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U. S. FOREST SERVICE
RESEARCH PAPER NC-18
SEPTEMBER 1967

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SOME VARIABLES AFFECTING HARDWOOD CONTROL with STEM INJECTIONS of 2,4,5-T

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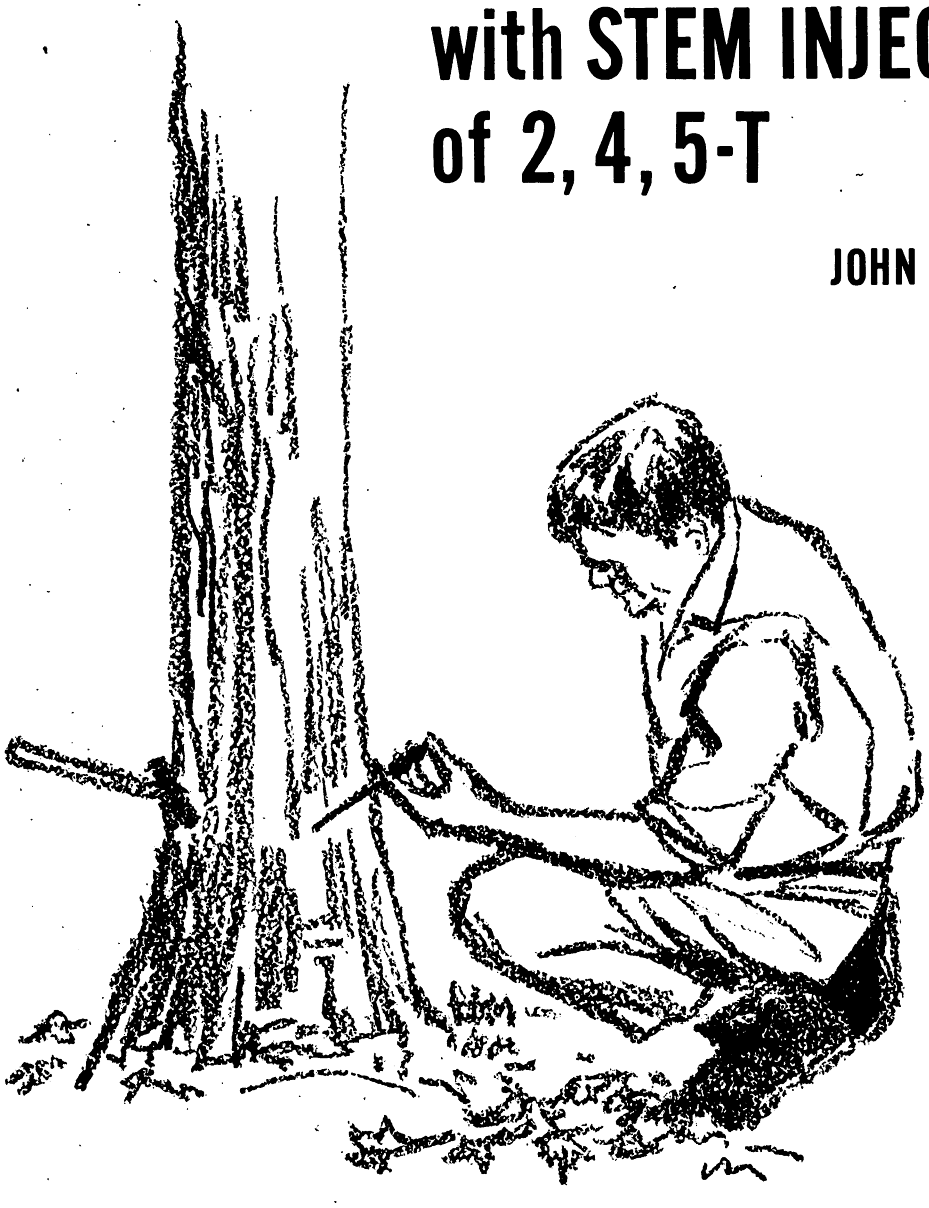

NORTH CENTRAL FOREST EXPERIMENT STATION
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U. S. DEPARTMENT OF AGRICULTURE

Contents

NOTE: The author is Leader of the Silviculture of Mixed Hardwoods Project. He is headquartered at the Station's field office in East Lansing, Mich., which is maintained in cooperation with Michigan State University.

NORTH CENTRAL FOREST EXPERIMENT STATION
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Some Variables Affecting Hardwood Control With Stem Injections of 2,4,5-T

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To reduce the costs of killing weed hardwoods, many foresters use 2,4-D and 2,4,5-T in spaced stem injections rather than in edge-to-edge or overlapping cuts (complete frill girdles). The success of spaced stem injections depends, however, on many interacting variables. Some of the most apparent ones are the concentration or quantity of the herbicide formulations required per injection, spacing between injections, season of the year, and tree size and species. Just how and why these variables affect results has been little understood.

In 1962 comprehensive studies were started in Lower Michigan to learn how to use spaced stem injections to control low-quality mixed hardwoods at the least cost. The first study was designed to determine the effectiveness of a water-soluble amine salt of 2,4,5-T compared with an oil-soluble ester. The results demonstrate conclusively that the amine salt is better than the ester under all comparable conditions studied. However, its effectiveness varies greatly by season of the year and spacing between the injections. The damaged stem tissues found in trees killed and not killed by the treatments showed the general translocation that took place, which in turn helps explain the many variable results from tree injector studies and operations. This new information suggests new approaches for increasing the effectiveness of the stem injections and reducing costs in timber stand improvement operations.

The Study Area and Experimental Procedure

The study area was a 110-acre tract of mixed oak in Clinton County, Mich., near Lansing. The trees were about 65 years old and up to 80 feet tall; the stand was fairly dense — about 130 square feet of basal area per acre — and the tree crowns were crowded. The topography was nearly flat, and the soil was fine-textured and poorly drained. This combination of site features is very productive for oak.

Because of the many treatment variables to be compared, only one tree species, white oak (*Quercus alba* L.), was used for all combinations of the treatments. However, many of the treatments were also tried on other hardwoods to determine species resistance. The sample trees were single-stemmed and about 6 to 8 inches in diameter at breast height.

A complete randomized factorial design was used, with two herbicide formulations, five concentrations, four spacings, and three seasons combining into 120 treatments. Each treatment was replicated on five sample trees (total of 600) of similar size and vigor. The elements of the treatments were:

Herbicides: The triethylamine salt and the propylene glycol butyl ether ester of 2,4,5-T; both commercial formulations, 4-pound acid equivalent gallons.

Spacing between injections: 1, 2, 4, and 6 inches (edge to edge).

Concentrations of each formulation: 100 (undiluted), 50, 25, 10, and 5 percent by volume (acid equivalent per 100 gallons of carrier was 400, 200, 100, 40, and 20 pounds). The amine salt was diluted in water and the ester in No. 1 fuel oil.

Volume of herbicide per injection: 1 milliliter for 1- and 2-inch spacings, 2 milliliters for 4-inch spacings, and 3 milliliters for 6-inch spacings. These volumes were equivalent to about 1 milliliter per 3 inches of circumference or (roughly) per 1 inch of diameter.

Season of the year: Late dormancy, about 1 month before the buds started swelling (March 1962); peak of the growing season, about the time of full leaf development (mid-June 1962); and late growing season or early dormancy, about 1 month before leaf fall (late September or early October 1962).

An attempt was made to use an injection technique that would be accurate enough for experimental purposes and yet could be simulated with commercially manufactured tree injectors. A 2-inch-wide chisel was driven about ½ inch into the base of the tree with a short-handled sledge hammer. The herbicide was injected into each incision

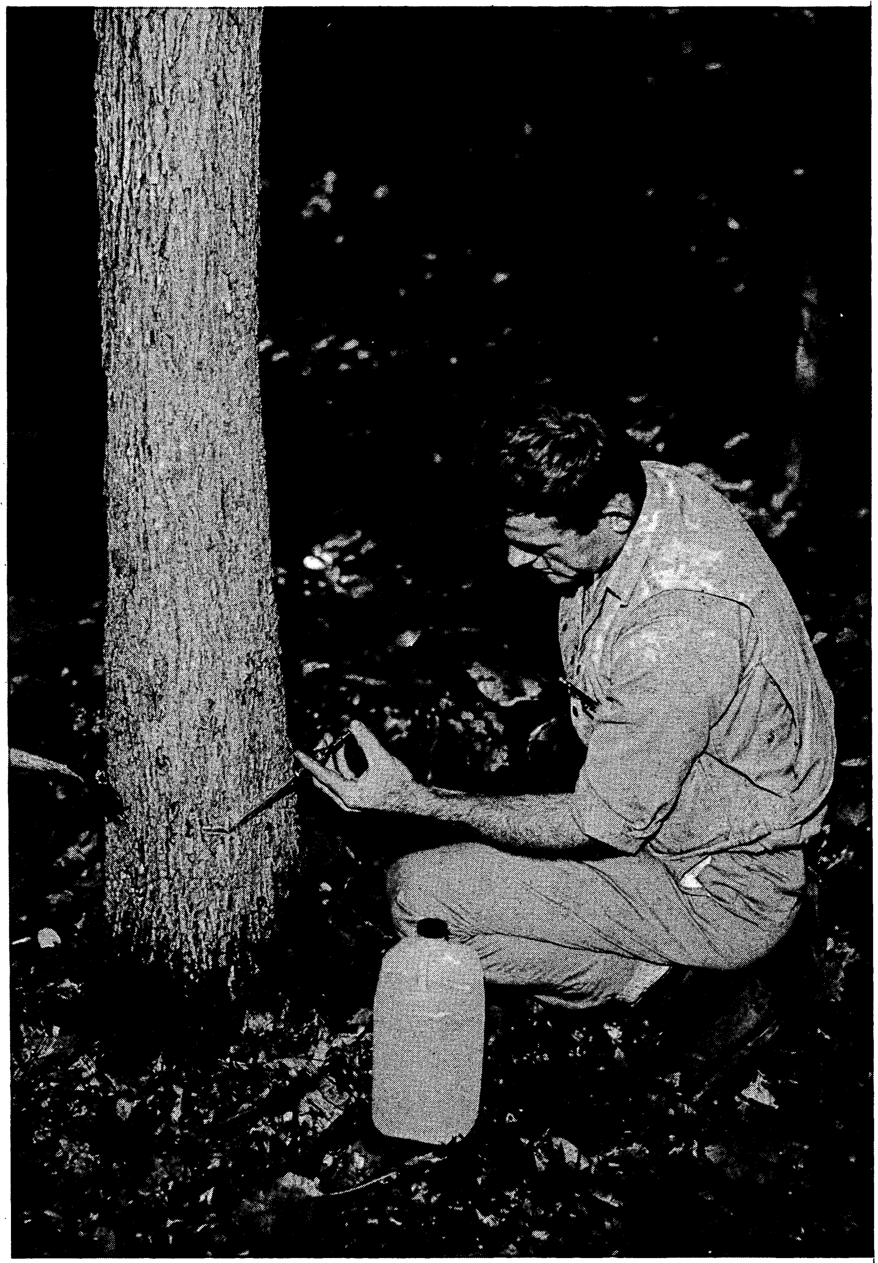

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FIGURE 1. — Injecting the herbicides with an automatic pipette into evenly spaced incisions made with a chisel.

with an automatic 2-milliliter pipette (fig. 1). This method gave reasonably consistent control over the width, depth, and spacing interval of the incisions and quantity of herbicide injected.

The injections were made 1 to 5 feet above the ground, depending on the presence of fire scars and other basal deformities. Our previous experience showed that herbicides injected into healed-over basal stem wounds were not effective. To test height effects further, several trees were injected about 20 feet above the ground (just below the crown) with the amine salt at 4-inch spacings.

The amount of apparent foliage damage or crown reduction on each tree was recorded annually to the nearest 10 percent for 3 years after the stem treatments. At the end of the third year, 81 treated but living trees (37 injected with the amine salt and 44 treated with the ester) and 80 killed trees were felled, and the stems were examined for killing effects in the conductive tissues.

Results

Crown Kill

After 3 years, analysis of variance showed all the major variables studied (herbicide formulation, concentration, spacing, and season of treatment) to be highly significant in terms of crown kill. Their effects on tree mortality were also important economically (table 1).

Amine salt versus the ester. — The amine salt killed 80 to 100 percent of the trees with concentrations diluted down to 25 percent at 1-inch spacing between the injections at all seasons. In June this concentration was equally effective at spacings up to 6 inches apart.

The maximum number of trees killed by the ester treatments was 60 percent. This was obtained with 1 milliliter of undiluted ester per injection for spacings 1 and 2 inches apart in March and 1 inch apart in June. The next best results, 40 percent of the trees killed, was obtained when the ester was diluted with oil to 50 percent by volume and injected at 1- and 2-inch spacings in March. Only an occasional tree was killed with lesser concentrations or at wider spacings.

The comparative results show that at least four times more ester than amine is required to kill oak at 1- and 2-inch spacings between injections in March. The ratio of ester to amine is much larger at wider spacings and at other seasons of the year.

Seasonal effects. — The ester of 2,4,5-T was most effective in March, less effective in June, and completely ineffective in October with the treatments tried (table 1). However, it killed too few trees for seasonal effects to be fully appraised. The amine salt was definitely most effective when stem-injected during the peak of the growing season. The June treatments killed three times as many trees as the March treatments and twice as many as the October ones. The salt is therefore at least twice as effective when injected during the growing season as during the dormant season.

Interrelations of concentrations and spacings. — The concentration or quantity of 2,4,5-T per injection had to be increased as the distance between spacings was increased in order to kill the trees. For example, during the dormant season the 6-inch spacing was ineffective with any of the quantities of 2,4,5-T amine used. However a few trees were killed with the same concentrations at 4-inch spacings, more at 2-inch spacings, and all trees at 1-inch spacing with concentrations of 50 percent and higher. During the growing season, the 25-percent concentration of the amine killed all trees when injected at all spacings up to 6 inches apart; but at 1-inch spacings concentrations as low as 10 percent killed all the trees.

Height of spaced injections. — This appeared to have little effect on top kill when placed above basal stem defects. In fact, trees treated by injections 3 to 5 feet above the ground seemed easier to kill than those treated near the root collar. The several trees stem-injected 20 feet above the ground just below the crown during the growing season were top killed in about 2 weeks.

Basal Sprouting

Less than 2 percent of the hardwoods top killed by the treatments (and none of those top killed by injections 20 feet above the ground) developed basal sprouts after 3 years. In fact, more treated trees that were not top killed developed basal sprouts than those showing top kill effects. In contrast, most hardwoods that were cut or completely frill girdled in this same tract without chemical treatment developed basal sprouts the first growing season. And in our 1954-55 treatments with 2,4-D and 2,4-5-T in complete frill girdles on red and white oak in this stand, about half the trees sprouted.

Species Resistance

White oak was selected initially as a test species in this particular study because we had some evidence that it might be more resistant to systemic herbicides than red or black oaks. Our 1954 results, using the amine salt and ester formulations of 2-,4-D and 2,4,5-T in complete frill girdles, showed white oak to be more difficult to kill, at least in April, then northern red oak. Then too,

Table 1. — *Percentage of white oaks killed 3 years after stem injections of 2,4,5-T amine and ester at different concentrations, volumes, spacings, and seasons of the year*[1]

Concentrations (percent)	March 1962		June 1962		October 1962	
	Ester	Amine	Ester	Amine	Ester	Amine
			1 ML. PER 1-INCH SPACING			
100	60	80	60	100	0	100
50	40	100	0	100	0	100
25	0	80	0	100	0	80
10	0	20	0	100	0	60
5	0	60	0	60	0	60
			1 ML. PER 2-INCH SPACING			
100	60	60	0	100	0	100
50	40	40	0	100	0	100
25	0	40	20	100	0	60
10	0	0	0	60	0	0
5	0	0	0	40	0	0
			2 ML. PER 4-INCH SPACING			
100	0	0	0	80	0	40
50	0	20	0	100	0	0
25	20	20	20	100	0	0
10	0	0	0	60	0	0
5	0	0	0	40	0	0
			3 ML. PER 6-INCH SPACING			
100	0	0	0	100	0	40
50	0	0	0	100	0	0
25	0	0	20	100	0	0
10	0	0	0	60	0	0
5	0	0	0	20	0	0

1/ Four-pound acid equivalent gallons were used with both herbicides. The amine (triethylamine salt) was diluted with water, and the ester (propylene glycol butyl ether ester) with No. 1 fuel oil. Spacing was measured edge to edge of 2-inch cuts made ½ inch deep with a wood chisel. Each of the 120 treatments was applied to 5 trees. Trees completely defoliated in August 1965 were considered dead.

the xylem vessels of white oak are normally blocked by tyloses. However, these tyloses are most abundant in the older xylem being transformed to heartwood and are normally not found in the new sapwood where vertical translocation takes place.

In the spaced injection treatments, especially at lower concentrations and wider spacings, white oak was consistently killed more easily than northern red oak. Since both species were of similar diameter and growing side by side in the same stand, these results indicate that northern red oak might be more resistant to stem injections of 2,4,5-T than white oak. However, this resistance could be caused by tree characteristics other than species. The northern red oaks generally appeared more vigorous and many of them had larger crowns than white oak of the same stem diameter. Elm and ironwood (hophornbeam) were killed as easily as white oak, but hickory was difficult to kill.

What causes species resistance other than crown size and branching characteristics could not be determined. Perhaps it is anatomical differences. Wiant and Walker (1961) found that ring-porous species were more easily killed by complete mechanical stem girdles than diffuse-porous species. Our results showed that translocation was much slower in diffuse-porous species from spaced stem injections; at least top kill effects took longer to show up.

Killing Effects in Conductive Tissues

The killing effects observed in the conductive tissues of the stem from 2,4,5-T in this study and the apparent translocations that took place have been described in a previous paper (Arend 1967). The results are briefly reviewed here as background for the ensuing discussion.

The damage in the conductive tissues showed that the superior effectiveness of the amine salt over the ester was due, in part at least, to the increased vertical translocation above the injections to the crown and possibly to phloem translocation away from the foliage to other parts of the tree, including movement down the stem to kill the underlying cambium. The difference was not due to tangential movement between the injections in the xylem.

Too few trees were killed with the ester to assess its lethal effects; but evidence from the few killed trees and from those not killed by the treatments indicates that the ester is translocated in the same pattern as the amine but to a lesser extent with the same quantities.

Tangential movement. — The tangential killing effects in the sapwood caused by oil-diluted ester were similar to those caused by the water-diluted amine salt. In sound trees, the sapwood was killed tangentially for an average distance of only 0.2 inch on each side of the injections (fig. 2). Above the injections the killed portion of the sapwood gradually narrowed (fig. 3). The exception to this limited tangential movement was found in trees that had incipient stages of decay in the heartwood, with possible extensions into the sapwood. Under these conditions, both formulations of 2,4,5-T moved profusely in all directions, and presumably could kill trees by girdling them. This type of damage was found in several killed trees.

Radial movement. — The injected 2,4,5-T killed the sapwood radially inward from the bottom of the injections to various depths, but no deeper than the heartwood in normal trees. The most important lethal effects appeared to be obtained by radial movement between the xylem and the phloem; both of these vital tissues including the cambium were seriously damaged. The inner bark and cambium above and below the injections were killed as far up and down the stem as the underlying damage found in the xylem. This was especially noticeable in trees not killed by the treatments (figs. 2 and 3). Stout and Hoaglund (1939) also found radial movement between the xylem and the phloem with radioactive isotopes of potassium, sodium, and phosphorus when they were absorbed by the roots.

Vertical movement above the injections. — Streaks of dead conductive tissue (both xylem and phloem) extended to various heights along the stem above the injections, depending on the 2,4-5-T formulation, its concentration, the quantity applied, and season of the year (fig. 3). For example, where it could be measured in unkilled trees, the amine salt killed the sapwood, cambium, and inner bark above the injections two to four times higher up the stem than the ester at the same concentrations. The amine salt injections made during the peak of the growing season also killed the conductive tissues twice as high up the stem as the dormant-season applications.

In trees showing complete crown kill 3 years after the treatments, the dead sapwood channels above the injections could generally be traced to the base of several main branches. The most important difference found in the stems of killed versus unkilled trees was a narrow band of killed sapwood in the upper portion of the stem. This band decreased in radial depth downward from the top and usually disappeared above the injections (fig. 4), its length varying with the quantity of amine injected. This killing effect in the sapwood appeared to result from radial movement of the herbicide from the phloem as it was carried down the stem from the foliage.

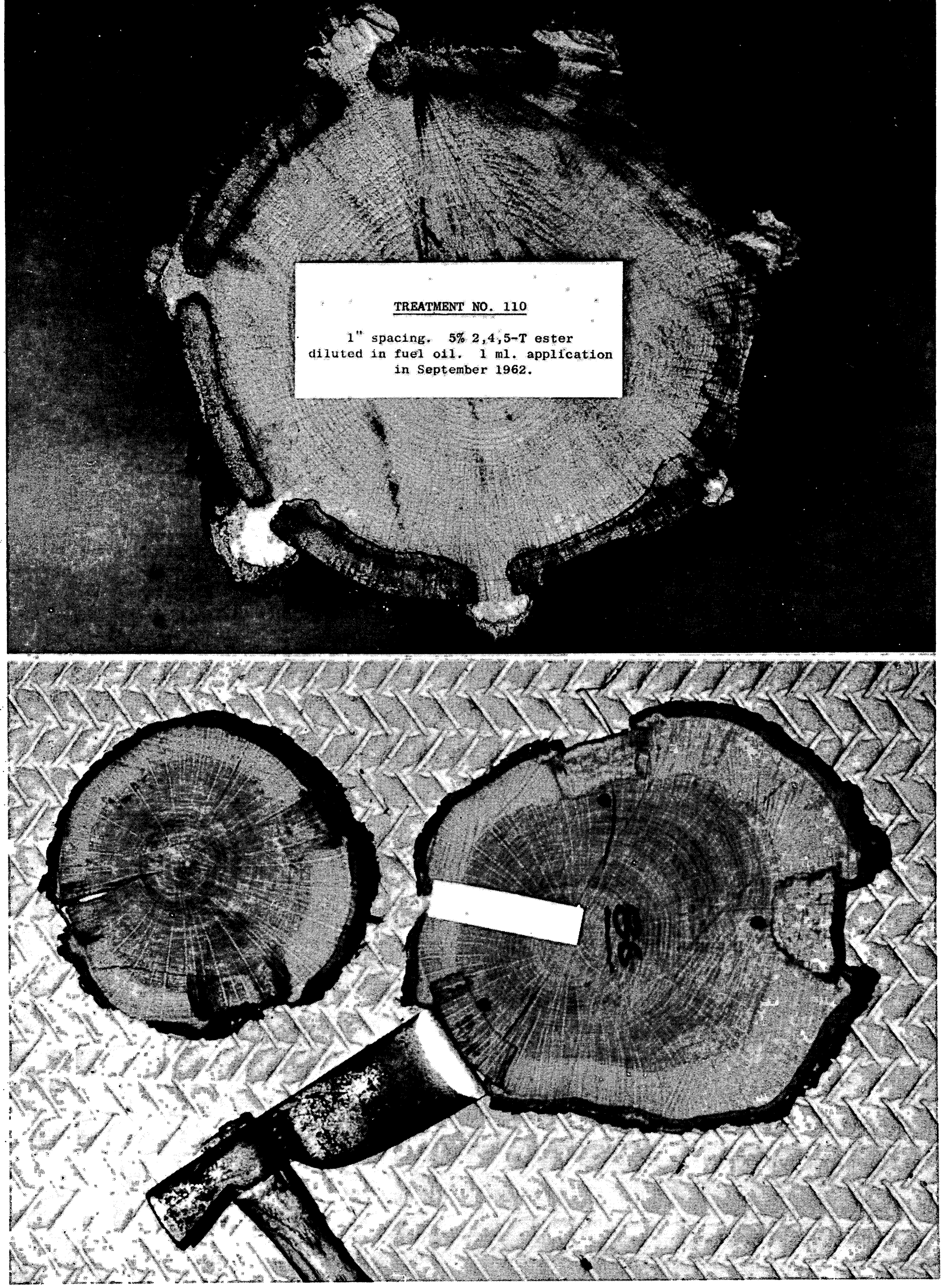

FIGURE 2. — Cross sections of the stems of unkilled white oak showing the limited tangential movement of injected 2,4,5-T, 3 years after treatment. *Upper photo*: 1 milliliter of 5-percent concentration by volume of 2,4,5-T ester diluted in fuel oil. Spacing between the injections was 1 inch (edge to edge). *Lower photo*: 3 milliliters of 25-percent concentration by volume of 2,4,5-T ester diluted in fuel oil. Spacing between the injections was 6 inches (edge to edge). Smaller cross section was taken halfway up the stem, the larger cross section at the site of the injections. F-516604 & 605

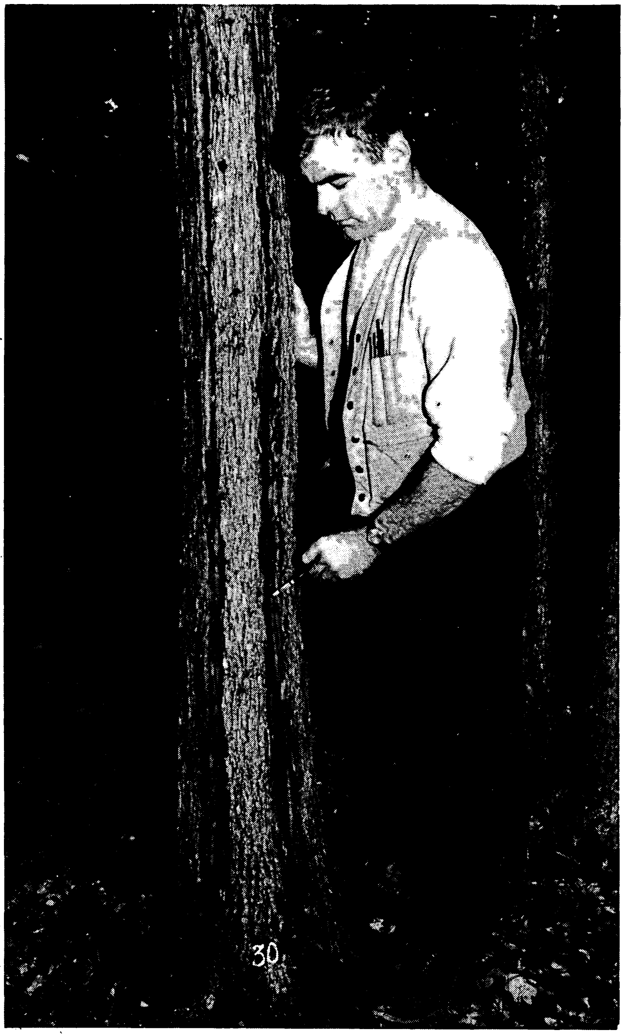

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FIGURE 3. — Narrow streaks of killed sapwood, cambium, and phloem above the injections in unkilled white oak trees. Treatment was 2 milliliters of undiluted 2,4,5-T amine injected at 6-inch spacings (edge to edge).

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FIGURE 4. — Cross sections of the trunk of a killed white oak injected with 1 milliliter of 2,4,5-T amine at 1-inch spacings in March 1962. The bottom section, site of the injections, shows no apparent damage to the tissue between the injections. The top section taken at a height of 50 feet, immediately below the crown, shows a wide band of dead sapwood. The middle section, taken at a height of 40 feet, shows a narrower band of dead sapwood.

Vertical movement below the injections. — The xylem and phloem below the injections were killed for distances of about 6 inches to 3 feet — again in narrow paths about the width of the injections. Although this killing effect added to the total stem damage, its contribution to tree mortality was apparently unimportant. Its extent appeared to be influenced somewhat by the same variables affecting upward movement above the injections. The downward movement below the injections could have taken place in both the xylem and the phloem. The reverse xylem flow at this point, according to Sudia and Linck (1963) and Zimmerman,[1] could have resulted from the tension in the water column of the xylem being broken by the injection, permitting movement in both vertical directions until an equilibrium was established.

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[1] *Personal conversation with Dr. Martin H. Zimmerman, Harvard Forest, Petersham, Massachusetts.*

Discussion

The superior crown kill results of the water-soluble amine salt compared with the oil-soluble ester formulations of 2,4,5-T obtained in this comprehensive study are similar to those reported by many investigators from more limited tests: Westing (1955) in Michigan, Leonard (1956) in California, Gibbs (1959) in Texas, Peevy (1962) in Louisiana, Starr (1963) in Mississippi, Benzie and Ringold (1964) in Minnesota, and others. Many of them also found that 2,4-D amine is at least as effective in basal stem injections as 2,4,5-T amine.[2] It is also about one-third less expensive. However, we used 2,4-5-T in both formulations in this study in order to specifically compare a water-soluble amine salt with an oil-soluble ester of the same basic acid under nearly identical conditions.

The results conclusively demonstrate the superiority of the water-soluble amine salt over the oil-soluble ester in basal injections. In addition, the damage found in the conductive tissues from the different injection treatments, especially the amine salt, and the effects of height of the stem injections on tree kill are new information that helps to explain many previously unexplainable results.

Apparently smaller quantities of the amine salt (one-fourth or less) killed more trees than the ester mainly because of more extensive translocation up the stem to the crown and then away from the foliage by way of the phloem, the latter movement permitting extensive damage to the cambium and roots. Such translocation explains how trees are killed not only by spaced stem injections but also by complete frill girdles. And it also helps explain the role of major variables, such as concentrations, spacings between injections, and tree size, and their interrelationships.

With complete stem girdles, the phloem is entirely severed and the sapwood is cut to various depths. This mechanical injury alone stops translocation of foodstuffs through the phloem to the roots. If the sapwood is also completely severed, water movement from the roots to the leaves is cut off and the tree crown is killed, mainly from desiccation. The addition of certain chemicals like 2,4,5-T will help to kill the tree. The 2,4,5-T will move upward, and slightly downward — the extent of its vertical movement depending on its formulation, concentration or quantity applied, and season of the year. If sufficient herbicide is applied, it will reach the foliage and hasten top kill. Downward movement below the complete girdle is affected by the same variables, but with most herbicides it is limited. This explains the early observation that low frills and higher concentrations of 2,4,5-T will reduce sprouting (Arend 1953). There is virtually no tangential movement in the xylem which explains why with small quantities of diluted 2,4,5-T, the frill girdle must be complete (Carnes and Walker 1956). Adding a diluted 2,4,5-T solution to complete frill girdles reduces costs because the girdle can be shallow since the chemical will move in toward the heartwood to kill the remaining unsevered active xylem. The diluted 2,4-5-T will also hasten top kill, reduce basal sprouting, and prevent the shallow frill girdle from healing over.

With spaced stem injections, both the phloem and the active xylem are only partially severed. The herbicide needs to translocate to more than half of the crown and preferably from the foliage to the roots via the phloem to reduce and even prevent basal sprouting. Trees top killed by this method seldom sprout. Generally less labor is required to make spaced injections than complete frill girdles, but because of the extensive translocation needed to kill the tree, larger quantities of the herbicide are required, the amount depending on many variables.

The complete chemical frill girdle method will always have application for the selective control of weed trees, especially large ones that are difficult to kill by spaced stem injections. Costs can be reduced by knowing which method to use on a specific weed tree.

Quantity of 2,4,5-T required per injection. — The 2,4,5-T must be applied in sufficient quantity to reach the crown. Otherwise, only narrow streaks of sapwood and the overlying cambium and inner bark (phloem) about the width of the injections will be killed to various heights along the stem (fig. 3). Northern oaks are quite resistant to this type of damage. We have oaks still living 5 years after being damaged by unsuccessful stem injections of 2,4-5-T spaced 1 inch apart.

The first herbicide requirement discovered for spaced stem injections using 2,4-5-T ester diluted in oil was that higher concentrations were needed (Smith 1959). This was also true for ammonium sulfamate (ammate); this systemic herbicide, when applied in supersaturated water solutions, was effective in complete frill girdles but not in spaced injections. There, it had to be applied in concentrated crystalline salt form to basal stem cups spaced about 4 inches apart in order to kill the tree, an illustration of the higher concentration requirement of herbicides for use in spaced injection treatments (Peevy 1949).

[2] *Red maple* (Acer rubrum L.), *however, is more susceptible to 2,4,5-T amine stem injections than to 2,4-D amine,* (*Day, 1960*).

Many other variables also influence the quantity of 2,4,5-T required per injection and per tree. Tree size determines the vertical distance the herbicide must translocate to reach the crown and the amount of foliage that must be reached. Anatomical differences among species, individual crown characteristics, and conditions affecting transpiration could affect the lethal quantity of 2,4,5-T per injection.

Spacing interval required between the injections. — The injections need to be spaced around the stem to permit the herbicide to reach a majority of the crown. Postlewait and Rogers (1958) found that radioactive isotopes of phosphorus-32 and iodine-131 injected into the stems of shagbark hickory, red pine, and blue beech moved up the trunk in the xylem in narrow paths and passed into the branches most closely associated with that section of the transpiration stream. Therefore, the number of injections around the tree and their width (total circumference injected) determines the amount of foliage affected. However, uniform distribution of the injections around the stem is more essential than the proportion of the stem injected. Watson and Mesler (1964) found that frill girdling one-half of the circumference and adding Tordon was ineffective on pole-size and larger oaks whereas equally spaced injections that severed 50 percent of the circumference killed the same size trees.

Many results also show that trees — especially the smaller ones — can be killed by severing less than 50 percent of the circumference with stem-injected herbicides. The criterion appears to be the proportion of the crown reached by the herbicide. Our study showed that if 60 percent or more of the crown exhibited some effects of the herbicide injections within 1 to 2 full growing seasons after the treatment, the tree would die. Character of the branching off the main stem as well as crown size affect the spacing required between injections. One injection of systemic herbicide may kill a small sapling because a major portion of the crown is reached. But trees with large spreading crowns — especially those with low, large branches or forked stems — require closely spaced injections as well as large quantities of herbicide per injection to kill them.

Effects of tree size. — Generally as trees increase in size, larger quantities of 2,4,5-T per injection and closer spacing of the injections are required. The effects of tree size persist even though, with the same spacing and quantity of herbicide per injection, the total volume of herbicide received per tree is directly proportional to the diameter of the stem — i.e., as the stem diameter doubles the volume of herbicide per tree will also double. This constant increase of herbicide per tree with increasing stem diameter appears to be effective for trees up to small sawtimber size; but larger quantities per injection and closer spacing are generally required to kill large sawtimber trees. Apparently the crowns of larger trees increase greatly in size with larger stem diameters.

The fixation loss characteristic of the phenoxy herbicides as they move through the conductive tissues may be another reason why more 2,4,5-T is required as the tree increases in size.

Height of spaced stem injections. — Trees in this study were killed by spaced stem injections at any height above the ground, including some just below the crown. Probably the higher the injection, the more herbicide translocated to the foliage. Generally about 20 percent fewer injections are required at breast height compared to stump height at the same effective spacing. This reduced number of injections not only reduces the herbicide used, but it speeds up the work and increases the number of trees that can be treated per day. This information provides incentive for developing tools to make injections higher on the stem than is convenient with most tree injectors now available. One such tool meeting this requirement is a hypo-hatchet.[3]

Why seasonal effects? — This study and most others show that hardwoods can be killed with a smaller quantity of 2,4,5-T amine applied at wider spacings between injections during the peak of the growing season than during the dormant season. This effect can result in a substantial difference in costs; and specific prescription rates should be worked out for each forest region based on stages of growth.

The possible reasons for the seasonal differences in effectiveness of the phenoxy herbicides include the following: First, during the growing season transpiration is rapid, the injected herbicides move quickly in the transpiration stream to the foliage, and there is less opportunity for fixation losses along the translocation route. In contrast, injections in the dormant season remain near the injection sites or at most move up the stem slowly until the foliage develops (Witherspoon 1964). Consequently more dormant-season-injected 2,4,5-T can be absorbed and fixed in the xylem, and less is available when it moves to the foliage in the spring. Secondly, the new tree tissues developing during the peak of the growing season may be more susceptible to 2,4,5-T. Overbeek (1947) found that 2,4-D was most active against cells in the meristematic state.

A few cases have been reported where 2,4,5-T amine injected during the growing season was in-

[3] *Several types of hypo-hatchets are now being manufactured.*

effective in controlling hardwoods. We found one instance in northern Michigan where injected 2,4,5-T amine defoliated red maple within a few days, but the trees leafed out the next year without showing further damage to the trees. In the Southeast, McGee (1966) reported that 1-milliliter quantities of 2,4,5-T amine injected in April when the leaves were just developing caused them to fall and the treatments were less effective than July treatments. Apparently, under certain early season growing conditions too large dosages of stem-injected 2,4,5-T amine can cause the leaves to fall off without killing the tree.

Another seasonal effect possible with spaced stem injections is reduced tree kill when soil moisture is critical during the mid- or late growing season. Merkle and Davis (1967) found that 2,4,5-T did not move readily in the phloem of beans under low moisture stresses. This could explain the poor tree kill from foliage sprays and spaced injections of 2,4,5-T that has occurred during the periods of critical soil moisture common in many forest regions during the growing season.

Conclusions

1. A triethylamine salt of 2,4,5-T was at least four times more effective in spaced stem injections on northern oak than a propylene glycol butyl ether ester of 2,4,5-T. Not only were smaller quantities of the amine salt required per injection, but wider spacings between the injections were possible.

2. About one-half the quantity of amine per injection was required during the growing season compared to the dormant season to kill pole-size oak. With the same quantity of amine per injection, pole-size oak could be killed with spacings of 6 inches (edge to edge) between the injections during the growing season compared to about 2 inches during the dormant season.

3. Height of the spaced injections on the stem had no apparent effect on tree kill if placed above basal deformities and below the crown. Oaks were most easily killed by spaced stem injections just below the crown. However, because of the limited downward movement of 2,4,5-T below the injections, complete edge-to-edge injections and complete chemical frill girdles which entirely sever the phloem should be placed close to the root collar to reduce basal sprouting.

4. Trees top-killed by spaced stem injections with 2,4,5-T seldom develop basal sprouts regardless of the height of injections on the stem.

5. Studies of stem damage indicated that the superior effectiveness of the amine salt compared to equal quantities of the ester resulted from more extensive translocation in the conductive tissues.

6. The tangential killing effects in the xylem were not important. Also no difference was found between the amine salt and the ester, including the dilutions in water and No. 1 fuel oil.

7. The quantity of 2,4,5-T required per injection appears to depend on its formulation, season of the year treated, spacing between the injections, and tree size, particularly the size and character of the crown. The spacing distance between the injections also appears to depend on the same variables.

8. Trees with large spreading crowns and forked stems are difficult to kill by spaced stem injections with 2,4,5-T.

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effective in controlling hardwoods. We found one instance in northern Michigan where injected 2,4,5-T amine defoliated red maple within a few days, but the trees leafed out the next year without showing further damage to the trees. In the Southeast, McGee (1966) reported that 1-milliliter quantities of 2,4,5-T amine injected in April when the leaves were just developing caused them to fall and the treatments were less effective than July treatments. Apparently, under certain early season growing conditions too large dosages of stem-injected 2,4,5-T amine can cause the leaves to fall off without killing the tree.

Another seasonal effect possible with spaced stem injections is reduced tree kill when soil moisture is critical during the mid- or late growing season. Merkle and Davis (1967) found that 2,4,5-T did not move readily in the phloem of beans under low moisture stresses. This could explain the poor tree kill from foliage sprays and spaced injections of 2,4,5-T that has occurred during the periods of critical soil moisture common in many forest regions during the growing season.

Conclusions

1. A triethylamine salt of 2,4,5-T was at least four times more effective in spaced stem injections on northern oak than a propylene glycol butyl ether ester of 2,4,5-T. Not only were smaller quantities of the amine salt required per injection, but wider spacings between the injections were possible.

2. About one-half the quantity of amine per injection was required during the growing season compared to the dormant season to kill pole-size oak. With the same quantity of amine per injection, pole-size oak could be killed with spacings of 6 inches (edge to edge) between the injections during the growing season compared to about 2 inches during the dormant season.

3. Height of the spaced injections on the stem had no apparent effect on tree kill if placed above basal deformities and below the crown. Oaks were most easily killed by spaced stem injections just below the crown. However, because of the limited downward movement of 2,4,5-T below the injections, complete edge-to-edge injections and complete chemical frill girdles which entirely sever the phloem should be placed close to the root collar to reduce basal sprouting.

4. Trees top-killed by spaced stem injections with 2,4,5-T seldom develop basal sprouts regardless of the height of injections on the stem.

5. Studies of stem damage indicated that the superior effectiveness of the amine salt compared to equal quantities of the ester resulted from more extensive translocation in the conductive tissues.

6. The tangential killing effects in the xylem were not important. Also no difference was found between the amine salt and the ester, including the dilutions in water and No. 1 fuel oil.

7. The quantity of 2,4,5-T required per injection appears to depend on its formulation, season of the year treated, spacing between the injections, and tree size, particularly the size and character of the crown. The spacing distance between the injections also appears to depend on the same variables.

8. Trees with large spreading crowns and forked stems are difficult to kill by spaced stem injections with 2,4,5-T.

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