EFFECT OF TIME FROM TREATMENT TO DISTURBANCE ON WOODY PLANT CONTROL WITH TRICLOPYR, PICLORAM AND/OR 2,4-D

by

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TABLE OF CONTENTS

Tables and Figures

Study 1

Study 2

GENERAL INTRODUCTION

The Piedmont and Coastal Plain physiographic provinces fall within the Southern Pine Forest Region where much of the burden of the nations present and future timber demands are placed. Within this region, the Coastal Plain supports the most extensive and productive sites in the South (Barrett 1980). A favorable topography, for easier accessibility, and contiguous site quality, for extensive management units, makes this region suitable for intensive forest management.

Loblolly pine (Pinus taeda L.) is found throughout most of the South and is considered one of the more valuable species for the forest industry in this area. Favorable growth and versatility as to site requirements are two attributes that make this species popular. Loblolly pine and other preferred pine species, however, are shade intolerant; less valuable hardwood species which are more tolerant often capture the site during early stand establishment. Hardwood vegetation dominated 40 percent of the pine acreage following harvests between 1957 and 1977 (Knight 1977). In addition, there has been a decline in commercial timberland in the South due to row crop and pastureland development, and urban and industrial expansion (USDA 1982). The present and predicted decline is greatly influenced by nonforestry uses on land holdings of nonindustrial private owners who control much of the South's forests. Despite reforestation laws and cost sharing programs, much of this land is not reforested with desirable species. A lack of information concerning silvicultural choices, costs of reforestation, and the misconception that pine will become reestablished naturally have been cited as major contributing factors (Royer and Kaiser 1983). This places a burden on corporations in the forest industry to work in conjunction with private land owners, sharing their knowledge of silvicultural options, and to practice intensive forest management on their relatively small land holdings so as to obtain maximum yields.

The pulp and paper industry is the greatest user of the wood in this region (Barrett 1980). In addition, industry ownership in the South is projected to increase in the future (USDA 1982). Because corporate ownerships are generally large and contiguous, they are able to attack their silvicultural needs in a more sophisticated, intensive and efficient manner (Newbold 1979). One such form of intensive management is vegetation control. Loblolly pine has shown favorable responses to hardwood brush removal on natural and planted pine stands (Cain and Mann 1980; Clauson 1978). Chemical site preparation through aerial spraying provides an effective means of early weed control in hardwood stand to pine plantation conversion.

Aerial spraying for site preparation has become an integral part of corporate forestry vegetation management programs. When used in conjunction with prescribed burning the added effect of the herbicides includes insured top kill, an added prevention against sprouting, and a reduction in logging slash (Newbold 1979). Chemical site preparation for pine plantation establishment is essentially a three step process in which (1) herbicides are applied to the vegetation remaining after a harvest, (2) a waiting period is allowed for the chemicals to translocate and the vegetation to dry, and (3) the site is then cleared of the remaining dead stems and slash by burning (site disturbance).

With these factors in mind two studies were designed with the following sets of objectives:

<u>Study 1</u>

1. To compare four chemical combinations used for site preparation in southeastern forests.

2. To analyze the effect of time on the chemical efficacy as a result of different waiting periods between application and disturbance.
3. To provide a method, using environmental data and plant-tissue samples, to predict chemical efficacy.

Study 2

1. To compare the distribution of triclopyr, picloram and 2,4-D in red maple (Acer rubrum L.) when triclopyr was used alone at a high rate or in combination with picloram and 2,4-D at a low rate.
2. To compare the concentrations in the roots or shoots of red maple growing under two ambient temperatures.
3. To compare the concentrations in the roots and shoots of red maple as a result of a varying time for translocation from the foliage into the plant.

LITERATURE REVIEW

Chemical site preparation is gaining widespread acceptance for use as a silvicultural management technique. While its use is not always warranted, relative to standard techniques of site preparation, the use of chemicals has produced excellent control of unwanted vegetation. There are four major factors which influence the efficacy of the chemical site preparation system. 1) The selection of chemical(s) and formulations can affect the level of control achieved as not all chemicals, or ways in which they are formulated, produce the same effect. 2) Chemical efficacy is not always consistent across species and the selection of chemicals for use is based on the target species which need to be controlled. 3) Translocation of herbicides to the below ground portion of the plant is essential for a lasting control of woody perennials. The rate at which the chemicals move within the plant can be affected by the species which is being treated and/or the environmental conditions before, during, and after application. 4) Burning a sprayed site after sufficient herbicide translocation is an effective means of removing remaining debris. The burn can also provide additional control of species that resprout after sublethal chemical injury or for those stems which were missed by the application.

Site Preparation Chemicals and Combinations

Factory formulations

There are fourteen herbicides in sixteen formulations registered for chemical site preparation in the southeast (Gjerstad and Minogue 1985). Of the fourteen available, five make up the bulk of what is actually applied. Glyphosate (N-(phosphonomethyl)glycine) is formulated as Roundup[1] and is available for site preparation in southern pine. Roundup is a broad spectrum, aliphatic herbicide that is effective on grasses, herbs, and woody plants. This chemical is foliar-active, has no soil activity, and is applied in the fall.

Hexazinone [3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione] is classified as a triazine herbicide and is active on grasses, herbs, and woody vegetation. Formulations for site preparation include Velpar L[2] and Pronone 5G and 10G.[3] All formulations are

[1] A trademark of Monsanto Company, St. Louis, Missouri 63166.

[2] A trademark of E. I. duPont de Nemours & Co., Wilmington, Delaware 19898.

taken up by the roots; however, Velpar L can be absorbed through the leaves as well. Adequate moisture is required for uptake by the roots. Applications by either chemical are made between winter and early spring.

Triclopyr {[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid} is a relatively new herbicide. Formulations for foliar applications include Garlon 3A[4] containing 3 lb ae/gal formulated as a triethylamine salt and Garlon 4[4] containing 4 lb ae/gal formulated as a butoxyethyl ester. Both chemical formulations are effective as broad spectrum brush killers applied as a foliar spray in early summer.

Two formulations of picloram (4-amino-3,5,6-trichloropicolinic acid) for foliar application are used extensively in forestry. Tordon 101[4] is a mixture of picloram and 2,4-D [(2,4-dichlorophenoxy)acetic] acid containing 0.54 and 2.00 lb ae/gal, respectively. Both components exist in this formulation as triisopropanolamine salts. Tordon K[4] contains only picloram at 2.00 lb ae/gal formulated as a potassium salt. These chemicals are also applied in early summer.

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[3] A trademark of Pro-Serve Inc., Memphis, Tennessee 38116.

[4] A trademark of Dow Chemical USA, Midland, Michigan 48640.

Many formulations of 2,4-D exist. One formulation is Esteron 99[4] which contains 3.8 lb ae/gal of 2,4-D formulated as the butoxyethyl ester. 2,4-D is effective alone or in combinations with other compounds. Other chemicals less commonly employed, yet which are registered for site preparation include dicamba (3,6-dichloro-o-anisic acid) dichlorprop [2-(2,4-dichlorophenoxy) propanoic acid] fosamine [ethyl hydrogen (aminocarbonyl)phosphonate] and MSMA (monosodium methanearsonate) (Gjerstad and Minogue 1985).

Chemical combinations

With a limited number of herbicides available for forestry use, particularly for aerial applications, chemical combinations have proven to be very effective for the broad spectrum kill needed for site preparation. Picloram pellets applied with foliar sprays of triclopyr or 2,4,5-T [(2,4,5-trichlorophenoxy)acetic acid] gave effective control of hardwood brush in Louisiana (Haywood 1980). Picloram, triclopyr and 2,4,5-T when used alone gave only 41, 63, and 54 percent topkills respectively on red maple (Acer rubrum L.); a hard-to-kill species. However, picloram and triclopyr together produced a 98 percent topkill on red maple.

Fitzgerald and Dunagan (1983) found that mixtures of Garlon 3A and Tordon 101 were more effective than when either was used alone in reducing the number of sweetgum (Liquidambar styraciflua L.) and red oak (Quercus spp.) stems two years after application and burning. Triclopyr, picloram, and 2,4-D at rates of 3.00, 0.54, and 2.00 lb ai/acre, respectively, reduced the number of sweetgum stems 96 percent. Picloram and 2,4-D at the same rates and triclopyr at 2.00 lb ai/acre reduced red oak stems 96 percent.

In a site preparation study, picloram alone at 5.00 lb ai/acre without burning produced 100 percent topkill in hickories (Carya spp.) and 80 percent topkill in blackgum (Nyssa sylvatica Marsh.) 2 years after treatment (Miller 1982). Still picloram, when used alone, is not as effective as mixtures. Carter and Buchanan (1971) found that picloram alone at 1.00 lb ai/acre gave only a 32 percent kill when applied aerially on high quality sites in Alabama. However, when 2,4-D was added to picloram to produce a formulation of 4 + 1 lb ai/acre respectively, efficacy increased to a 59 percent stem kill. Picloram + 2,4-D at 2 + 8 lb ai/acre produced an 88 percent stem kill.

Time Allowed for Chemical Activity

To maximize chemical effectiveness in site preparation, adequate time must be given to allow for translocation of herbicides to the root systems of hardwoods before the tops are damaged by burning or slashing. Removal of tops before the herbicide has reached the root systems negates the benefit of using a systemic chemical; the only benefit gained may be the browning of the tops to facilitate a burn. Evidence from translocation experiments indicates that chemical movement is rapid and is complete within only a few days. In greenhouse experiments, Bovey and Mayeux (1980) applied picloram and triclopyr separately to honey mesquite (*Prosopis glandulosa* Torr.). Ten days after foliar application, the concentration in the roots reached a maximum. By the third observation (day 30), the concentration had declined in the roots and was lower than the first observation (day 3).

When chemicals are applied for site preparation there are indications that translocation is not as rapid as observed in greenhouse studies. Field trials indicate that efficacy can be adversely affected by cutting or burning too soon after spraying. A possible explanation of the differences may reside in the different sizes of treated individuals, the larger field plants requiring more time for translocation. Hall and Brady (1976) conducted a field study in which a 0.75 percent solution of the potassium salt of picloram was applied to three hardwood species: sweetgum, red maple and cherrybark oak (Quercus rubra var. leucophylla Ashe.). Concentrations in the roots reached a peak 5 weeks past the spray date; after 9 weeks, concentrations in the roots were still higher than measurements taken at week 1 in red maple and sweetgum.

Formulations can affect the rate of penetration into the plant as well as the movement once within the plant. Bovey et al. (1983) compared absorption and translocation of triclopyr ester and triclopyr amine in honey mesquite Initially, the leaves absorbed more triclopyr from the application of the ester than the amine salt; however, after 24 hours the concentrations absorbed were nearly the same. Triclopyr (amine) was found to be readily absorbed when a surfactant had been added to the formulation; mobility within the plants was rapid with either formulation.

Explanations of the increased efficacy of picloram when used in combinations has been studied. Davis et al. (1968b) found that the addition of 2,4,5-T to picloram when applied to honey mesquite increased uptake of picloram two-fold after 22 hours and basipetal transport was increased four-fold. These results are consistent with Davis et al. (1972)

who found that the addition of 2,4,5-T at increasing amounts caused an additive effect. The addition of 2,4,5-T appears to contribute as an additional herbicidal effect as well as increase the absorption of picloram which is readily translocated once within the plant.

Paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) is a contact desiccant that increases leaf-cell permeability and has been tested as an additive to increase absorption. Hall and Brady (1971) found that paraquat either reduced or had no effect on the activity of 2,4,5-T or dicamba. Carter and Buchanan (1971) obtained similar results when a mixture of picloram and paraquat was used. Davis et al. (1968b) found that paraquat reduced the transport and depressed the phytotoxicity of picloram.

Herbicide translocation and penetration rates are affected by environmental conditions before, during and after application. Since growth regulator type herbicides are most active when plants are vigorously growing, conditions which favor the plant tend to favor herbicide activity. Davis et al. (1968a) studied the effects of moisture stress on the absorption and translocation of herbicides in honey mesquite and winged elm (Ulmus alata Michx.) Plants were pretreated for 5 days to various levels of moisture stress before application of picloram or

2,4,5-T. Foliar uptake of picloram was reduced in mesquite but not in winged elm due to moisture stress; 2,4,5-T absorption was unaffected. The primary effect of moisture stress is on the movement of herbicides within the plant. In the same study, Davis et al. noted that moisture stress significantly reduced herbicide transport in woody plants. They found a significant reduction in the transport of picloram and 2,4,5-T as a result of moisture stress. Drought reduces the amount of herbicide that enters solution; hence, the medium for transport is unavailable. Transport is affected by the level of stress and the herbicide used, and varies with target plant species. Other observations support the reduced transport due to drought stress (Brady 1974; Miller and Starr 1963). While soil moisture must be adequate for herbicides to be effective, excess moisture can have an adverse effect. Excess soil moisture was shown to dilute the chemical concentration and thus reduce the phytotoxicity of picloram (Neary et al. 1979).

Photoperiod and temperature have also been shown to affect translocation. Light and temperature influence carbohydrate production and transport in the symplast, thereby influencing the movement of foliar-applied chemicals. In a study involving triclopyr, picloram and

2,4,5-T, Radosevich and Bayer (1979) found that transport was highest under warm temperatures and long days. A long photoperiod and high relative humidity provide an extended time for stomatal opening which can facilitate the entry of herbicides through stomata. High relative humidity will also slow the rate of drying of spray deposits and influence hydration of the cuticle, both of which aid absorption (Hull 1970; Bukovac 1976).

Species Susceptibility

Different hardwood species vary as to their susceptibility to herbicides. Gross morphology, specialized structures, and the cuticle of the leaf are important factors in herbicide penetration (Bukovac 1976). The cuticle serves as the primary barrier to penetration of foliar applied chemicals. Whether enough chemical is absorbed to produce a toxic effect can be the result of varying makeup and/or thickness of the cuticle. King and Radosevich (1979) reviewed the leaf characteristics of tanoak (Lithocarpus densiflorus Hook. & Arn.) in relation to triclopyr absorption. The greater amount of epicuticular wax and thicker cuticles of mature leaves were associated with reduced absorption. Leaf surfaces with abundant specialized structures, particularly stomata and stellate trichomes, were associated with greater absorption. Radosevich and Bayer (1979) found that picloram, triclopyr and 2,4,5-T movement did not move well in tanoak which, along with reduced penetration, may explain the poor control observed with this species.

Byrd et al. (1977) found that efficacy changed with varying herbicide concentrations. Using low volume ground and aerial applications, triclopyr at 9 to 12 lb ai/acre was required to obtain an 80 percent control or greater of such hard-to-kill species as dogwood (Cornus florida L.), red maple, and black cherry (Prunus serotina Ehrh.). Two species were considered tolerant: American holly (Ilex opaca Ait.) and sweetbay magnolia (Magnolia virginiana L.). Both holly and sweetbay magnolia are noted for having thick leathery leaves (typical of broadleaf evergreens) attributing to their resistance. Timing the application to coincide with the period of susceptibility of the target plant is an important factor for effective control of certain species. South (1982) found this relationship with leaves as well as cotyledons in sweetgum. Phytotoxicity to oxyfluorfen [2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-trifluoromethyl)benzene] decreased from 100 percent on newly emerged to 10 percent on 5-week-old cotyledons. Corresponding to the reduced injury was an increase in epicuticular wax which reduces wetting of the plant and subsequently reduces herbicide penetration.

Davis et al. (1972) applied picloram and/or 2,4,5-T on five different days during the growing season to coincide with stages of growth in honey mesquite. Concentrations of picloram in the phloem 48 hours after application were highest when applied on June 19, which corresponds to a time observed as optimum for treating this species.

Hall and Brady (1976) found sugar levels in leaves and roots of twelve woody plants explained species susceptibility. More susceptible species such as sumac (Rhus copallina L.) accumulated increasing levels of sugars in both leaves and roots during the May-to-July spray season. More resistant species such as red maple and dogwood had highest sugar levels in roots and shoots in May, followed by a drastic decrease in the roots during June. In general, most species accumulate sugars during the spray season (May-June-July). This increases the gradient between sugar levels in the leaves and roots promoting rapid basipetal movement along the gradient.

Site Disturbance

After a site is harvested their is generally a large amount of debris left that can severely impead a planting operation for site regeneration. Prescribed burning for site preparation is an effective means of vegetation control and slash removal. Effective control can be obtained for at least one year following a burn (Cooper 1971). The use of a chop-and-burn system has been extensively employed in the southeast. The effects and behavior of burning, however, are not completely understood nor are they consistent (Martin 1978). Control of unwanted hardwood vegetation by burning alone does not last and sites usually require some form of release early in the rotation. Burning following chemical treatment is an added factor helpful for the control of some hard-to-kill species. Nelson et al. (1983) compared three chemical treatments, hexazinone at 6.72 kg ai/ha, triclopyr at 4.48 kg ai/ha, and a combination of hexazinone at 4.48 kg ai/ha plus triclopyr at 2 kg ai/ha, to chopped and burned plots. All plots were burned in late July after a May 19 application. Percent reduction in hardwood stems from 1981 to 1982 was 89, 88, 81, and 24 percent, respectively.

Effective burns may be achieved by optimum timing following chemical application. If the site is burned too soon after application the vegetation is still moist and herbicides have not been allowed to translocate to the root systems. If the site is burned too late, late season herbs that germinate and/or hard-to-kill species that resprout reduce the effectiveness of the burn. More intensive and effective burns are achieved when vegetation is dry, resulting in reduced sprouting and greater consumption of slash (Sandberg and Ward 1981).

Summary

To optimize the control achieved by a chemical treatment for site preparation, the proper chemical combination can produce a broad spectrum kill that can substantially reduce hardwood competition. To further enhance the chemical treatment adequate time should be given before site disturbance to allow for the herbicides to reach the root systems of target species. A combination of the most effective chemical treatment and proper timing of disturbance can enhance early pine plantation establishment.

DETERMINATION OF THE EFFECTIVE TIME FOR CHEMICAL ACTIVITY IN SITE PREPARATION USING TRICLOPYR, PICLORAM AND/OR 2,4-D

ABSTRACT

Four chemical combinations used for site preparation in southern pine, including triclopyr {[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid}, picloram (4-amino-3,5,6-trichloropicolinic acid), and 2,4-D [(2,4-dichlorophenoxy)acetic acid] were screened for the most effective control of selected hardwoods. The chemical combinations were tested on Piedmont and Coastal Plain physiographic sites and were examined for the optimum amount of time for chemical activity between application and slash disposal (site disturbance). A combination of triclopyr and picloram at 2 and 1 lb ai/ac, respectively each gave the best overall control of hardwood brush. The amount of time required to obtain the optimum chemical control, presumably related to translocation, was found to be six to eight weeks after application to the foliage. Chestnut oak (_Quercus prinus_ L.) control was successfully predicted on the bases of plant tissue and environmental data.

INTRODUCTION

The field of forest vegetation management is growing rapidly and the use of herbicides for site preparation is gaining widespread acceptance. The biological responses (Cain and Mann 1978; Clauson 1980) and the economic benefits (Stewart and Row 1981) of chemical site preparation have been demonstrated extensively. It is not yet conclusive what level of weed control is acceptable for young stands to produce optimum growth; however, relative to the chop-and-burn system, the level of control achieved by chemical site preparation is excellent (Nelson et al. 1983).

There are three basic steps to the chemical site preparation system: the application of the herbicides to the vegetation that remains after a harvest, a waiting period for the chemicals to translocate, and a "disturbance" of the site, usually by prescribed burning. The success of this system can be affected by the chemical(s) used, the amount of time allowed between spraying and disturbance, and the intensity and type of disturbance used for slash disposal.

The forester's selection of chemicals is quite limited relative to those confronting weed problems in agronomic or horticultural crops. To obtain the broad spectrum kill of hardwood brush necessary for chemical site preparation, herbicide mixtures have proven to be very successful. Three herbicides used on unwanted woody competition, triclopyr, picloram, and 2,4-D, have been shown to be more effective in combinations than when either was used alone (Haywood 1980).

The chemical cost in site preparation is a substantial investment; therefore, to obtain the most benefit from the treatment adequate time should be given between application and disturbance. This insures that the chemical has had time to translocate from the leaves to the roots before the crowns are consumed by fire or in some way separated from the root system. Greenhouse tests have shown peak translocation to the root system in just a few days (Bovey and Mayeux 1980); however, field trials indicate control can be adversely affected by burning too soon after application. Hall and Brady (1976) found that concentrations of picloram in the roots of woody plants peaked five weeks after application to the foliage. Still, by waiting too long the burn intensity can be reduced by the germination of late season herbs or the resprouting of hard to kill woody species. Therefore, the window of time for the most beneficial burn should be within a time frame soon after chemical translocation has peaked.

Burning can do more than just decrease slash on a site. An effective burn can broaden the spectrum of kill on individuals which may be missed by the chemical or those that may be damaged but not killed. The response to a burn, however, is variable and can be subject to numerous conditions which include weather, fuel load and fuel moisture.

This experiment was designed to examine the efficacy of four chemical combinations used for site preparation in southern pine, and to determine whether environmental data and plant tissue moisture content could be used to predict control response, to aid in the determination of an optimum disturbance time.

METHODS AND MATERIALS

Study Site and Design

Two sites scheduled for chemical site preparation, one representing the Coastal Plain, and the other representing the Piedmont physiographic provinces were chosen for the experiment. Both sites were located on land owned and managed by Chesapeake Corporation, Timberlands Division. The first of the two sites was located in Richmond County, Virginia. This county lies on the peninsula between the Potomac and Rappahanock rivers known as the Northern Neck.

The topography was generally flat or gently sloping and the soils, classified in the Suffolk series (sandy loam), had a weak fine structure. The growing season lasts approximately 194 days (April 15 to October 26). Precipitation is well distributed throughout the year with a maximum in July and a minimum in February (Crockett 1972; SCS 1982). The second site was located in the northeast part of Appomattox County, Virginia. There is no up-to-date soil survey for this area; however, analysis of the particle size distribution of the upper horizon keys this soil as a loam. This soil has strong structure and is derived from shale. Because of the relatively steep topography and past land uses, the soils show signs of moderate to heavy erosion. The growing season lasts approximately 168 days from April 29 to October 14. Precipitation is well distributed throughout the year with a maximum in August and a minimum in October (Crockett 1972).

Both study sites consisted of separate installations of the experiment. There were four whole plots (chemical treatments) completely randomized with three replications. The four chemical treatments included:

1) triclopyr at 4 lb ae/ac
   (Garlon 4 at 1 gal/ac)
2) triclopyr at 2 lb ae/ac + picloram at 0.81 lb ae/ac + 2,4-D at 3 lb ae/ac
   (Garlon 4 at 0.5 gal/ac + Tordon 101 at 1.5 gal/ac)
3) triclopyr at 2 lb ae/ac + picloram at 1 lb ae/ac
   (Garlon 4 at 0.5 gal/ac + Tordon K at 0.5 gal/ac)
4) triclopyr at 1.5 lb ae/ac + 2,4-D at 5.7 lb ae/ac
   (Garlon 4 at 0.75 gal/ac + Esteron 99 at 1.5 gal/ac)

Each plot represented an aerially applied swath, and was approximately 50 feet in width and 400 feet in length. The chemicals were applied by helicopter on 24 June 1983 in 15 gal/ac of total spray solution. The weather was clear with less than 2 mph wind speed.

To assess the effect of time for chemical activity split-plots were assigned cutting dates following the application. Split plots are approximately 100 feet in length (50 feet wide). Using hand cutting tools (chain saws and hand clippers) up to ten individuals of each species, five species per site, were cut on each cutting date for each split-plot. Cutting the individuals was chosen over burning the plots because of the expected difficulty in burning small blocks, the unexplained variability observed between burns, and the desire to observe what effect the chemical application could supply solely. Before cutting each individual, crown height and diameter were taken. Cuttings started after "brown-out" (approximately four weeks past the spray date) and continued at two week intervals for ten weeks. Each individual was tagged with a unique identifier. Utilizing green strips located adjacent to the study area, a control cut was installed for each of the four cutting dates. On each visit (includes spray date and 4 cutting dates) stem and leaf samples were taken consistently from only three of the five species on each site for each split-plot to determine moisture content. Samples were weighed then dried in an oven at 68 degrees C until weights stabilized. A hygrothermograph was placed on each site to record temperature and humidity data for the period from the spray date to the final cut. Additional weather data were obtained from nearby weather stations located in Warsaw and Appomattox, Virginia (Nat. Oceanog. Atm. Admin. 1983). Crown regrowth was measured in the Winter of 1983-84 and again in the Fall of 1984. Measurements of the individuals regrowth included crown height, two perpendicular crown diameters and stem diameters of all sprouts within a clump at 15 centimeters above the origin. The measurements were used to determine crown volume and basal area.

Analysis

The results were expressed as percent kill (the percentage of stems judged to be dead) and percent control. Percent control was determined using equations 1-3.

$$PC = \frac{CR - TR}{CR} * 100 \; ; \qquad (1)$$

where, PC = percent control (%),
CR = estimated control (untreated) regrowth (m^3),
TR = treated regrowth (m^3).

An estimation of the control (untreated) regrowth was determined for each individual plant based on its original size before cutting and its expected recovery:

$$CR = OS * R; \qquad (2)$$

where, OS = the original size before treatment (m^3),
R = expected recovery (decimal fraction).

Expected recovery was determined for each site * species combination based on the amount of resprouting observed for control untreated individuals:

$$R = \frac{OS - RG}{OS}; \qquad (3)$$

where, RG = the measured regrowth of the control (untreated) plant (m^3).

This was used to determine crown volume or basal area control. The response data were analyzed using analysis of variance or analysis of covariance to determine factor and interaction significance. Percent kill values were analyzed after arcsine transformation. Significant means were separated using Duncan's Multiple Range test.

RESULTS

Response to Chemical Treatment

For species response to chemical treatment there were significant differences and consistent trends. For percent kill, there was very little separation between chemical treatments in the first year. White oak (Quercus alba L.) was the only species to have a significant separation between the means (Table 1). Second year responses extenuated differences between treatments. Due to a loss of two replications of the triclopyr + picloram treatment between the first and second year measurements, no statistical comparisons could be made between this and other treatments on the Piedmont site. The triclopyr + 2,4-D treatment performed significantly lower than triclopyr alone on three of the five species assayed. It was also significantly lower than the triclopyr, picloram and 2,4-D treatment on two of the five species. Triclopyr, picloram and 2,4-D in combination performed the lowest on the treatment of scarlet oak (Quercus coccinea Muench.). On the Coastal Plain site, where the triclopyr + 2,4-D treatment was not included, triclopyr alone performed significantly lower than triclopyr + picloram on black cherry (Prunus serotina Ehrh.) showing a 44 percent kill vs. 84 percent kill respectively. There were, however, no other separations between treatments.

Table 1. Percent kill by chemical treatment (triclopyr, picloram, and/or 2,4-D)[1]. Observations given for first and second year assessment on the Piedmont and Coastal Plain physiographic provinces[2].

	Year 1				Year 2			
	Triclopyr	Triclopyr + 2,4-D	Triclopyr + picloram + 2,4-D	Triclopyr + picloram	Triclopyr	Triclopyr + 2,4-D	Triclopyr + picloram + 2,4-D	Triclopyr + picloram
	(%)							
Piedmont								
Acer rubrum	94 a	82 a	85 a	96 a	66 a	46 a	56 a	87
Quercus prinus	79 a	79 a	87 a	90 a	61 a	43 b	64 a	55
Quercus alba	67 b	82 ab	78 ab	91 a	85 a	66 b	88 a	84
Quercus coccinea	87 a	84 a	91 a	88 a	83 a	70 b	62 b	89
Nyssa sylvatica	100 a	100 a	100 a	100 a	92 a	93 a	96 a	100
Coastal Plain								
Acer rubrum	81 a	--	93 a	85 a	78 a	--	86 a	95 a
Prunus serotina	81 a	--	92 a	86 a	44 b	--	79 ab	84 a
Liquidambar styraciflua	76 a	--	96 a	89 a	68 a	--	80 a	60 a
Liriodendron tulipifera	75 a	--	96 a	84 a	71 a	--	79 a	78 a
Quercus falcata	81 a	--	95 a	91 a	66 a	--	75 a	76 a

[1] Percent kill = number of individuals judged dead/total number of individuals.

[2] Row means within years not followed by the same letter differ at the 0.05 significance level (Duncan's MRT).

Since values of percent control using basal area and crown volume control were nearly identical, only percent control by crown volume is presented (Table 2). White oak control was significantly lower (first year results) for triclopyr vs. triclopyr + picloram. By the second year the separation between treatments on the Piedmont site was the same as observed for the percent kill. The triclopyr treatment had a significantly higher control of red maple (Acer rubrum L.) chestnut oak (Quercus prinus L.) and white oak over the triclopyr + 2,4-D treatment, and a significantly higher control of scarlet oak relative to the complete treatment using all of the chemicals. The three chemicals together produced a significantly higher control than triclopyr + 2,4-D for white oak. There were no significant differences on the Coastal Plain site; however, control was quite low for the triclopyr treatment of black cherry relative to the other treatments. This was consistent with the results from percent kill.

Response to Disturbance Timing

Four of the ten species had a significant response to disturbance timing (Table 3). Chestnut oak and scarlet oak were the only species to show a significant response to disturbance timing based on percent kill. The values for

Table 2. Percent control of crown volume by chemical treatment (triclopyr, picloram, and/or 2,4-D)[1]. Observations given for first and second year assessment on the Piedmont and Coastal Plain physiographic provinces[2].

	Year 1				Year 2			
	Triclopyr	Triclopyr + 2,4-D	Triclopyr + picloram + 2,4-D	Triclopyr + picloram	Triclopyr	Triclopyr + 2,4-D	Triclopyr + picloram + 2,4-D	Triclopyr + picloram
	(%)							
Piedmont								
Acer rubrum	94 a	82 a	85 a	98 a	90 a	72 b	86 ab	94
Quercus prinus	81 a	80 a	88 a	90 a	74 a	55 b	72 ab	70
Quercus alba	72 b	78 b	84 ab	91 a	90 a	78 b	90 a	92
Quercus coccinea	91 a	88 a	95 a	93 a	94 a	87 ab	80 b	97
Nyssa sylvatica	100 a	100 a	100 a	100 a	96 a	98 a	99 a	100
Coastal Plain								
Acer rubrum	87 a	--	95 a	87 a	94 a	--	96 a	98 a
Prunus serotina	82 a	--	93 a	90 a	62 a	--	88 a	87 a
Liquidambar styraciflua	93 a	--	96 a	95 a	84 a	--	90 a	87 a
Liriodendron tulipifera	95 a	--	98 a	93 a	80 a	--	84 a	84 a
Quercus falcata	90 a	--	98 a	93 a	82 a	--	86 a	85 a

[1] Percent control = (CR - TR)/CR; where, TR was the resprouting response of chemically treated plants and CR was its expected growth without chemical treatment. The prediction of CR was developed from the resprouting response of plants not chemically treated.

[2] Row means within years not followed by the same letter differ at the 0.05 significance level (Duncan's MRT).

those individuals cut four weeks after application were lower than for those cut at six, eight or ten weeks.

All of the oak species showed a significant response to disturbance timing. White oak control was significantly lower when cut at week four relative to those cut at weeks eight or ten. For chestnut and scarlet oak second year results indicate control can be adversely affected by cutting as early as four weeks after application. Southern red oak was the only species on the Coastal Plain site that had a significant response to disturbance timing; control was best when cut at week ten relative to week four.

<u>Prediction Equations for Percent Control</u>

Both sites experienced droughts in July and August that were well below normal rainfall. The average departure from the normal for the Coastal Plain during these two months was -2.44 inches. For the Piedmont site the departure averaged -1.74 inches below normal. Before the spray date, however, both sites experienced above normal rainfall, a departure of 0.44 inches on the Coastal Plain and 0.24 on the Piedmont during the months of May and June. In the three to four days prior to application of the herbicides, both sites received an abundant amount of rainfall (1.79 inches on the Coastal Plain and 2.49 inches on the Piedmont). This

Table 3. Second year percent kill and percent control of crown volume response to disturbance timing[1]. Disturbance timing evaluated at 4, 6, 8, and 10 weeks following application[2].

Species	Percent Kill				Percent Control			
	Week				Week			
	4	6	8	10	4	6	8	10
	(%)							
	Piedmont							
Acer rubrum	55 a	66 a	53 a	51 a	84 a	87 a	80 a	78 a
Quercus prinus	42 b	57 a	68 a	57 a	50 b	67 a	77 a	73 a
Quercus alba	77 a	74 ab	78 a	89 a	76 b	85 ab	92 a	92 a
Quercus coccinea	57 b	80 a	78 a	74 a	74 b	93 a	90 a	91 a
Nyssa sylvatica	97 a	92 a	93 a	93 a	99 a	97 a	97 a	98 a
	Coastal Plain							
Acer rubrum	85 a	88 a	84 a	89 a	95 a	95 a	96 a	97 a
Prunus serotina	74 a	76 a	65 a	56 a	84 a	87 a	80 a	69 a
Liquidambar styraciflua	66 a	81 a	52 a	77 a	80 a	96 a	81 a	91 a
Liriodendron tulipifera	73 a	75 a	76 a	80 a	80 a	83 a	84 a	85 a
Quercus falcata	60 a	76 a	72 ab	83 a	70 b	90 a	83 ab	95 a

[1] Percent kill = number of individuals judged dead/total number of individuals. Percent control = (CR - TR)/CR; where, TR was the resprouting response of chemically treated plants and CR was its expected growth without chemical treatment. The prediction of CR was developed from the resprouting response of plants not chemically treated.

[2] Row means within percent kill and percent control not followed by the same letter differ at the 0.05 level (Duncan's MRT).

however, marked the beginning of the summer drought in which precipitation was 0.52 inches on the Coastal Plain and 1.02 inches on the Piedmont prior to the installation of the first cutting (Nat. Oceanog. Atm. Admin. 1983). Therefore, plant tissue moisture contents showed a substantial decrease in the first month following application.

After sufficient drying and breakdown of the plant tissue hydration was correlated with rainfall. A method of removing the variance in tissue hydration due to rainfall was devised. A crude approximation of the effect of precipitation, rainfall divided by days since an event, was regressed against moisture content using the model:

$$MC = b_0 + b_1 (RF/D); \qquad (4)$$

where, MC = moisture content of the plant tissue samples (%),
b_0 = the model intercept (%),
b_1 = the slope coeficient,
RF = rainfall (inches),
D = days since a rainfall event.

This method was successful in removing variation due to precipitation such that the residual tissue moisture content values followed a logical pattern of increased drying with time since treatment.

Prediction equations of percent control were developed for each chemical treatment based on residual tissue moisture content, original size, and cumulative heat sum.[5] (Table 4). In order to avoid over-fitting of the models, the number of variables was reduced to these three based on the trial and error of many variable transformations. Modeling was attempted for all species for which moisture content data were taken; however, chestnut oak responded best to attempts at modeling "percent control" with environmental and physiological data. This was consistent in that none of the other species elicited a significant response to disturbance timing. Regardless of the response variable (percent control of crown volume, percent control of basal area, or percent kill), all resulting models had similar coefficients. Residual tissue moisture content was a variable selected for all of the treatments applied to chestnut oak. This relationship is observed in Figure 1 which shows the mirror image of percent control to residual stem moisture content. Moisture content and heat sum could be important variables for prediction to standardize the models and make them applicable in the field.

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[5] Cumulative heat sum was the sum of the average daily temperature from the spray date to the time of cutting.

Table 4. Multivariate prediction equations for percent control of crown volume, percent control of basal area, and percent kill of chestnut oak.

Treatment	Dependent Variable[1] (%)	Intercept (%)	Residual tissue moisture content (%)	Original crown volume (m^3)	Log of heat sum[2]	Coefficient of Determination
Triclopyr	PCCV	92.948	-0.945	-1.670		0.750
	PCBA	88.585	-0.981	-1.392		0.681
	PK	86.425	-1.086	-2.058		0.604
Triclopyr + 2,4-D	PCCV	242.596	0.345	-21.543	-15.206	0.898
	PCBA	265.279	0.327	-21.223	-18.529	0.909
	PK	279.027	0.277	-18.296	-22.202	0.752
Triclopyr + picloram + 2,4-D	PCCV	84.480	0.875	-5.540		0.755
	PCBA	76.728	1.086	-2.058		0.782
	PK	72.674	1.069	-4.778		0.712

[1] Dependent variables PCCV, PCBA, and PK are percent control crown volume, percent control basal area, and percent kill, respectfully.

[2] Log of heat sum is the natural log of the sum of the average daily temperature from the spray date to the time of cutting.

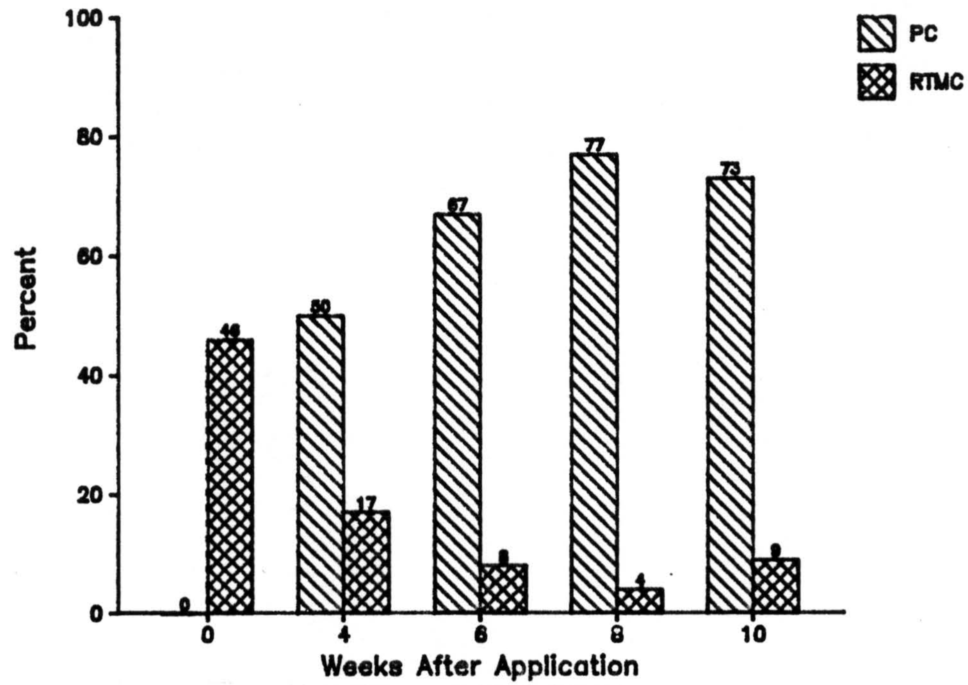

Figure 1. A comparison between mean percent control of crown volume (PC) and mean residual tissue moisture content (RTMC) (n=3 observations at each cutting date for each variable). RTMC was the variation that remained after removal of variation in tissue moisture content attributed to rainfall.

DISCUSSION

Herbicide Efficacy Assessment

All of the response variables used to evaluate the efficacy of the different herbicide treatments showed consistency in the results. Based on these results, a ranking of the treatments from best to worst would be triclopyr + picloram, triclopyr alone, triclopyr + picloram and 2,4-D, and triclopyr + 2,4-D. The efficacy observed by the triclopyr + 2,4-D treatment was consistently poor. Of the five species treated with triclopyr + 2,4-D, four had some measure of efficacy (percent kill or percent control) that was significantly lower than the treatment of triclopyr alone. Three of those species had response measures for triclopyr + 2,4-D that were significantly lower than the triclopyr + picloram and 2,4-D treatment.

Herbicide combinations are preferred for site preparation so as to obtain the broad spectrum kill desired. Triclopyr picloram combinations are recommended because of past efficacy tests (Haywood 1980). However, because of the mobility of this chemical it is not recommended for application near sensitive crops, particularly tobacco (Nicotiana tabacum L.) These results indicate that control of common southern hardwood species with triclopyr alone was not significantly different from triclopyr-picloram combinations except on black cherry.

Disturbance Timing Assessment

There was a greater response to disturbance timing on the Piedmont relative to the Coastal Plain site which could be linked to many factors. Moisture stress brought on by extremely dry conditions, as experienced during the translocation period, can cause decrease in the movement of herbicides within a plant (Davis et al. 1968). Still, there are no indications, based on the weather information available, that the conditions on the Piedmont or Coastal Plain were different. One might suspect that the soil conditions that differ (clayey on the Piedmont, sandy on the Coastal Plain) may have contributed to an imposed water stress on the Piedmont site because of less available water.

The fact that the soil conditions differ may also have contributed to another phenomenon such as soil activity. Picloram has been shown to be soil active; because the sandy soil of the Coastal Plain could have provided a more suitable medium for soil transport, the effect of time could have been masked due to herbicide entry into the plant by root uptake. Scifres et al. (1977) reported that leaves abscised from sprayed plants that fall to the soil surface can serve as a source of herbicide to the plant's roots. Leaves that fell to the ground, or tops that were cut and left to lie could have been sources of herbicide to the roots, and moved into the soil profile by rains that followed in the fall.

Another possible explanation could be the species differences. Only oak had a significant response to disturbance timing in the second year. Hardwood species vary in their susceptibility to herbicides. Attributes, such as leaf thickness, can reduce or slow penetration and subsequently have an impact on the rate of translocation. This was shown in an extreme case by King and Radosevich (1979). They found that the resistance of tanoak (Lithocarpus densiflourus Hook. and Arn.) to herbicide injury was attributed to its thick mature leaves.

Prediction of the Optimum Burn Time

Values for percent kill and percent control of chestnut oak were very similar between triclopyr and triclopyr + picloram and 2,4-D (Tables 1 and 2). The model intercepts were also similar (Table 4). The very large intercept for the model for triclopyr + 2,4-D could have been the result of overall poor control observed for this chemical treatment. The model developed for the triclopyr treatment is the only one with consistent coefficients. The response variables' relationship to residual tissue moisture content was negative as expected. Also the relationship to original size was negative as the larger the individuals were the more difficult they were to kill. For the other two treatments all response variables had a negative relationship to original size; however, both showed a positive relationship to residual moisture content.

The ability of predicting percent control could prove to be an important tool for the forest land manager faced with the decision of when to burn. Gross approximations made from these data, such as six to eight weeks is an adequate time for complete chemical activity, are adequate for the time being. However, the inclusion of plant attributes (ie. moisture content, size) and some measure that relates to environmental conditions, to predict the optimum burn time would be most effective. The data presented were a comparison between samples taken on a plot, related to that plot's mean response. Models developed from samples tied back to the individual's response could provide a much better fit to the variables. Still, these results indicate that the response is fairly uniform to the plot mean and thus provides evidence that the use of samples like these are practical for a site estimation of when to burn.

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THE EFFECT OF TEMPERATURE AND TIME SINCE APPLICATION ON THE DISTRIBUTION OF HERBICIDES IN RED MAPLE

ABSTRACT

The effect of temperature and time on the distribution of foliar-applied triclopyr {[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid}, picloram (4-amino-3,5,6-trichloropicolinic acid), and 2,4-D [(2,4-dichlorophenoxy)acetic acid)] were observed in red maple (Acer rubrum L.). Detection of the herbicides in the shoots and roots using gas chromatography revealed that triclopyr was not consistently affected by temperature differences; however, overall more herbicide reached the roots of red maple growing in a 21° C than those growing in a 29° C temperature. Triclopyr concentrations in the roots reached a peak much earlier than picloram or 2,4-D which did not peak until 42 days after application.

INTRODUCTION

The efficacy of a foliar-applied herbicide is related to the chemical penetration and translocation. The rate of penetration and translocation is in turn affected by environmental conditions before, during and after application as well as the chemical(s) used. Davis et al. (1968a) examined the effect of moisture stress on the uptake and translocation of herbicides. While herbicide absorption into the leaves was generally unaffected by moisture stress, the pretreatment of plants to moisture stress reduced the transport of picloram and 2,4,5-T [(2,4,5-trichlorophenoxy)acetic acid] in honey mesquite (Prosopis glandulosa Torr.) and winged elm (Ulmus alata Michx.). Radosevich and Bayer (1979) studied the effect of a combination of temperature and photoperiod on the movement of herbicides in several species. Simulated conditions of early summer (16 h photoperiod with 29 and 13^{0} C day and night temperatures) were compared to conditions of early spring (12 h photoperiod with 13 and 4^{0} C day and night temperatures). All herbicides (triclopyr, picloram and 2,4,5-T) were most mobile in the plant under early summer conditions. Generally, conditions which favor plant growth also favor herbicide activity.

Herbicide combinations have proven to be an effective means of controlling hard to kill species and broadening the spectrum of kill (Haywood 1980; Bovey and Meyer 1985). Some chemicals can be made more effective by using combinations. Davis et al. (1968b) showed that the uptake and transport of picloram in honey mesquite was increased in the presence of 2,4,5-T. Paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) was shown to be antagonistic when applied with picloram reducing transport (however, not absorption) and suppressing its phytotoxicity. It was suspected that the suppression of phytotoxicity was the result of paraquat's destructive effect on the transport system.

In the use of these herbicides for chemical site preparation to establish pine plantations, it is generally found that triclopyr + picloram combinations are more effective than triclopyr alone on red maple, a hard-to-kill species (Haywood 1980). An effective combination often used employs the combination of triclopyr with a formulation of picloram that includes 2,4-D. The effect of picloram and 2,4-D added to triclopyr and the rate of triclopyr are subject of concern. The objectives of this study were to compare the distribution of triclopyr, picloram and 2,4-D in red maple (*Acer rubrum* L.) when triclopyr was applied alone at a high rate or in combination with picloram and 2,4-D at a lower rate. Concentrations in the roots or shoots were compared relative to the effect of temperature or time since application to the foliage.

METHODS AND MATERIALS

Design

The experiment was set up as a completely randomized design. Dormant red maple seedlings obtained from a private nursery during the spring of 1984 were planted in each of 40, one cubic foot pots containing a 1:1 mixture of Pro Mix BX and sand. After potting, the seedlings were placed inside growth chambers set at the predetermined temperatures until they were actively growing (approximately three weeks). Daytime temperatures (16 hour photoperiod) consisted of 29 and 21^{0} C. Both chambers were maintained at a constant night temperature of 21^{0} C. Relative humidities were adjusted to 70 and 50 percent for the high and low temperatures respectively so as to maintain a constant vapor pressure deficit (1.23 KPa). The seedlings were sprayed on July 25 and 26, 1984 using 196 l/ha of total spray solution. The application was made using an experimental spray hood. The soil was protected from direct application by an approximate one inch layer of perlite at the base of the seedling. The seedlings were allowed to dry and then returned to their respective chambers.

Chemical treatments included:

1) Triclopyr at 4.45 kg/ha, and

2) Triclopyr at 2.22 kg/ha + picloram at 0.90 kg/ha and 2,4-D at 3.34 kg/ha

On each harvest date four pots were randomly selected from each temperature, two from each chemical treatment. The dates included: 7, 14, 28, 42, and 56 days after application.

Herbicide Detection and Analysis

Analysis was performed on the roots and shoots (division at the root collar) on the five harvest dates. Roots or shoots for a pot were combined to make up a replication. Samples were frozen then freeze-dried before being ground. Extraction of the herbicide involved the weighing out of a 10 g sample of plant tissue and adding 180 ml of 0.1N NaOH. The sample was blended in a Polytron homogenizer for 30 seconds, the blades were rinsed with 20 ml 0.1N NaOH and the rinse was combined to the sample. After shaking the sample for 30 minutes, a 10 ml-aliquot of the caustic solution was removed and acidified with 7 g NaCl and 1 ml 6N H_2SO_4, and the residues were extracted with 20 ml of 3/7 ether/hexane. This sample was then shaken for five minutes. After centrifuging at 2000 rpm, the ether/hexane was drawn off and placed in a vial containing 15 ml of 0.1N $NaHCO_3$. The ether/hexane-bicarbonate mixture was then shaken for 5 minutes, centrifuged and the ether/hexane was discarded. An additional 20 ml portion of ether/hexane, following the same procedure as above, was partitioned against the bicarbonate mixture and the ether/hexane discarded. Added then to the bicarbonate solution was a 10 ml portion of diethyl ether; this was shaken, centrifuged and the ether discarded. Four-six g of NaCl was added to the bicarbonate solution. Then slowly, 1 ml 6N H_2SO_4 was added to the mixture and left to sit until CO_2 was no longer evolved. A 10 ml portion of ether was added, the sample was shaken, centrifuged and the ether placed in a 15-ml conical centrifuge tube. This step was repeated with 5-ml of ether and added to the first extract. The extract was evaporated to 2 ml on a 40° C water bath under a gentle stream of nitrogen. Diazomethane (approximately 0.25 ml) was added to the solution and the mixture was evaporated to 1.0 ml on a water bath.[6]

Two ul were then injected into a 180 cm x 4 mm column of 3% OV-3 on 80/100 mesh Gas Chrom Q. The concentration in ug/ml of the esters in the final solution was determined by comparing peak height to that of the standard. Percent

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[6] Procedure by R.D. Glas. The Dow Chemical Company. Midland Michigan 48640

recovery was determined by the analysis of fortified samples. Recovery for triclopyr, picloram and 2,4-D was 82, 70, and 90 percent, respectively. Corrected concentrations were determined by dividing the sample concentrations by percent recovery and multiplying by 100. Analysis of variance was used to determine temperature, harvest and interaction significance. Means were separated using Duncan's multiple range test.

RESULTS AND DISCUSSION

Temperature Effect

Comparisons were made between the herbicide concentrations found in the root or shoot at the two temperatures. The values observed for triclopyr in the shoot were higher when applied to plants growing under the higher temperature (Table 1). Bukovac (1976) reported that predisposing plants to high temperatures (20 to 30° C) and high humidity (70 to 100 %) resulted in greater absorption. This factor could have influenced the higher concentrations found in the shoot. Still, 2,4-D and picloram concentrations were higher in the shoots of red maple subjected to the lower temperature.

Plants treated with a combination of triclopyr, picloram and 2,4-D, and exposed to a lower temperature, had higher herbicide concentrations in the roots relative to those exposed to a higher temperature (Table 1). The p-values for differences between the means of triclopyr, picloram and 2,4-D at the two temperatures were .3704, .2837 and .4572, respectively. Therefore, more herbicide, when applied in combination, moved to the roots of seedlings treated with the lower temperature. These results are inconsistent with those of Radosevich and Bayer (1979) who found that higher temperatures increased herbicide mobility. The difference may have been in the temperature extremes, 13 and 29° C for the 1979 publication and 21 and 29° C for this study. These results imply that translocation rates increase with temperature but reach a point where the higher temperatures impair herbicide movement.

Despite the doubling of the rate of triclopyr, when applied alone, resulting concentrations in the roots were greater only for the higher temperature. There are two possible explanations. 1) Picloram and 2,4-D could have facilitated the movement of triclopyr. These two chemicals showed an increase in root herbicide concentrations as a result of the lower temperature and correspondingly could have aided in the translocation of triclopyr. 2) The results could have been affected by an interaction between the temperature and rate of triclopyr applied. Under the

Table 1. Herbicide concentrations (ng/mg of dry weight) in roots and shoots of red maple as affected by temperature.

Herbicide	Temperature (° C) 21	29	p-value[1]
	------(ng/mg)------		
		Shoot	
Triclopyr (4.45 kg/ha)	29.24	36.04	.3546
	.3385[2]	.1482[2]	
Triclopyr (2.22 kg/ha)	27.36	30.93	.6378
2,4-D (3.34 kg/ha)	79.51	75.05	.5502
Picloram (0.90 kg/ha)	59.40	54.63	.4680
		Root	
Triclopyr (4.45 kg/ha)	1.70	2.28	.5149
	.4580[2]	.2226[2]	
Triclopyr (2.22 kg/ha)	3.39	1.46	.3704
2,4-D (3.34 kg/ha)	30.52	24.31	.4572
Picloram (0.90 kg/ha)	13.80	6.54	.2837

[1] p-values for comparisons between row means.
[2] p-values for comparisons between mean triclopyr concentrations within plant part and within temperature.

conditions of the high temperature, mobility of the three chemicals applied in combination was less. If triclopyr, having a high phytotoxicity, moved slower in the plant as a result of the higher temperature, it may have caused less destruction of the transport system; a destruction similar to that observed with the addition of paraquat to picloram (Davis et al. 1968b). Correspondingly, a lower concentration of applied triclopyr, when temperatures were optimum for transport, could have resulted in greater mobility of the chemicals versus a higher concentration that resulted in destruction of the transport system.

Time Effect

There were very little changes in herbicide concentrations of the shoots over time. Shoot concentrations were initially high (at 7 days) and remained high for all chemicals (Table 2). There was more 2,4-D in the shoots than either of the other chemicals applied. Values for triclopyr in the roots were highest only 7 days after application for both treatments and no significant differences were detected up to day 56. Triclopyr root concentrations could have peaked before the first harvest (day 7). Bovey and Mayeux (1980) found triclopyr translocation to be rapid in honey mesquite. In a

Table 2. Herbicide concentrations (ng/mg dry weight) in red maple roots and shoots 7, 14, 28, 42 and 56 days after application to the foliage[1].

Herbicide	Days after application				
	7	14	28	42	56
	(ng/mg dry weight)				
	Shoot				
Triclopyr (4.45 kg/ha)	36.81 bcd	45.52 b	26.15 bcd	16.31 d	38.42 bc
Triclopyr (2.22 kg/ha)	36.17 bcd	35.30 bcd	21.46 cd	21.36 cd	31.33 bcd
2,4-D (3.34 kg/ha)	76.04 a	84.82 a	76.39 a	80.23 a	59.36 a
Picloram (0.90 kg/ha)	52.23 bcd	62.47 bc	50.16 bcd	60.84 bcd	59.36 b
	Root				
Triclopyr (4.45 kg/ha)	3.00 d	2.28 d	1.90 d	1.52 d	1.23 d
Triclopyr (2.22 kg/ha)	7.29 d	1.20 d	1.35 d	0.89 d	1.40 d
2,4-D (3.34 kg/ha)	19.99 bc	24.79 b	23.58 b	46.56 a	22.14 bc
Picloram (0.90 kg/ha)	2.46 d	6.27 d	11.20 cd	22.80 bc	7.10 d

[1] Means within the same plant part (root or shoot) not followed by the same letter differ at the alpha = 0.05 significance level.

greenhouse test, when applied to the foliage, triclopyr concentrations peaked in the roots only 3 days after application.

Greater amounts of picloram and 2,4-D were moved to the roots up to 42 days after application. Hall and Brady (1976) found picloram concentrations were highest in the roots 5 weeks after application in red maple, sweet gum (Liquidambar styraciflua L.) and cherrybark oak (Quercus rubra var. leucophylla Ashe.). The decline observed with these data following peaks were also observed by Hall and Brady.

Red maple is a difficult species to control with triclopyr alone. Based on the relative amounts of picloram and 2,4-D in the roots as opposed to triclopyr it is understood why the addition of chemicals to facilitate control is necessary. Lower rates of triclopyr may be necessary for optimum translocation and efficient use of the chemical on red maple. The resistance often observed by this species to triclopyr may be the result of rapid death of the tissue in the upper shoot resulting in decreased translocation and subsequent resprouting.

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GENERAL CONCLUSIONS

Percent control, when computed rather than estimated, is most often a comparison between plot means: treated mean response to an untreated check. Due to an inability to maintain uniform original sizes between treated and untreated subject plants in this study, the percent control values that were computed in this manner were biased. The method devised for comparison between treatments proved successful in reducing the variability induced by a lack of uniformity between original sizes.

In comparing the chemical treatments the only one which showed a consistently poor control was the triclopyr + 2,4-D treatment. These results are consistent with reports of possible antagonism between these two chemicals.[7] This may be one of the reasons the formulation of picloram alone is a preferred choice as an additive to triclopyr over picloram + 2,4-D. Still, the level of control observed in this study with triclopyr or triclopyr- picloram mixtures, without the added effect of a burn, was excellent. Evidence from the second study supports the use of chemical combinations for

[7] Personal communication with C. T. Lichy, Dow Chemical U.S.A., Georgetown, SC 29440.

control of hard-to-kill species.

A greater number of species on the Piedmont than the Coastal Plain site showed a response to disturbance timing. Since only the oak species showed a response to disturbance timing this may have been a reflection of the fact that there were more oak species in the study on the Piedmont site or it may have been a reflection of the different site characteristics, or both. The adequate time for translocation to the root systems of hardwood species appears to be six to eight weeks based on the field study. This is further supported by the results of the translocation study which observed herbicide peaks in the roots six weeks after application to the foliage.

The use of plant and environmental data to predict target-plant response could prove important for land managers using chemical site preparation. Prediction of the optimum disturbance time is possible, but would require more information than is available from these data. Complete information for all species observed (moisture content, original size, and individual sprouting response) could improve the precision of the models.

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EFFECT OF TIME FROM TREATMENT TO DISTURBANCE ON WOODY PLANT CONTROL WITH TRICLOPYR, PICLORAM AND/OR 2,4-D

by

Patrick L. Burch

(ABSTRACT)

Two studies were designed to test three herbicides and factors which influence their efficacy. In the first study four chemical combinations used for site preparation in southern pine, including triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid), picloram (4-amino-3,5,6-trichloropicolinic acid), and 2,4-D [(2,4-dichlorophenoxy)acetic acid] were screened for the most effective control of selected hardwoods. The chemical combinations were tested on Piedmont and Coastal Plain physiographic sites and were examined for the optimum amount of time for chemical activity between application and slash disposal (site disturbance). Efforts were also made to use target-plant and environmental data to predict chemical efficacy. A combination of triclopyr and picloram at 2 and 1 lb ai/ac, respectively, each gave the best overall control of hardwood brush. The amount of time required to obtain

the optimum chemical control, presumably related to translocation, was found to be six to eight weeks after application to the foliage. Chestnut oak (*Quercus prinus* L.) control was successfully predicted on the bases of plant tissue and environmental data.

In a second study the effect of temperature and time on the distribution of foliar-applied triclopyr, picloram, and 2,4-D were observed in red maple (*Acer rubrum* L.). Detection of the herbicides in the stems and roots using gas chromatography revealed that triclopyr was less affected by temperature differences; however, overall more herbicide reached the roots of red maple growing in a 21^{0} C than those growing in a 29^{0} C temperature. Triclopyr concentrations in the roots reached a peak much earlier than picloram or 2,4-D which did not peak until 42 days after application.