in using propionic compounds in particular circumstances. Possibly a mixture of 2,4-D or 2,4,5-T and "Silvex" or "Kuron" may reduce or delay regrowth more effectively than any of the pure formulations used separately.

(b) Contact, translocated

There are many water-soluble herbicides which are translocated but non-selective. Such chemicals can be used either in foliage, cut-stump or wound treatments. Being water-soluble, they can be translocated to various parts of the tree once they reach the phloem (Sampson and Schultz 1956). Plant cells which have prolonged contact with the chemicals are killed. That cells are not immediately killed is necessary to the effective translocation of the chemical. Herbicides of this type achieve similar effects in different ways: e.g. ammonium sulphamate tends to precipitate the proteins of the protoplasm, whereas arsenicals break down the structure of the nucleus, and most salts have a plasmolytic action (Sampson and Schultz 1956).

The rate of translocation, the dosage needed and the time of greatest susceptibility vary with species.

(1) *Ammonium sulphamate ("ammate")*

Ammonium sulphamate is a yellow crystalline substance, very soluble in water, which has a systemic effect on most plants. It is translocated rather rapidly from foliage to stems and underground parts of many tree species (Coulter 1950; Barrons 1952). Translocation of ammate is considered by some to be of lesser importance than its burning action (Anon. 1954a); at any rate, the rapid killing of leaves and stems does not appear to be detrimental to the degree of final control (Peevy 1949). However, the chemical must move through the plant to be effective and it has been shown in experiments with privet and mockernut hickory that ammate moves upwards rapidly in the xylem and downwards slowly in the phloem (Carvell 1955). Since movement in the xylem is most rapid in the growing season, when the transpiration rate is high, this is probably the reason for the superior root kill by dormant-season wound treatments with ammate as compared with treatments at other seasons. During the dormant season the upward movement in the xylem is at a minimum. The relatively slow downward movement of ammate in the phloem accounts for the better results attending wound treatments, the nearer they are to the base of the stem (Rudolf and Watt 1956).

Ammate can be very effective in wound and cut-stump treatments particularly. Also, it has proved to be quite effective on many species as foliage spray, but because of the large amount of chemical required, it is more expensive than chlorophenoxyacetic preparations used to achieve the same results. About 30 times as much ammate as 2,4-D or 2,4,5-T is needed to produce comparable results (Coulter 1950).

Ammate can be applied either as crystals or as a liquid, in water or oil. Recommended concentrations for foliage spray applications vary from $\frac{3}{4}$ lb. (Anon. 1954a) to 2 lbs. (McQuilkin 1953) per gallon of water. Very much higher concentrations are usual in wound and cut-stump treatments. It is considered superior to other herbicides for killing certain species such as oaks, hickories, maples, wild cherries (Jacobs 1950) and ash (Day 1950).

A highly concentrated form of ammate, known as "Ammate X" (McCormack 1957) with a concentration of 95 per cent as compared with the usual 80 per cent is now available. Other noteworthy characteristics are the following. Ammate is non-toxic to animals generally, although some people are allergic to long-continued contact with the chemical and may develop a skin rash. It is highly corrosive to metals, brass and galvanized material especially. Also, ammate has fire-retardant properties, and, on decomposition, a residual effect as a fertilizer.

(2) *Arsenical compounds*

Sodium arsenite and arsenic pentoxide are effective herbicides that are relatively cheap. Their main disadvantage is their toxicity to man and beast.

Sodium arsenite is very soluble in water, and has been used successfully in a variety of wound treatments. Pines up to 30 feet tall and 5 inches in diameter have been killed by the insertion of only one chemical tab per tree; hardwoods need more tabs per tree (Anon. 1954c). Application in frills and notches has given excellent results. This chemical has also been used, but much less extensively, as a foliage spray (Maisenhelder 1948), but this practice is not recommended, because of the danger of using such a highly toxic substance in this manner.

Expressed in lbs. of white arsenic, lbs. of lye (soda), and gallons of water respectively, effective formulations include 1-0-1, 1-$\frac{1}{2}$-4, 1-1-2, 1-1-4, 1-2-1, 1-2-2, 1-3-4, 2-$\frac{1}{2}$-1, and 4-1-$\frac{3}{8}$. The lye is dissolved in water to which is added *slowly* a paste made by mixing the white arsenic with water, boiling the mixture for at least an hour, then adding water to give the required quantity of solution (Anon. 1943).

Arsenic pentoxide largely superseded sodium arsenite as a herbicide in New South Wales. It appears to be more effective on trees that are liable to sprout. Recommended concentrations are $\frac{3}{5}$ and $1\frac{1}{2}$ lbs. per gallon of water (Anon. 1943).

Arsenically treated wood should not be used as fuel since the smoke may be toxic.

(3) *Substituted ureas*

Of this group, those known as CMU, DCMU and PDU are the best known. They are non-selective and may be used in powder or pellet form in incisions; or they may be used in spray applications to the soil surface around the base of the stem. Oaks and associated woody species have been killed satisfactorily by CMU and DCMU; PDU is slightly more active. Symptoms of urea herbicide toxicity appear slowly; foliage becomes chlorotic, then dies and falls (Ray 1957).

The substituted ureas are equally effective at all seasons (Elwell 1954) at least in Oklahoma, and are non-toxic to animals. There appears to be a slight increase in inflammability when material sprayed with CMU is still wet (Ward 1956).

(c) Contact, non-translocated

Included in this group are the various oils used as herbicides, and those chemicals whose main effect is as a contact poison with little or no translocation within the plant.

(1) *Sodium chlorate*

This is a white crystalline salt, very soluble in water, and a strong oxidizing agent. Organic material treated with sodium chlorate becomes highly inflammable when dry, and may ignite spontaneously. Borax, sodium carbonate, arsenic trioxide or calcium chloride may be added to reduce the fire hazard (Ahlgren *et al* 1951). Equal part mixtures of sodium chlorate and calcium chloride have reduced the inflammability of treated materials compared with those untreated (Ward 1956).

Sodium chlorate is ineffective in injection treatments, but has been satisfactory in killing sprouts (Pessin, 1942).

(2) *Dinitrophenols*

In large amounts the dinitrophenols are toxic to man, and may cause skin irritation. Because there is little or no translocation when applied to foliage, sufficient spray must be used to wet the vegetation thoroughly. When applied to the soil, quantity used is less important than uniform distribution (Ahlgren *et al* 1951).

One of the best known of this group is DNOSBP (DNBP) which is soluble in oil but not in water. It is possible to dissolve the chemical in oil and then form an emulsion in water by the addition of an emulsifying agent.

As a foliage spray, DNOSBP gives an immediate kill of leaves but has little residual effect. As a basal spray, damage is much more severe, and in the case of aspen, in Michigan, many treated stems were unable to resprout (Day 1947).

(3) *Trichloroacetic acid* (TCA)

Salts, such as sodium trichloroacetate, of TCA, are most effective on grasses, but are also injurious to many shrubs and trees. The ammonium salt is also effective, but is more caustic and corrosive than the sodium salt. The action is that of a soil poison: toxicity persists in soil usually for a few weeks, occasionally for a year or more. Sodium tricholoracetate is highly hygroscopic.

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(4) *Herbicidal oils*

Some oils, chiefly the aromatics, are themselves toxic to plants (Anon. 1954a). Two types of toxicity are recognized: a) acute, and b) chronic. Acute toxicity resulting from oils is shown by a rapid "burning" of treated foliage. Chronic toxicity causes a slow chlorosis and subsequent death. Acute and chronic toxicities appear to be related to the lower and higher boiling-point aromatic oils respectively (Crafts and Reiber 1948). Very light oils, e.g. gasoline, induce rapid burning of leaves but the oil evaporates quickly and, unless large volumes are used, injury is usually slight (Ahlgren *et al* 1951). Diesel oil seems to be both acutely and chronically toxic to vegetation.

Only those tissues actually in contact with an oil herbicide are directly affected, but, although the oils are not mobile in the vascular system, internal penetration by diffusion may be deep. Because of their low surface tension, oils spread over surfaces in a thin film. This aids penetration of the cuticle. Movement through the internal tissues of the plant may be through either the intercellular spaces (Minshall and Helson 1949) or lipoid phase diffusion (Sampson and Schultz 1956), or combinations of the two. Oils are soluble in the lipoids of the cell walls, and gaseous exchange is inhibited if the walls become saturated. The disruption of internal water relations has also been mooted as a likely cause of cell mortality due to oils (Minshall and Helson 1949). In addition to these physical disruptions to plant metabolism, oils have a chemically toxic effect, the degree depending on their content of unsaturated compounds. The toxicity of oils can be increased by the addition of small quantities of fortifying agents such as sulphur, pentachlorophenol or dinitrocresol.

The practice of adding oils to hormone type sprays in an effort to increase their effectiveness is not recommended. The initial results may be spectacular, but in most instances the quick killing of foliage prevents the entry and/or translocation of the hormone herbicide. No decrease in sprouting vigour can be expected in such cases. Only if such small amounts of oil are added that no large amount of quick killing of plant tissues follows may oil be added without detriment to foliage sprays. Because of this, the use of non-toxic oils as herbicide carriers in aerial sprays is being studied (Ray 1957). However, there does not appear to be any valid reason for adding oil and it is better to avoid the practice unless any particular advantage can be demonstrated.

Oils are the usual diluents in basal sprays. Diesel, fuel (Nos. 1 and 2), and waste transformer oils are all satisfactory for this purpose.

6. Diluents and Additives

Diluting agents or carriers facilitate a uniform distribution of highly concentrated chemicals. Water is the most commonly used diluent. Oils are used as carriers for basal sprays and have sometimes been used as foliage spray diluents. With translocated herbicides, however, the use of more than a small proportion of oil will inhibit translocation of the herbicide as described previously.

Additives are substances which increase the effectiveness of herbicides, and include wetting agents, sticker-spreaders, emulsifiers and the like. Aqueous formulations of ammate and of the amine salts of 2,4-D and 2,4,5-T usually require an emulsifier and sticker-spreader (Sampson and Schultz 1956). Various wetting agents have appeared to increase the absorption of hormone herbicides (Tam 1947; Rudolf 1951) but none have been consistent in increasing the kill obtained (Coulter 1950). However, in contrast to the limited absorption of the ammonium salt of 2,4-D after the first 4 hours when applied pure in aqueous solution, Rice (1948) showed that the addition of Carbowax 1500, a wetting agent, resulted in the salt being absorbed continuously for 72 hours. The use of Carbowax 1500 greatly increased absorption of the ammonium salt of 2,4-D at low temperatures (46°F. to 55°F.) in one instance, but in two other experiments the total amount of the salt absorbed was positively correlated with temperature with or without the presence of the wetting agent (Rice 1948).

7. Factors Influencing the Effectiveness of Herbicidal Treatments

A large number of factors influence the success of herbicidal treatments, and until more is known about them, apparent inconsistencies will occur in the results obtained. Some of the factors which are known or believed to affect results are listed below; not all will affect any one particular treatment (e.g. variations in topography will be important in aerial spraying but not in basal treatments), but it is considered that the presentation of such a list is of value if only to indicate the range of factors.

(*a*) Tree species
(*b*) Age of tree
(*c*) Size of tree
(*d*) Vigour of tree: rate of plant growth
(*e*) Type of leaf cuticle
(*f*) Density of vegetation
(*g*) Presence or absence of moss at base of stem
(*h*) Stage of foliage development
(*i*) Bark thickness
(*j*) Herbicidal method used
(*k*) Season of application, (importance increases with increasing latitude)
(*l*) Formulation used, and its concentration
(*m*) Type of diluent
(*n*) Dosage
(*o*) Droplet size of sprays
(*p*) Spray pressure
(*q*) Losses of chemical from drift, volatilization, etc.
(*r*) Weather, especially temperature during and precipitation following treatments
(*s*) Soil moisture
(*t*) Water deficiency in the plant
(*u*) Soil fertility
(*v*) Topography.

PART II—HERBICIDAL TREATMENT OF INDIVIDUAL SPECIES

1. Alder. (*Alnus rugosa* (Du Roi) Spreng. var. *americana* (Regel) Fern.)

(*a*) *Control measures used and success achieved.*

(1) *Foliage spray, ground*

There is little difficulty in obtaining a good top kill of alder.

Evaluation of experiments begun 2 and 3 years previously in northern Wisconsin showed that 90 per cent or more of treated mature alder were killed by foliage sprays using the isopropyl ester of 2,4,5-T at a concentration of 2150 p.p.m. in water at 100 gallons per acre (Anon. 1950b).

In Upper Michigan, alder was found to be hypersensitive or sensitive to foliage sprays of 2,4-D formulations and to ammate applied in the middle of the growing season (Day 1948).

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Good control of alder by combination chlorophenoxyacetic acid esters at 8000 p.p.m. in water during the middle of the growing season has been reported (Rudolf and Watt 1956). Ammate at 4 lbs. per gallon also gave good results when applied at mid-growing season when new growth had lost its initial succulence. Less concentrated formulations of 2,4-D or 2,4,5-T esters or of ammate gave only fair control, but applications around the middle of the growing season still gave the best control.

An interesting experiment carried out in a Wisconsin swamp used several 2,4-D formulations as foliage sprays on alder whose density was from 6,000 to 11,000 stems from 8 to 12 feet tall and from 4,000 to 6,000 sprouts from 2 to 3 feet in height per acre (Stoeckeler and Heinselman 1950). Very good results were obtained with "Esteron 245" at 2150 p.p.m. both on sprouts and on older growth. Good results were given by "Esteron 44" at 3380 p.p.m. and by ammate at 4 lbs. per gallon of water: sprouts and older growth reacted similarly.

The following treatments proved to be highly effective when applied during the period from July 1 to August 15: methyl ester of 2,4-D at 1000 p.p.m. in water; methyl ester of 2,4-D at 1665 p.p.m. in kerosene; and the sodium salt of 2,4-D at 1000 p.p.m. plus sodium chlorate in water (Day 1947). Other formulations only slightly less effective included the methyl ester of 2,4-D at 1500 p.p.m. in water, the ethyl ester of 2,4-D at 1250 p.p.m. in water, and the methyl ester of 2,4-D at 1665 p.p.m. with DNOSBP at 0.025 lb. per gallon in kerosene sprayed both on foliage and on stem. Variable results attended the use of 2,4-D sodium salt at 1000 p.p.m. and of DNOSBP at 0.05 lb. per gallon, the latter being applied to foliage and stem.

Foliage sprays of 2,4-D esters were found to be "quite effective" in killing old alder, but sprout growth increased subsequently (Stoeckeler and Heinselman 1950).

Foliage spray, aerial

Aerial spraying techniques have been successful in killing alder, and it is likely that they will become more widely used.

A "good kill" of alder, willow and other brush species was obtained by the use of mixtures of 2,4,5-T and 2,4-D esters in diesel oil and water (Anon. 1954d; Roe 1955). The spraying was carried out in summer in Minnesota.

Although it is not safe to assume that one species will react to herbicidal treatment in a similar manner as another species of the same genus (Coulter 1954), the experience with *Alnus rubra* control in the Oregon coastal region may be worth citing in this instance. Aerial spraying for the release of planted 2 to 8 feet tall Sitka spruce, Douglas fir, and Port Orford cedar from suppressing alder (*Alnus rubra*) 10 to 20 feet tall in the Oregon coastal region was undertaken during the winter and spring of 1948. These tests indicated that aerial spraying with 2,4-D was the cheapest and most satisfactory method of conifer release, and subsequently an area of 1,000 acres was so treated. The elimination of alder was virtually complete, but the other deciduous tree and brush species were not seriously injured. The formulation used on most of the area was 2 lbs. acid equivalent of the isopropyl ester of 2,4-D with 2 oz. of a sticker-spreader mixed with 8 gallons of water: the formulation used on the rest of the area was similar except that the diluent was 7 gallons of water with 1 gallon of diesel oil. No difference in results between these treatments was apparent.

(2) *Basal treatment*

Good control is reported by the use of 2,4,5-T ester at 4000 to 5000 p.p.m. in oil, combination 2,4-D and 2,4,5-T esters at 10000 p.p.m. in oil, and of

DNOSBP at 0.05 lb. per gallon of oil. These treatments are effective during the middle part of the growing season before hardening-off has taken place (Rudolf and Watt 1956). Dormant season treatment with 2,4,5-T ester at 4000 to 5000 p.p.m. in oil gave fair control only.

(3) *Poison wound treatment*

Very little work has been done on this type of treatment, probably because of the success achieved in foliage spray methods. However, alder has been found to be hypersensitive to the sodium salt of 2,4-D inserted in powder form under the bark (Day 1947).

(4) *Cut stump treatment*

In northern Wisconsin, kills of 90 per cent or more have been obtained by swabbing freshly cut stumps with ammate solution at a concentration of 2 lbs. per gallon of water (Anon. 1950b). This treatment cost $25 per acre.

In a Wisconsin swamp, extremely dense alder was treated variously with herbicides. The most effective treatment was to cut the alder in May, leaving prominent stumps which were daubed in July with ammate at 2 lbs. per gallon. This reduced the number of stems by 99 per cent within 18 months. A similar treatment applied in August was much less effective in reducing sprouting, but this may have been due to the failure to find and treat some of the low stumps which were covered by cutting slash (Stoeckeler and Heinselman 1950).

The methyl ester of 2,4-D at 3000 p.p.m. in kerosene has been reported to be very effective (Day 1947). Rather less effective were 2,4-D methyl ester at 1665 p.p.m. in kerosene and 2,4-D methyl ester at 1665 p.p.m. with 0.025 lb. of DNOSBP per gallon in kerosene; DNOSBP at 0.05 lb. per gallon in kerosene had little effect. All these treatments were given between July 1 and August 15 to freshly cut stumps ranging from 1 to 5 inches in diameter.

Good control during the middle part of the growing season after hardening-off is reported with combination 2,4-D and 2,4,5-T esters at 8000 p.p.m. in water (Rudolf and Watt 1956).

(*b*) *Problems of regrowth*

The indications are that regrowth of alder is much less of a problem than regrowth of aspen or birch. Not only is alder susceptible to foliage sprays (by means of which any regrowth can be controlled easily) but cut-stump treatments can give good control.

(*c*) *Factors specially important*

There do not appear to be any outstanding features which are of special importance in herbicidal control of alder. The species is susceptible to a wide variety of herbicidal treatments.

2. Aspen. (*Populus tremuloides* Michx.)

(*a*) *Control measures used and success achieved.*

(1) *Foliage spray, ground*

Success has been achieved to varying degrees in treatments of this kind. The most satisfactory and consistent results have been obtained in the treatment of young aspen suckers (Worley *et al* 1954; Jankowski 1955; Anon. 1956b).

Two-year-old aspen suckers were treated with 2,4-D amine ("Formula 40"), "Esteron 44", "Esteron 245" and "Esteron Brush Killer" at concentrations of 1000, 3000 and 5000 p.p.m. (Atkins 1956a). The treatment was given in August 1951 at Petawawa Forest Experiment Station, Ontario. All 12 treatments proved effective.

In Minnesota, 2-year-old aspen suckers were foliage-sprayed in the summer of 1949. Early season spraying was initially more effective than mid-season, although possibly the ultimate results are similar (Hansen and Ahlgren 1950).

In an inconclusive experiment in Michigan (Day 1948), various formulations were applied to aspen during the summer (July 1 to August 15). Assessing reaction as hypersensitive, sensitive, semi-tolerant or tolerant, aspen proved sensitive to the methyl ester of 2,4-D at 1665 p.p.m. in kerosene, and to ammonium sulphamate in water. The sodium salt of 2,4-D at 1000 p.p.m. plus sodium chlorite in water produced reactions varying from sensitive to tolerant, while 2,4-D ethyl ester at 1250 p.p.m. in water and the sodium salt of 2,4-D at 1000 p.p.m. in water without sodium chlorite were even less effective. The ineffectiveness of 2,4-D ethyl ester in water is surprising, particularly in view of the relative success of the 2,4-D methyl ester in kerosene, (*see* page 36 (4)). It seems probable that the results were influenced by some factor or factors not considered.

Ammonium sulphamate seems to give good control of aspen (Day 1948; Atkins 1956; Pike 1956; Rudolf and Watt 1956), but is very expensive in the quantities needed. There are indications that 2,4,5-T esters are more satisfactory than other 2,4-D or 2,4,5-T chemicals with the possible exception of 2,4-D amine (Anon. 1955; Jankowski 1955). Complete top-kill of succulent growth after one mid-season application of "Esteron 245" at 1000 to 2000 p.p.m. in water and of "Esteron Brush Killer" at 3000 p.p.m. in water has been obtained (Rudolf and Watt 1956), but on non-succulent growth identical treatments have given fair control only, i.e. one application has not given complete top-kill.

In regard to the evaluation of the effects obtained by herbicidal treatments, it should be noted that when low concentrations are used, death may be delayed until the year following the treatment (Pike 1956).

The choice of herbicide may also be influenced by secondary considerations: e.g. raspberry may become very dense if 2,4-D (to which it is tolerant) is used to remove competing aspen, whereas 2,4,5-T would kill a high percentage of the raspberry.

Foliage spray, aerial

Aspen scrub is apparently difficult to kill by the aerial spray techniques now available. Results to date have been very variable (Anon. 1953; Roe 1955) and no large scale operations should be contemplated until a greater chance of success can be demonstrated.

Good top-kill has been obtained by aerial spraying in Lower Michigan, but results in Minnesota have been unsatisfactory (Roe 1955). In Michigan, 600 acres of aspen scrub were sprayed and good top-kill obtained, and although subsequent suckering was heavy, a good kill of 2-year-old suckers was obtained by re-spraying (Roe 1955).

Under (unspecified) favourable conditions, 2 lbs. or less of 2,4-D or 2,4,5-T per acre has been enough to injure severely all the common broad-leaved tree and shrub species, including aspen, commonly considered as weeds (Anon. 1953) in the Lake States, but sprouting was prolific. The herbicides had a negligible effect on the conifers being released when spraying was done in late July or in August.

Again in the Lake States, on an area sprayed 4 years previously when aspen suckers, hazel brush and willows were overtopping natural and planted pine, it was found that only 18 per cent of the conifers were in need of release compared with the 83 per cent needing release in unsprayed control areas (Anon. 1954d).

Large-scale aerial spraying operations have been carried out at a total cost of less than $5 per acre (Anon. 1954d).

(2) *Basal treatment*

Considerable success in the control of aspen has been obtained by basal treatment methods. The most important factors affecting results seem to be size of tree treated, season of application, volume of chemical formulation applied per unit area and possibly the proportion and distribution of stems treated.

Treatment during the period of active growth (from early June to early August) in Michigan with an oil solution of DNOSBP at 0.05 lb. of toxicant per gallon to a height from ground-level of 4½ feet was 100 per cent effective in the case of aspen up to 3 inches d.b.h. (Day 1947). Within 10 days the cambium became discoloured and this was followed by leaf withering and death of the tree. On larger trees, the results were less satisfactory; there was incomplete kill in the 3- to 5-inch d.b.h. class, while many trees larger than this appeared to be uninjured. Trees killed by this method in 1945 showed no sign of sucker development within 2 years. Preliminary results indicated that suckering will not occur when a portion only of the aspen trees in a stand is treated.

This last point has important silvicultural implications. It may well be that there is greater merit and better control in killing a smaller percentage, say 50 to 60 per cent, of the aspen than the 90 to 100 per cent usually aimed at if there is much less resprouting. The following explanation of the phenomenon is suggested. Natural grafting between the roots of neighbouring aspen is known to occur. It seems that if the aerial parts of a tree are removed or poisoned, then the vigour of its root system is such that one of two things will happen. If the root system is connected by root grafts to others of living trees, then the still-living part will supply water and nutrients to adjacent aspen with which it has connections. On the other hand, if there are no such connections, or if adjacent root-connected aspen are also killed or removed, then root vigour is enough to result in profuse development of new sucker shoots. Thus, if this explanation is valid, as well as there being an optimum percentage, there will also be an optimum distribution of aspen to be eradicated for securing best results with a minimum of effort and expense.

Again in Michigan, good results were obtained with DNOSBP at 0.05 lb. per gallon in kerosene and with the methyl ester of 2,4-D at 1665 p.p.m. plus DNOSBP at 0.05 lb. per gallon (Day 1948).

Studies of the effect of consecutive annual basal treatments on aspen were begun in central Pennsylvania in 1950 (Worley *et al* 1954). Tests were carried out in dense aspen of fire origin, mostly less than 2 inches in basal diameter and from 10 to 15 feet tall, which were suppressing white and red pine planted immediately after a fire in 1946. Growing season treatments gave better results than dormant season applications, but even in 1954 suckering was still evident. Root excavations showed that although the aerial part of the tree may be killed by basal sprays, the roots may live to produce root suckers. Portions of roots extending up to 4.3 feet from the root collar could be killed, and yet suckers could be produced 7 feet further out along the root.

Experiments in northern Lower Michigan starting in February 1950 included a study on the effect of basal treatments on aspen through the growing season (Arend 1953). Treatments were given as sprays of "Esteron 44", "Esteron

Ten Ten", "Esteron 245" and "Esteron Brush Killer" mixed with grade 3 diesel oil. Concentrations of 2 per cent and 4 per cent by volume (i.e. 8 and 16 lbs. acid equivalent per 100 gallons) were applied to the basal part of individual trees to heights of 2 feet and 4 feet. The stems were drenched thoroughly to produce run-off completely around the tree.

These experiments indicated that all these ester formulations of 2,4-D and 2,4,5-T in diesel oil at concentrations of from 2 to 4 per cent by volume, in sufficient quantity, are capable of killing the aerial parts of aspen. As noted previously, the volume of herbicide applied per unit area is very important. Only slight differences in efficiency in respect of top-kill and regrowth were noted between the 2 per cent and 4 per cent concentrations when the stem was sprayed to a height of 4 feet. A 2 per cent concentration applied to 4 feet gave consistently better results than a 4 per cent concentration applied to 2 feet of stem.

Another point well shown by the experiments (Arend 1953) is that the season at which a treatment is applied has a marked influence on the length of time required to reveal the final results. Scrub aspen basal-sprayed with from 2 per cent to 4 per cent mixtures by volume of 2,4-D and/or 2,4,5-T esters in diesel oil during the dormant season usually show dead tops by the end of the first growing season after treatment. Trees treated during the dormant season usually flush in spring, but the foliage becomes yellow shortly after full leaf development. Treatments given during the early growing season begin to produce visible effects within about 10 days. Aspen treated in late July or August will probably not show effects until the following growing season. During the late growing season, and in the autumn and winter, when larger volumes of herbicidal formulation are required, aspen is generally more resistant to basal sprays than at other times of the year when smaller volumes will produce equal or superior results. The esters of 2,4,5-T appear to be rather more effective than those of 2,4-D.

The experiments show further that scrub aspen may be killed without subsequent sprouting and suckering for at least 3 years in northern Lower Michigan by basal sprays applied during the summer months of late June, July, and August. Further, it is concluded that the season of treatment has a considerable effect on the concentration and volume of spray required for effective top-kill and restriction of subsequent sprouting (Arend 1953).

A similar experiment, also in Lower Michigan, was aimed at the removal of aspen and other broadleaved species suppressing planted white and red pines. Basal spraying to 4 feet with 2 per cent "Esteron 44", 2 per cent "Esteron 245" and 2 per cent "Esteron Brush Killer" all in oil each gave first-season kills of aspen of 100 per cent with both spring and summer treatments (Anon. 1950b).

Basal spraying of aspen to 2 feet during the period from full leaf development to the end of the growing season has been successful in killing aspen, no sign of suckering occurring within 4 years after treatment (Anon. 1953). This control was obtained in the Lake States by a formulation of 12 lbs. of 2,4,5-T ester (4 lbs. acid equivalent per gallon) per 100 gallons of diesel oil (Anon. 1952). This formulation is recommended as a general year-round mixture (Anon. 1953; Arend 1953).

It is reported (Worley *et al* 1954) that at extremely high concentrations (up to 400 lbs. per 100 gallons of oil), 2,4,5-T is not so effective as at 16 to 40 lbs. per 100 gallons of oil. Presumably, the immediately affected tissues are killed so rapidly by very high concentrations that translocation is inhibited, and total damage limited.

Basal treatments were carried out at Petawawa Forest Experiment Station, Ontario, using formulations of "Esteron 245" and "Esteron Brush Killer" in spring (April 1952) and autumn (August 1951) applications to 8 species, including aspen, native to the region (Atkins 1956b). Mature trees of from 11 to 15 inches d.b.h. were treated with formulations containing one pint of herbicide to 3 gallons of diesel oil, i.e. about 4 per cent herbicide by volume. "Esteron Brush Killer" in both spring and autumn applications gave 100 per cent kill. Severe damage was reported for the autumn "Esteron 245" treatment, while the spring treatment was less effective, some trees being unharmed. All aspen saplings succumbed to all four treatments.

(3) *Poison wound treatment*

A number of methods, involving notches, holes, slits under bark, and chemical frills have been used on aspen with generally good results. This type of treatment is usually preferred in the case of large-sized trees.

Ammonium sulphamate (ammate) has been particularly effective. Applied in holes bored into the stem, ammonium sulphamate has given good results in summer treatments in the Lake States (Day 1948). The sodium salt of 2,4-D inserted in slits under the bark was equally effective.

In the Lesser Slave Lake area of northern Alberta, competing aspen were successfully killed by treating shallow notches, spaced from 6 to 8 inches apart around each stem just above the root collar, with ammonium sulphamate crystals (Quaite 1953). The aspen ranged in d.b.h. from 5 to 17 inches; crystals were applied at the end of May, and (to other trees) in the middle of August. Within a few days after treatment, some foliage of most of the trees turned yellow and shrivelled. Although the crystals were absorbed quickly, usually within 24 hours, the final effect could not be determined until at least a year had elapsed. Some trees, apparently dead within a few weeks after treatment, bore green branches a year later, while a few trees were definitely dead one year after treatment, although apparently healthy during the first summer. Applications of 2 or 3 teaspoons of crystals per notch was 100 per cent effective in killing aspen whether applied in spring or late summer. At one teaspoon per notch the spring and late summer treatments gave kills of 50 per cent and 100 per cent respectively. The heavier treatments killed or greatly weakened many adjacent untreated aspen, but the lightest treatment had little effect in this respect. There was no suckering from large trees killed by this method. It should be noted that only a few of the aspen in the stand were so treated, and, as has been suggested previously, this may reduce suckering by treated trees.

Aspen suppressing planted white and red pines in Lower Michigan were treated with ammate crystals inserted in notches cut in the bases of stems larger than 5 inches in basal diameter (Anon. 1950b). Total kill of aspen resulted, but in the case of a spring application, 12 to 40 red pines per acre in 2 different plantations died in the vicinity of treated aspen. Nothing is said of any subsequent aspen suckering.

Again in Lower Michigan, chemical frill-girdling using 1 per cent by volume of 2,4,5-T in diesel oil has been suggested for the control of aspen and other hardwoods (Anon. 1952). The closer a frill girdle is to the root collar the less is the regrowth for most hardwood species, and the method is most easily used on trees of more than 4 inches d.b.h. In one experiment (Anon. 1952), only one-third of stems treated between July and October sprouted within 3 years, but half of the trees treated between December and May produced sprouts.

Good control at all seasons has been obtained by 2,4,5-T ester, at 4 lbs. acid equivalent per hundred gallons of oil (Rudolf and Watt 1956) and this formulation has been found superior to ammonium sulphamate at from $\frac{3}{4}$ to 1 lb. per gallon of water. The methyl ester of 2,4-D at 1665 p.p.m. in kerosene plus DNOSBP at 0.05 lb. per gallon applied in holes bored into the stem gave poor results (Day 1950) as did applications of 2,4-D methyl ester at 3000 p.p.m. in kerosene similarly used. A concentration of 1665 p.p.m. of the methyl ester of 2,4-D, without the addition of DNOSBP, gave results rather better than either of the more concentrated and fortified formulations.

(4) *Cut stump treatment*

Treatments in this category have not been as successful as either the basal or poison wound methods and, because of the cost of cutting, this method has been tried less frequently than the other common methods.

In mixedwood stands (aspen and white spruce) of northern Alberta all the aspen within a given radius of individual spruce were cut and 1 tablespoon of amate crystals for each 3 inches of stump diameter was sprinkled on the sapwood region of stumps 3 inches or more in diameter. Stumps of smaller diameter than this were cut to leave a V-shaped cut into each of which was poured 1 tablespoon of crystals (Quaite 1953). The results, after one year, showed that sprouting and suckering were prevented in areas where the average stump diameter exceeded 1 inch. Large, untreated aspen up to 40 feet from treated stumps were often killed although small aspen within a few feet of the stumps remained alive. Sprouting was prevalent in areas where the average stump diameter did not exceed 1 inch, and in these areas few adjacent untreated aspen were killed. This may indicate that, in this area, root grafting between adjacent aspen begins about the time basal diameters reach 1 inch, although this presumably will vary according to the density of aspen.

In northern Alberta, the cut stump method is generally not as efficient as poison wound methods in reducing or preventing subsequent regrowth (Quaite 1953).

One of a number of experiments carried out at Petawawa Forest Experiment Station, Ontario, was aimed at inhibiting the development of root suckers from stumps of cut aspen. "Esteron 245" and "Esteron Brush Killer" were used in concentrations of 1 pint and $1\frac{1}{2}$ pints respectively to 3 gallons of diesel oil (Atkins 1956a). In the main treatment the tops and sides of the stump were sprayed thoroughly; minor treatments carried out were spraying of tops only, and use of water as the diluent instead of oil. None of these treatments was successful but this may have been due to a delay of some weeks between cutting and treatment.

(b) *Problems of regrowth*

Aspen has a strong faculty for producing suckers from roots, and this makes lasting control of aspen considerably more difficult than it would be otherwise. Cut or girdled aspen trees produce numerous sprouts and suckers within a radius of 100 feet of the parent tree (Arend 1953). However, the vigour of root suckering declines with age, and shows a seasonal variation in that root systems of trees cut in the summer develop fewer suckers than those of trees cut at other times of the year.

Ground foliage sprays are effective against young aspen suckers, but are otherwise not recommended. Aerial foliage sprays are ineffective and cut-stump treatments, while more promising than foliage spray methods, are too costly for general use.

Young aspen are probably best controlled by basal applications during the growing season after the time of full leaf development. Older trees succumb most readily to poison wound treatments of ammate or 2,4,5-T esters applied in the late summer or early autumn. In both instances, the amount of suckering is probably reduced by leaving untreated a moderate percentage of the aspen present.

(*c*) *Factors specially important*

The following factors appear to have particular importance in herbicidal treatment of aspen:

(1) Age of the tree
(2) Method used
(3) Proportion of trees in a stand treated
(4) Season of application
(5) Type of herbicide used.

3. Birch (*Betula papyrifera* Marsh.)

(*a*) *Control measures used and success achieved.*

(1) *Foliage spray, ground*

There are insufficient data from which to draw any firm conclusions, although it seems probable that good top-kill can be obtained by foliage sprays. Subsequent sprouting may be troublesome but it is not known to what extent.

In northern Sweden, the foliage of sprouts from *Betula pubescens* have been killed by application of aqueous solutions of either 0.3 per cent to 0.4 per cent methoxone or 0.2 per cent to 0.4 per cent 2,4-D between the time of full leaf expansion and August 1 (Fransson 1953). *Betula pubescens* and *B. papyrifera* are similar in many respects and, although it does not necessarily follow, it is likely that treatments effective against one would be effective also against the other.

Single applications of 2,4-D ester in water to birch scrub in the Lake States at 2000 to 3000 p.p.m. have not given complete top-kill: fair control only at any time during the growing season is reported (Rudolf and Watt 1956). No greater success has attended the use of aqueous formulations of 2,4,5-T (ester) at 1000 to 2000 p.p.m.; in fact these were effective only up to the middle of the growing season.

Foliage spray, aerial

Preliminary results appear encouraging in the treatment of birch in Minnesota. Most large trees and brush in treated areas have been defoliated by applications of as little as 1 lb. of chlorophenoxyacetic acid in 2 gallons of formulation per acre (Roe 1955). In southern Ontario, birch has been found to be very susceptible to 2,4,5-T preparations at the rate of 2 lbs. of herbicide to 2 gallons of fuel oil per acre (Larsson 1957). Good control is reported from 2,4-D ester at 1 lb. per acre in water emulsion and from the corresponding 2,4,5-T formulation applied as aerial sprays during the middle of the growing season (Rudolf and Watt 1956).

(2) *Basal treatment*

At Petawawa Forest Experiment Station, Ontario, April and August applications of "Esteron 245" and "Esteron Brush Killer", at 1 pint per 3 gallons of diesel oil, gave poor results (Atkins 1956b); damage to the birch ranged from none to severe in both April treatments, while the August treatments were ineffective.

(3) *Poison **wound treatment***

A successful method of killing trees (not sprouts) of *Betula pubescens* has been developed in northern Sweden (Fransson 1953). Pockets are cut into the sapwood of the trunk, and 2,4-D in powder or liquid form is injected. An average minimum dose is 1.5 grams for trees of 4 inches in diameter. Treated trees die in about 2 years, after which they may be felled, if desired, without the appearance of any new shoots.

b) *Problems of regrowth*

The reaction of birch to herbicidal treatments is difficult to assess because of the limited amount of information available. However, there is likely to be more difficulty in preventing sprout development after treatment than in obtaining a good top-kill, but in birch this problem should be no greater, and probably will be much less, than in aspen.

c) *Factors specially important*

Too little is known of the pertinent factors to hazard an opinion here.

4. Hazel. (*Corylus cornuta* Marsh.)

(*a*) *Control measures used and success achieved.*

(1) *Foliage spray, ground*

Although not all attempts to control hazel have had the effect desired, enough successes have been achieved to show that good control can be obtained at low cost.

In white birch-aspen-pine type forest, perpetuation of pine is difficult: the low survival rate of pine regeneration is often caused, at least in part, by competition from hazel. At the Petawawa Forest Experiment Station, herbicidal treatment was carried out on an area where hazel formed a low understorey beneath white and red pine with an admixture of white birch and trembling aspen (Atkins 1956a). Spraying was carried out in August using 4 herbicides each at 3 concentrations. Observations over a 2-year period showed that 2,4-D amine, "Esteron 44", "Esteron 245" and "Esteron Brush Killer" were all about equally effective in killing hazel. Complete mortality was obtained by all formulations, although concentrations of 1000 p.p.m. acted more slowly than higher concentrations. There were no differences between the 4 herbicides in their effects on the small white pine regeneration present, but while concentrations of 1000 p.p.m. caused little or no damage, concentrations of 5000 p.p.m. were definitely harmful. It was concluded that good control could be obtained with 2,4-D esters at 2000 p.p.m. in water.

Sprouting occurred within 2 years on practically all hazel which had been given such treatment, but not to such an extent as to interfere with pine reproduction for at least 5 years (Day 1950).

In the northern Lake States, tests were carried out over an area of 7 acres in the spring of 1947 with 2 chemicals each at 3 concentrations. Duplicate tests at each concentration were made in May and June in brush which had a density of 25,650 stems (of which 83 per cent were hazel) per acre (Zehngraff and von Bargen 1949).

A second test, in brush of 18,320 stems (of which 88 per cent were hazel) density per acre, was divided into 2 phases; (a) the release of planted trees by the application of small amounts of chemical, using 2 chemicals at 3 concentrations; (b) release of natural white pine reproduction using 2 chemicals at 3 concentrations. There were 2 replications and 2 seasons of application, viz. 1.9. 1947 and 1.7. 1948.

A third test covered the same conditions as the second part of the second test.

The treated areas were examined later when it was found that all brush had been killed even by the low levels involving 2,4-D (83 per cent) at 2½ lbs. per acre and ammate at 50 lbs. per acre.

The results provided the basis for the following tentative guide to the amounts of herbicide required to kill 1,000 stems of hazel brush:

Herbicide	Amount in 2 gallons of water
2,4-D (83.5 per cent acid equivalent) ammonium salt	0.5 oz.
2,4,5-T (43 per cent equivalent) isopropyl ester	0.1 pint
"Esteron 44" (44 per cent acid equivalent)	0.1 pint
Ammate	1.0 lb.

Of these, ammate kills hazel much the quickest, but, except at such exceedingly high levels of concentration as 200 lbs. per acre, it results in much more resprouting than do 2,4-D preparations. The difference in subsequent sprouting of top-killed hazel between "normal" and "high" concentrations of 2,4-D was insignificant. Furthermore, 2,4-D is considerably safer than ammate in releasing conifers from suppression especially after late summer hardening-off, for conifers are virtually unaffected by 2,4-D in the quantities used.

The droplet size giving the best results was that which gave a spray intermediate between heavy and fine mist. Too fine a spray has a tendency to drift and evaporate, while if the spray is too coarse there is excessive loss from dripping.

The studies show that hazel brush can be eliminated successfully and at low cost by herbicides. Density of brush was found to be important in determining the most effective amounts of chemical and diluent per acre[4]. The season of application was found also to be important especially in regard to the amount of damage to desirable species in release operations.

In Upper Michigan it was found that hazel, among other species, was hypersensitive or sensitive to foliage sprays of 2,4-D and to ammate applied during the middle of the growing season (Day 1950). There is other evidence that 2,4-D is very effective in controlling hazel (Day 1947; Zehngraff and von Bargen 1949; Stoeckeler and Heinselman 1950; Pike 1956).

A dense underbrush of hazel presents a problem in the regeneration of white spruce both before and after logging in the white spruce-aspen stands of Manitoba and Saskatchewan. Studies were undertaken (Pike 1956) to determine the usefulness of herbicidal treatments. In an area where the hazel underbrush had a density of 40,000 stems per acre, tests were carried out with aqueous solutions of ammate, 2,4-D and 2,4,5-T in various concentrations and volumes. Most of the treatments resulted in a big decrease in the number of old hazel stems within a year of treatment, but many stems, apparently killed during the first year, gave signs of life during the second year, and succumbed finally in the third year after treatment. New hazel shoots appeared in quantity, presumably from established root systems, during the second year after treatment and increased in numbers steadily thereafter. There was a pronounced increase in numbers of individuals of other minor tree species which reached

[4] See page 10, comments on "high" and "low" volume applications.

a maximum 3 years after treatment and declined subsequently in the face of increasing competition from the hazel which was re-establishing itself.

These tests showed 2,4-D to be the most effective and economical of the herbicides used. Also, the least sprouting had occurred 4 years after treatment not only with 2,4-D but with the most dilute formulation of this herbicide, viz. 750 p.p.m. It is suggested that volume of formulation used rather than strength is the most important factor in securing root-kill.

Hazel is hypersensitive to the methyl ester of 2,4-D at 3000 p.p.m. in water, hypersensitive or sensitive to the ethyl ester of 2,4-D at 1250 p.p.m. in water and to the sodium salt of 2,4-D at 1000 p.p.m. with sodium chlorate in water, and sensitive to methyl ester 2,4-D at 1665 p.p.m. in kerosene with or without the addition of 0.025 lb. of DNOSBP per gallon (Day 1947). DNOSBP used alone had little effect, while sodium salt 2,4-D at 1000 p.p.m. in water produced variable effects.

Ammate seems to have definite possibilities in the control of hazel, particularly in regard to minimizing the amount of regrowth. The effect seems to be more lasting than that of 2,4-D in respect of regrowth (Day 1947; Pike 1956), and in some instances the use of ammate during the early part of the growing season has completely inhibited regrowth (Day 1948). On the other hand, after spraying with hormone herbicides for 3 seasons in a row, hazel in northern Minnesota was still sprouting (Anon. 1953), although a reduction in density was achieved.

Foliage spray, aerial

Little information is available, but it is likely that aerial spraying would be effective in view of the success of ground foliage spray application. A single spraying may give reduced competition from hazel for as long as 8 years (Anon. 1955).

(2) *Basal treatment*

Fair control only by dormant season basal treatments has been obtained using 2,4-D ester at 4000 p.p.m. in water (Rudolf and Watt 1956).

Basal spraying during the first week of August in Manitoba using 2,4,5-T at 20 lbs. acid equivalent per 100 gallons of diesel oil cost $98.70 per acre (Pike 1956). Spraying was carried out after growth had ceased on underbrush having a total density of 122,000 stems per acre, of which 101,000 were hazel. All underbrush stems were wetted from ground-level to a height of 18 inches, and although all foliage died within a few days of treatment, not enough time has elapsed to be able to evaluate the long-term effect.

The effectiveness of foliage spraying in hazel control makes it unlikely that there is any advantage in persisting with basal methods, which are likely to be expensive.

(3) *Poison wound treatment*

Such treatment is unpractical because of the smallness of hazel stems, and unnecessary in view of the ease of control obtainable by other means, especially foliage sprays.

(4) *Cut stump treatment*

It is reported that hazel is hypersensitive to methyl ester 2,4-D at 4500 p.p.m. in kerosene in cut-stump treatments (Day 1947), but again, because of the effectiveness of foliage sprays against hazel, there has been little need of cut stump methods.

(*b*) *Problems of regrowth*

Hazel sprouts prolifically after cutting, but certain treatments mentioned above have been successful in curbing or even eliminating this characteristic. Ammate seems to be particularly effective in this respect, especially when applied rather early in the growing season, but 2,4-D formulations too have shown promise.

The problem of regrowth of hazel is not nearly so great as that of aspen, especially since foliage treatments are easy and effective to apply.

(*c*) *Factors specially important*

Apart from the general considerations (enunciated in Part I) in respect to season of treatment, and the amounts of herbicide and diluent required to give satisfactory results in brush of various densities, the only point that need be mentioned here is the promise shown by ammate in the inhibition of regrowth.

5. Mountain Maple (*Acer spicatum* Lam.)

(*a*) *Control measures used and success achieved.*

(1) *Foliage spray, ground*

Mountain maple is relatively resistant to herbicidal treatment.

The species has been found to be generally tolerant to several 2,4-D formulations (including ethyl and methyl esters and unspecified salts of the parent acid) at from 1000 to 4500 p.p.m. in water, kerosene and fuel oil (Day 1947, 1948).

Tests at Basswood Lake, Minnesota, in 1949 involving "Esteron 44", "Esteron 245" and "Esteron Brush Killer" at 1500 p.p.m., 3000 p.p.m. and 3000 p.p.m., respectively, as foliage sprays during early, mid and late summer all gave unsatisfactory control. The stems killed averaged only 16.5 per cent of those treated. The maximum kill (36 per cent) was obtained by "Esteron 245" at 3000 p.p.m. in early summer. Early and mid summer treatments were a little more effective than those applied in late summer except in the case of "Esteron 44" which showed the reverse trend (Hansen and Ahlgren 1950).

Severe wilting of mountain maple foliage 3 weeks after treatment with 2,4,5-T has been observed (Baskerville 1956) but subsequent effects have yet to be determined.

Good control is reported with mid-season application of 2,4,5-TP ester spray at 3 lbs. acid equivalent per 100 gallons of water (Rudolf and Watt 1956).

Although it is reasonable to suppose that more effective treatments can be devised, it is probable that the applicability of such treatments will be limited to well-defined conditions. The 2,4,5-trichlorophenoxypropionic acid preparations seem to be among the most promising of the herbicides.

Foliage spray, aerial

Aerial spraying of mountain maple has been carried out with both 2,4,5-T and "Silvex" at $\frac{1}{4}$ gallon of herbicide (1 lb. acid equivalent) in 1 gallon of diesel oil and $3\frac{3}{4}$ gallons of water per acre (Morais 1956). The preliminary results indicate that "Silvex" has produced very much more defoliation than has 2,4,5-T.

(2) *Basal treatment*

A few basal treatments have been successful. A formulation of 2,4,5-T ester at 2 per cent concentration in oil has given good control when applied in the dormant season: 2,4,5-T ester at 4 per cent concentration in oil has given good results when applied during the early part of the growing season (Rudolf and Watt 1956). However, in another instance, treatment of mountain maple with basal sprays of 2,4,5-T in diesel oil at concentrations of 2 per cent and 4 per cent by volume were found to be more effective when applied in autumn than in the spring (Anon. 1953). Subsequent sprouting was prolific in all cases.

(3) *Poison wound treatment*

There do not appear to be any reports of this method being used; as in the case of hazel, stems of mountain maple are generally too small to make poison wound treatment practical.

(4) *Cut stump treatment*

At 3000 p.p.m. in kerosene, 2,4,5-T ester was applied to stumps of mountain maple at intervals during the summer and autumn (Drinkwater 1953). The stumps ranged in diameter from 2 to 4 inches and the herbicides were applied immediately after cutting to the cut surface and to the stump bark. Of 40 stumps so treated, 34 were apparently dead one year later. Ammate applied as crystals (1 to 2 tablespoons per stump) or as an aqueous spray (2 lbs. per gallon) was very much less effective.

Combination esters of 2,4-D and 2,4,5-T at 8000 p.p.m. in oil have given good control during the mid growing season (Rudolf and Watt 1956).

(*b*) *Problems of regrowth*

Mountain maple regrowth is likely to prove a problem, although perhaps not such a major one as aspen regrowth. Present experience indicates that sprouting is to be expected after foliage and basal treatments, but cut stump treatments seem to be capable of killing sapling stumps.

(*c*) *Factors specially important*

As with other herbicide-tolerant species, satisfactory results can be obtained only if as many as possible of the factors influencing the action of the herbicide are operating in favour of the herbicide. This means that when these factors are variable, there may be limited periods only when particular treatments are effective. Too little is known to permit evaluation of the relative importance of the various factors, but the type of herbicide and season of application appear to be major factors involved. Formulations of 2,4,5-T or 2,4,5-TP applied as foliage sprays during the middle part of the growing season and 2,4,5-T formulations in oil in cut-stump treatments seem to offer the greatest degree of control at present.

6. Suggestions for Further Research

The following points are put forward as being worthy of further study:

(*a*) The amount of suckering by aspen seems to depend to a large degree on what proportion of the aspen stems in a stand is treated. It would be useful to determine the most satisfactory ratio of treated to untreated aspen to give maximum reduction of aspen. This ratio would probably vary with aspen density and distribution.

(*b*) A study of the reasons for such variable response by aspen to foliage sprays could provide information applicable not only to aspen but also to general practice. Aspen would be a good experimental species because of its sensitivity and variability in response to various factors influencing herbicidal treatments.

(*c*) A specific study of the results of delay between cutting and cut-stump treatment on the success of the treatment would be worthwhile.

(*d*) The influence of season of application on the effectiveness of herbicidal treatments is probably derived from a combination of, or interaction between, several factors such as air temperature, soil temperature, soil moisture, and stage of development of treated tissues. There would be value in determining the factors involved and their relative importance.

(*e*) Some measure is needed for the evaluation of the effect of herbicidal treatments. Where such treatments are aimed at releasing conifers from suppressing hardwoods, then the leader growth response may be a convenient measure: however, any response may be delayed and it would be desirable to have an independent measure which could be applied generally.

(*f*) The possibility of using MCPB, 2,4-DB or other herbicides in thinning stands of balsam fir, or in increasing the proportion of spruce in spruce-fir stands might be investigated.

(*g*) Much more needs to be known of the response of birch and mountain maple to herbicides.

(*h*) Studies of the effect of ammate applied to hardwoods on intermixed conifers, especially pine, would be worthwhile.

(*i*) Formulations of propionic compounds may well become of major importance after more field tests have been carried out.

(*j*) Ecological relationships involving the weed species must be more fully determined before herbicidal or any other type of treatment can be used to the best advantage.

(*k*) The optimum droplet size of foliage sprays is likely to vary with particular conditions, and especially with type of leaf surface and evaporation rate. These conditions should be investigated.

(*l*) Absorption of herbicides used as foliage sprays may be greatest during darkness and is most rapid during the first 4 hours after application. The advantages of spraying late in the day, as near to sunset as practicable, should be determined.

SUMMARY AND CONCLUSIONS

This report deals with herbicides in relation to the control of a number of hardwood species of particular importance in the aspen-birch-spruce-fir forest of boreal Ontario.

The information available is rather scanty. Reports on herbicidal operations often lack those details on which valid comparisons can be made. Many factors affecting herbicidal treatments have been shown to be of importance or of potential importance, and those reporting on herbicidal operations are urged to record a full account of existing conditions. For example, to state that treatment of maple with 2,4-D foliage spray at 100 gallons per acre was 75 per cent successful may be adequate for the particular purpose in hand. But the report would be much more valuable if it gave also the age, size, density and species of maple, the particular 2,4-D preparation used, the concentration of herbicide in the formulation, season of application, weather conditions before, during and after the time of application, droplet size, soil moisture conditions, criteria used in assessing success, etc.

There is considerable risk in attempting to draw conclusions from incomplete data, and, to a large extent, the conclusions reached here are based precariously on insecure foundations. This should be borne in mind, and any recommendations should be accepted as promising leads rather than as panaceas.

Alder is one of the easier species in which to obtain a good top-kill, both in mature stems and young sprout growth. Foliage sprays using a wide variety of chlorophenoxyacetic acid formulations have been successful when applied during the middle of the growing season. Basal treatment using 2,4-D and 2,4,5-T esters, and cut stump treatment using either chlorophenoxyacetic acid esters or ammate, have also given satisfactory results.

Aspen is much more difficult than alder to control with herbicides. Not only is top-kill more difficult to effect, but aspen root systems produce suckers in profusion. The only consistent success achieved has been in treatment of young aspen suckers by foliage sprays. Older aspen, after poisoning, may sprout less if adjacent root-graft-connected aspen are left unpoisoned, since it seems that a root system deprived of its aerial parts may supply sustenance, *via* root grafts, to adjacent unharmed trees, whereas if there are no such root-graft connections with living trees, sprouts can be expected in large quantities. The best method to use depends on the stage of development of the aspen to be treated: ground foliage sprays are effective on young aspen suckers, but sapling aspen are more susceptible to basal treatment, while larger trees succumb most readily to poison wound methods.

Less study has been made of control of birch than of aspen, but it appears that a good top-kill is not difficult to obtain by use of chlorophenoxyacetic acid foliage sprays. To what extent regrowth would occur is largely unknown. Poison wound treatment is, at present, the best means of dealing with large birch trees.

Hazel, like alder, is relatively easy to control. Good results have been obtained with 2,4-D foliage sprays applied during the middle of the growing season. So successful have been treatments of this type that other methods have been little explored.

Mountain maple has shown resistance to herbicides. Foliage sprays generally have been ineffective, but 2,4,5-TP ester may give better results than other chlorophenoxyacetic acid preparations used earlier. Basal treatment seems to hold some promise but more information is needed before specific herbicidal practices can be recommended. Sprouting is usual after foliage or basal treatment but cut-stump application of 2,4,5-T ester in kerosene has almost completely inhibited sprouting at least in one instance.

Thus alder and hazel are easy, and aspen, birch and mountain maple more difficult to control by means of herbicides.

APPENDIX 1

Herbicidal Substances

Agroxone (MCP)
ACS Low Volatile Brush Killer (Butoxy ethoxy propyl esters of 2,4-D and 2,4,5-T)
Alanap (N-1 naphthyl phthalamic acid)
Alchem H-176 Brush Control (Polypropoxy butyl esters of 2,4-D and 2,4,5-T)
Ammate (Ammonium sulphamate (80%))
Ammate X (Ammonium sulphamate (95%))
Ammonium nitrate
Ammonium sulphamate (Ammate)
Ammonium sulphamide
Ammonium thiocyanate
Ammonium trichloroacetate (69%)
ATA (Ammonium trichloroacetate)
Atlacide Chlorate (Sodium chlorate (59.2%) + fire retardant)
Barium chloride
Black Leaf 2,4,5-T Brush Killer (Propylene glycol butyl ether esters)
Bramco Brush-Kil Low Volatile 64 (Iso-octyl esters of 2,4-D and 2,4,5-T)
Bramco Brush-Kil Low Volatile 128 (Iso-octyl esters of 2,4-D and 2,4,5-T)
Brush Bane (Mixed esters of 2,4-D and 2,4,5-T)
Brush Bane 128 (Mixed esters of 2,4-D and 2,4,5-T)
Brush Bane Low Volatile (Esters of 2,4-D and 2,4,5-T)
Brush Bane Low Volatile 128 (Esters of 2,4-D and 2,4,5-T)
Brush-Cop (Butyl ester of 2,4-D and isopropyl ester of 2,4,5-T)
Brush Killer 50-50 (Butyl esters of 2,4-D and 2,4,5-T)
Brush Killer TX (Iso-octyl ester of 2,4,5-T)
Brush Killer X (Iso-octyl esters of 2,4-D and 2,4,5-T)
4C (4-chlorophenoxyacetic acid)
Calcium chlorate
Carbolic acid
Chipman Brush Killer (Iso-octyl ester of 2,4-D)
Chipman 2,4,5-T (Iso-octyl ester of 2,4,5-T)
4-chlorophenoxyacetic acid
3-(p-chlorophenyl)-1, 1-dimethylurea (CMU)
Chloropicrin (CP)
Chloroxone (MCP)
CIPC (Isopropyl N-(3-chlorophenyl) carbamate)
CMU (3-(p-chlorophenyl)-1, 1-dimethylurea)
Co-op Brush Killer (Mixed esters of 2,4-D and 2,4,5-T)
Copper chloride
Copper sulphate
CP (Chloropicrin)
CPA (Chlorophenoxyacetic acid)
Crag Herbicide 1 (Sodium 2,4-dichlorophenoxy ethyl sulphate)
Creosote
Cresylic acid
2,4-D (2,4,-dichlorophenoxyacetic acid)
Dalapon (2,2-dichloropropionic acid sodium salt)
2.4-DB (2,4-dichlorophenoxybutyric acid)
DCMU (3-(3,4-dichlorophenyl)-1, 1-dimethylurea)
2,4-DES (2,4-dichlorophenoxy ethyl sulphate)
2,4-dichlorobutoxyacetic acid (2,4-DB)

2,4-dichlorophenoxyacetic acid (2,4-D)
3-(3,4-dichlorophenyl)-1, 1-dimethylurea (DCMU)
2,2-dichloropropionic acid
Diesel oil
2,4-Dinitro-6 sec. butyl phenol (DINOSEB)
4,6-Dinitro ortho secondary butyl phenol (DNOSP, DNOSBP)
3,5-Dinitro-o-cresol (DNC)
Dinitrophenol (DNP)
DINOSEB (2,4-dinitro-6-sec. butyl phenol)
DNC (3,5-dinitro-o-cresol)
DNOSBP (2-sec-butyl-4,6-dinitrophenol)
DNOSP (4,6-dinitro ortho sec. butyl phenol)
DNP (Dinitrophenol)
Dow Formula 40 (Alkanolamine of 2,4-D)
Dowpon (2,2-dichloropropionic acid)
Endothal (3,6-endoxohexahydrophthallic acid)
3,6-endoxohexahydrophthallic acid (Endothal)
Erbon (2-(2,4,5-trichlorophenoxy) ethyl, 2,2-dichloropropionate)
Erco Low Volatile Brush Kill (Mixed esters of 2,4-D and 2,4,5-T)
Erocide (Sodium chlorate + fire retardant)
Esteron 44 (2,4-D isopropyl ester)
Esteron 64 (Mixed esters of 2,4-D)
Esteron 76E (2,4-D isopropyl and butyl esters)
Esteron 99 (2,4-D propylene glycol butyl ether esters)
Esteron Ten Ten (2,4-D propylene glycol butyl ether esters)
Esteron 245 (2,4,5-T propylene glycol butyl ether esters)
Esteron Brush Killer (2,4-D and 2,4,5-T propylene glycol butyl ether esters)
Ethylene oxide
Formaldehyde
Formula 40 (Dow Formula 40)
Green Cross Commercial Brush Killer 96 (2,4-D butyl ester and 2,4,5-T amyl ester)
IAA (3-indole-acetic acid)
3-Indole-acetic acid (IAA)
IPC (Isopropyl-N-phenylcarbamate)
Isopropyl-N-(3-chlorophenyl) carbamate (CIPC)
Isopropyl-N-phenylcarbamate (IPC)
Kansel (Butyl ether esters of 2,4,5-T)
Karmex W (CMU)
Kerosene
Kuron (2(2,4,5-trichlorophenoxy) propionic acid, propylene glycol butyl ether esters)
Later's Brush Killer (Isopropyl esters of 2,4-D and 2,4,5-T)
MCP (2-Methyl-4-chlorophenoxyacetic acid)
MCPA (2-Methyl-4-chlorophenoxyacetic acid)
MCPB (y(4-chloro-2-methylphenoxy) butyric acid)
Methoxone (MCP)
2-Methyl-4-chlorophenoxyacetic acid (MCP)
Monsanto 2,4-D—2,4,5-T Brush Killer (Butyl esters of 2,4-D and 2,4,5-T)
Monsanto 2,4-D—2,4,5-T Low Volatile Brush Killer (Butoxy ethoxy propyl esters of 2,4-D and 2,4,5-T)
Monsanto 2,4,5-T Brush Killer (Butyl ester of 2,4,5-T)
Monsanto 2,4,5-T Low Volatile Brush Killer (2,4,5-T butoxy ethoxy propyl ester)

Monuron (CMU)
Niagara Brush and Poison Ivy Killer (Butoxy ethanol esters of 2,4-D and 2,4,5-T)
Niagara Brush Killer (Butoxy ethanol esters of 2,4-D and 2,4,5-T)
Niagara Commercial Brush Killer (Butoxy ethanol esters of 2,4-D and 2,4,5-T)
Niagara 2,4,5-T (Butoxy ethanol ester of 2,4,5-T)
N-1-naphthyl phthalamic acid (Alanap)
Orchard Brand Low volatile Brush Killer (Propylene glycol butyl ether esters of 2,4-D and 2,4,5-T)
Ortho Brush Killer (Tetrahydrofurfuryl ester of 2,4,5-T)
Ortho 245 Brush Killer (Isopropyl ester of 2,4,5-T)
PCP (Pentachlorophenol)
PDU (Phenyldimethylurea i.e. 3-(phenyl)-1, 1-dimethylurea)
Pentachlorophenol (PCP)
Petroleum oils
Phenyldimethylurea (PDU)
Phenylmercuric acetate (PMA)
Phenyl mercuric chloride (PMC)
Pioneer 128 Oil Aircraft Mix (Butyl ester of 2,4-D)
PMA (Phenyl mercuric acetate)
PMC (Phenyl mercuric chloride)
Potassium bichromate
Potassium chromate
Propylene-glycol-butyl-ether-ester (Kuron)
Radapon (2,2-dichloropropionic acid)
Radapon Liquid (2,2-dichloropropionic acid)
Reddon Brush Killer (Mixed esters of 2,4,5-T)
2-sec. butyl-4,6-dinitrophenol (syn. 4,6-dinitro ortho sec. butyl phenol)
SES (Sodium 2,4-dichlorophenoxy ethyl sulphate)
Shell Brush Kill 10 (Iso-octyl ester of 2,4,5-T)
Shell Brush Kill 10 LV112 (Iso-octyl ester of 2,4,5-T)
Shell Brush Kill 11 (Iso-octyl esters of 2,4-D and 2,4,5-T)
Shell Brush Kill 11 LV112 (Iso-octyl esters of 2,4-D and 2,4,5-T)
Shell Brush Kill D (Butyl esters of 2,4-D and 2,4,5-T)
Shell Brush Kill T (Butyl esters of 2,4-D and 2,4,5-T)
Silvex (2(2,4,5-trichlorophenoxy)propionic acid)
Sodium arsenite
Sodium chlorate
Sodium chloride
Sodium 2,4-dichlorophenoxy ethyl sulphate (SES or 2,4-DES)
Sodium fluoride
Sodium hydroxide
Sodium trichloroacetate (STA)
STA (Sodium trichloroacetate 70.6%)
Stauffer Isooctyl Esters 2-2-E (Iso-octyl esters of 2,4-D and 2,4,5-T)
Stauffer 245T Isooctyl Ester 4E (Iso-octyl ester of 2,4,5-T)
Sumanox (Mixed esters of 2,4-D and 2,4,5-T)
2,4.5-T (2,4,5-trichlorophenoxy acetic acid)
245T Isooctyl Ester 96 (Iso-octyl ester of 2,4,5-T)
TCA (Trichloroacetic acid)
TCB (Trichlorobenzoic acid)
Trichloroacetic acid (TCA)
Trichlorobenzoic acid (TCB)
2(2,4,5-trichlorophenoxy)ethyl 2,2-dichloropropionate

2(2,4,5-trichlorophenoxy) propionic acid (Silvex)
Weedanol Low Volatile Brush Killer (Butoxy ethoxy propyl esters of 2,4-D and 2,4,5-T)
Weedone Brush Killer 32 (Butoxy ethyl esters of 2,4-D and 2,4,5-T)
Weedone Brush Killer 64 (Butoxy ethanol esters of 2,4-D and 2,4,5-T)
Weedone Brush Killer 977 (Butoxy ethanol esters of 2,4-D and 2,4,5-T)
Weedone Brush Killer L-329 (Butoxy ethyl esters of 2,4-D and 2,4,5-T)
Weedone Brush Killer L-329-T (Butoxy ethyl ester of 2,4,5-T)
Weedone 2,4-D Weedkiller Plus 2,4,5-T (Butoxy ethanol esters of 2,4-D and 2,4,5-T)
Weedone Industrial Brush Killer (Butoxy ethyl esters of 2,4-D and 2,4,5-T)
Weedone 2,4,5-T (Butoxy ethyl ester of 2,4,5-T)
y(4-chloro-2-methylphenoxy) butyric acid (MCPB)
Zinc chloride

NOTE: All herbicides offered for sale as such in Canada must be registered each year. The 1957 list of registered herbicides (Frankton 1957) shows the brand name, registration number, registrant and guaranteed active ingredient content of each herbicide.

APPENDIX 2

(*a*) Producers of Herbicides[1]

Alchem.
Allied Chemical and Dye Corporation.
American Chemical Paint Company.
Allied Chemical Services.
American Cyanamid Company.
British-American Chemical Company.
Carbide Chemicals Company.
Chemagro Corporation.
Chipman Chemical Company Inc.
Diamond Alkali Company.
Diamond Black Leaf Company.
Dow Chemical Company.
DuPont Chemical Company.
E. I. du Pont de Nemours and Company Inc.
Electric Reduction Sales Company.
Interprovincial Co-operatives.
JD and D Company.
Later Chemicals.
Dr. Leo Lorrain Laboratories.
Monsanto Canada.
Monsanto Chemical Company.
Naugatuck Chemicals.
Niagara Brand Spray Company.
Nichols Chemical Company.
Ortho Agricultural Chemicals.
Pioneer Grain Company.
O. M. Scott and Sons Company.
Shell Oil Company of Canada.
Sherwin-Williams Company of Canada.
Standard Agricultural Chemicals Inc.
Standard Oil Company.
Stauffer Chemical Company.
Thompson-Hayward Chemical Company.
Woodbury Chemical Company.

(*b*) Producers of Dyes[1]

Ciba Company—"Oil Red CY" at 1 lb. per 160 gallons of formulation is a satisfactory oil-soluble dye of use in cut-stump treatments.

Du Pont —"Du Pont Wood Stain Scarlet Conc. NS" at 1 lb. per 100 gallons of formulation is a satisfactory water-soluble dye of use in poison wound treatments.

(*c*) Producers of Spraying Equipment[1]

Original Enderes Company.
The Engine Parts Mfg. Company.
Food Machinery and Chemical Corporation.
The Hardie Mfg. Company.

[1] These lists are presented for information purposes only and neither discriminate against producers and products not shown nor endorse producers and products shown.

Harison Chemical and Equipment Company.
Kupfer Products Inc.
Monarch Mfg. Works Inc.
Northwest Agricultural Aviation Corporation.
Sorenson Mfg. Company.
E and E Sprayer Company.
Spraying Systems Company.
Tryco Mfg. Co. Inc.
W. A. Westgate Company.

APPENDIX 3

Explanation of Certain Terms

(*a*) *Acid Equivalent*

To state that a hormone herbicide of the 2,4-D or 2,4,5-T type has an acid equivalent of 43 per cent is to infer that if the herbicide were used to make the appropriate acid, then the yield of acid would be 43 per cent of the herbicide used. The acid equivalent may be given in terms of percentage by weight or of weight by volume, e.g. 40 per cent 2,4,5-T acid equivalent by weight or 4 lbs. of 2,4-D acid equivalent per gallon.

The acid equivalent of a proprietary concentrate will be shown on the label. In other cases reference must be made to the molecular formulae: it is then a question of dividing the molecular weight of the herbicide by the molecular weight of the parent acid and multiplying by 100 to obtain the acid equivalent as a percentage by weight.

e.g. molecular weight of 2,4-D acid = 221.04
molecular weight of 2,4-D butyl ester = 277.00
∴ acid equivalent of 2,4-D butyl ester $= \frac{221.04}{277.00} \times 100 = 80\%$

(*b*) *Concentration*

The concentration of a formulation of hormone herbicide may be expressed in different ways, thus:

(i) *p.p.m.* This is the ratio of the weight of the acid equivalent of the herbicide to the combined weight of the diluent and acid expressed as a proportion, e.g. 3000 p.p.m. of 2,4-D means, strictly, that of an aqueous formulation of 1,000,000 parts, 3,000 parts are 2,4-D and 997,000 parts are water. This is usually simplified to the number of parts by weight or volume of a herbicide in 1,000,000 parts of diluent, e.g. 3000 p.p.m. of a herbicide usually is taken to mean that the formulation is prepared from 3,000 parts of herbicide *and* 1,000,000 parts of diluent. Within the usual range of concentrations this approximation is accurate enough.

(ii) *per cent concentration* (weight). This is the p.p.m. ratio expressed as a percentage, e.g. 3000 p.p.m. is equivalent to 0.3 per cent acid by weight, i.e. per cent concentration $= \frac{\text{p.p.m.}}{10{,}000}$

(iii) *per cent concentration* (volume). This is the ratio of the volume of the concentrate to the volume of the diluent expressed as a percentage.

(*c*) *Calculation of Dosage with Hormone Herbicides*

$$\frac{\text{pounds of 2,4,5-T acid equivalent required per acre}}{\text{\% of 2,4,5-T acid equivalent in concentrate}} \times 100 = \text{Pounds of concentrate to be applied per acre.}$$

APPENDIX 4

Botanical Names of Species Mentioned

English Name	*Botanical Name*
Alder, (speckled)	—*Alnus rugosa* (Du Roi) Spreng. var. *americana* (Regel) Fern.
Alder, red	—*A. rubra* Bong.
Aspen	—*Populus tremuloides* Michx.
Birch	—*Betula papyrifera* Marsh.
Birch, European	—*B. pubescens* Ehrh.
Cedar, Port Orford	—*Chamaecyparis lawsoniana* (A. Murr.) Parl.
Cherry, wild	—*Prunus* L. spp.
Chokecherry	—*Prunus virginiana* L.
Fir (balsam)	—*Abies balsamea* (L.) Mill.
Fir, Douglas	—*Pseudotsuga taxifolia* (Poir.) Britt.
Hazel	—*Corylus cornuta* Marsh.
Hickory	—*Carya* Nutt. spp.
Maple	—*Acer* L. spp.
Maple, red	—*Acer rubrum* L.
Maple, mountain	—*A. spicatum* Lam.
Mockernut hickory	—*Carya tomentosa* Nutt.
Oak	—*Quercus* L. spp.
Oak, scrub	—*Q. ilicifolia* Wang.
Pine, jack	—*Pinus banksiana* Lamb.
Pine, red or Norway	—*P. resinosa* Ait.
Pine, Scots	—*P. sylvestris* L.
Pine, white	—*P. strobus* L.
Privet	—*Ligustrum* L. spp.
Raspberry	—*Rubus* L. spp.
Spruce, Norway	—*Picea abies* L.
Spruce, Sitka	—*P. sitchensis* (Bong.) Carr.
Spruce, white	—*P. glauca* (Moench) Voss

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