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The Response of Honey Mesquite to Herbicides

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SUMMARY

Any environmental factors restricting the growth and development of honey mesquite at or near the proper time of herbicide application may reduce control. For example, translocation of sufficient herbicide may be restricted during periods of drought, cool weather, or cool soils (clay sites), or by damage to the foliage by insects, hail, or grazing. Application of herbicide too early in the life cycle will decidedly reduce herbicide transport to the lower stem and roots, since the translocating system may not be fully developed. Late applications (after July 1), may present certain barriers to herbicide uptake by heavy cuticle development and/or restrictions to translocation because of inactive phloem. The type of herbicide and formulation also has a profound effect on herbicidal control.

Many of the factors responsible for the effectiveness of 2,4,5-T in killing honey mesquite as outlined by research work prior to 1960 are still valid today, even though new herbicides are available and improvements in application techniques have been made. Recent research explains why honey mesquite control is affected by such factors as stage of growth, herbicide type, timing of application, certain leaf characteristics, moisture stress, and other environmental factors. Further research is needed to find more effective herbicides and better application techniques, and to elucidate conditions needed for obtaining optimal honey mesquite control.

INTRODUCTION

Mesquite (*Prosopis* spp.) occupies an estimated 93 million acres of range and pasture land in the Southwest (58). Fisher (30) indicates the species of major concern in the United States are velvet mesquite (*Prosopis velutina*) in Arizona, and honey mesquite (*P. glandulosa*) in California, Arizona, New Mexico, Utah, and Texas. According to a survey made in 1964 (70), over half, 56 million acres, mostly of honey mesquite, grows in Texas.

Native inhabitants and early settlers in the Southwest considered mesquite a source of fuel, building material, utensils, and weapons (30). Various foods, beverages, and medicines were made from the fruit (legume) or seed, and glue and candy were made from the gum exudate. The legumes are eaten by livestock and wild animals, the wood is often used for fuel, and the trees shade animals and provide ornamental value for people.

Mesquite, however, has spread, and population densities have increased to an extent that interferes with ranching operations and livestock production. It has been postulated (30) that the large influx of grazing animals during the last 150 years was the most important single factor influencing the increased density of mesquite. The primary causes include overgrazing by livestock, reduction in rangeland fires, and reduced competition from grasses. Periodic drought also contributes to mesquite invasion by reducing competitive vegetative cover.

Mesquite competes with desirable forage by being an extravagant user of soil water (60). Well-established trees may produce roots 15 to 40 feet deep or lateral roots that extend as far as 50 feet from the base of the plant (33). Mesquite roots have been found as deep as 125 feet in a mine (60). The extensive root system of mesquite makes it well adapted for competing with other vegetation and for survival during drought. The presence of mesquite in extensive and dense stands on grazing lands is considered one of the major agricultural problems in the Southwest. Mesquite not only reduces production and utilization of herbaceous forage but also makes handling and locating of livestock difficult. Mesquite also produces thorns injurious to humans, livestock, and pneumatic-tire vehicles.

Mesquite is presently controlled on grazing lands by mechanical methods (dozing, chopping, grubbing, mowing, root plowing, chaining), herbicides, and prescribed burning. Herbicides are easier, faster, and usually less costly to apply than most mechanical methods. The search continues, however, for more effective, less expensive herbicides that are safe to apply near cropland, gardens, and ornamental vegetation. Controlled fire and biological methods are being investigated, but herbicides are likely to remain the most effective method for mesquite control. This paper explores the factors involved in herbicide effectiveness in controlling mesquite and will define the need for understanding the interaction among physiological processes of the plant, environmental conditions, and herbicide-related factors such as timing of application, formulation, application rate, distribution on foliage, and mode of action.

HISTORICAL REVIEW

The most successful and economical broadcast herbicide treatment for mesquite is aerial application of a low volatile ester of 2,4,5-T [(2,4,5-trichlorophenoxy)-acetic acid] (23). The herbicide has been applied in a 1:3 diesel oil/water emulsion carrier at 4 gallons per acre 40 to 90 days after bud break of honey mesquite in the spring (35). Herbicide rate is 0.5 to 1.0 pound per acre (40).

Early Research

As early as 1946, Fisher *et al*. (31) developed methods to kill honey mesquite by application of kerosene or diesel oil to the lower stem and bud zone of individual trees. Fisher *et al*. (31) defined the anatomy and morphology of honey mesquite and showed that the dormant buds on the underground stem of mesquite must be destroyed in order to kill the plant. The addition of 2,4,5-T ester (1.25 percent) to the diesel oil increases mesquite mortality (36). Additional work of Young and Fisher (76) indicated that wetting the base of the mesquite plant with 0.5 percent solution of 2,4,5-T ester in oil was an economical and effective control measure for a limited number of trees. An effective cut surface treatment consisted of painting either the concentrated 2,4-D [(2,4-dichlorophenoxy)acetic acid] amine formulation or a 1 percent solution of an ester of 2,4,5-T in diesel oil on the exposed stem (38). As early as 1948, Fisher and Young (36) reported that sodium arsenite, sodium chlorate, ammonium sulfamate, sulfamic acid, ammonium thiocyanate, 2,4-D, and 2,4,5-T were the only chemicals out of several hundred tested that were absorbed by the foliage and translocated in sufficient amounts to kill dormant buds on the underground stem. However, the researchers indicated that ideal conditions of absorption and translocation of chemicals were seldom attained in the Southwest, since moist contact of the chemical with the leaf surface was required for long periods (8 hours). Increasing chemical concentration on leaf surfaces above lethal concentrations did not improve translocation.

It was reported in 1949 that an ester of 2,4,5-T applied to the foliage of mesquite was a more effective treatment than several formulations of 2,4-D or other chemicals (77). During the same year, aerial applications were made to mesquite in different seasons (37). Most effective control was obtained at the full leaf stage (spring) with ample soil moisture (90 percent canopy reduction and 25 percent mortality). By 1951, an estimated 0.5 million acres of honey mesquite were treated commercially with broadcast foliar sprays of the ester of 2,4,5-T in Texas (41).

Factors Affecting Results

In 1956, Fisher *et al*. (32) defined the factors responsible for the effective control of mesquite with 2,4,5-T. They included the following:

1. Effective control depends upon translocation of a toxic amount of 2,4,5-T from foliage to the crown tissues.
2. Greatest translocation of 2,4,5-T occurs during a 50- to 90-day period after the first leaves emerge in the spring (most favorable time of treatment).
3. Maximum translocation of 2,4,5-T occurs when total sugar content in roots is accumulating at a rapid rate following the low level at the beginning of the full leaf stage.
4. Minimum translocation of 2,4,5-T occurs when total sugars in roots are decreasing rapidly and when reducing sugars are relatively abundant.
5. Most effective control of mesquite with 2,4,5-T occurs when soil moisture is adequate, a heavy foliage cover is present, and after rapid growth of new leaves and stems has ceased.
6. Effectiveness of aerial application of 2,4,5-T is reduced when either drought-restricted growth or when intermittent rainfall causes irregular foliage growth.
7. Greater effectiveness of 2,4,5-T occurs when applied to mesquite growing on sandy loam and deep sandy soils compared with heavy clay soils and on small plants with stems less than 3 inches in diameter compared with larger trees.
8. Carriers, whether oils alone, oil-water emulsions or water alone, have no apparent influence on the effectiveness of 2,4,5-T applications when used at 4, 8, or 12 gallons per acre total volume.
9. A rate of 0.5 pound per acre of low volatile ester of 2,4,5-T in 1:3 oil-water emulsion effectively and economically controls mesquite. Increasing the amount of 2,4,5-T does not increase the percentage of mesquite killed.
10. Droplet size of sprays, formulation of 2,4,5-T, and weather factors do not appreciably affect the effectiveness of 2,4,5-T. However, these factors must be considered in ease and safe handling of the herbicide under field conditions.

Although the principles as outlined were established 25 years ago, they are still valid today for honey mesquite control in Texas.

Fisher *et al*. (32) indicated that the low volatile ester and suspended acids of 2,4,5-T were more consistent in killing mesquite than either the high volatile esters or the amine formulations. Tschirley and Hull (73), Reynolds and Tschirley (61), and Valentine and Norris (74) also found that the esters of 2,4,5-T were consistently more effective on velvet mesquite and honey mesquite than amine formulations.

Behrens (8) reported that droplet size, spray volume, and herbicide concentration had no direct influence other than minor effects on response of mesquite or cotton to 2,4,5-T, but that droplet spacing was of major importance. An average droplet spacing of 3100 microns, equivalent to a deposition rate of 72 droplets per square inch, was considered the maximum spacing that would maintain a high level of herbicidal effectiveness.

Soil Treatments

Effective mesquite control has been obtained by spraying a narrow band of soil around the base of trees with a suspension of monuron [3-(*p*-chlorophenyl)-1,1-dimethylurea] in water or by application of pellet formulations of monuron (33). Workers in New Mexico (57) also reported effective control of mesquite with monuron. Monuron was more effective than fenuron (1,1-dimethyl-3-phenylurea) or diuron [3-(3,4-dichlorophenyl)-1,1-dimethylurea]. Although the practice has never been used extensively in Texas, it demonstrates the first use of substituted urea herbicides for mesquite control.

Herbicides such as picloram (4-amino-3,5,6-trichloropicolinic acid), dicamba (3,6-dichloro-*o*-anisic acid), karbutilate [*tert*-butylcarbamic acid ester with 3(*m*-hydroxyphenyl)-1,1-dimethylurea], bromacil (5-bromo-3-*sec*-butyl-6-methyluracil), tebuthiuron (*N*[5-1,1-eimethylethyl)-1,3,4-thiadiazol-2-yl]-*N,N'*-dimethylurea), and prometon [2,4-bis(isprogylamino)-6-methozy-*s*-triazine] (20, 51, 64, 69) when applied as soil treatments for honey mesquite control, have generally been ineffective at economical rates.

Herbicide Mixtures

In 1967, Robison (62) was first to report that equal-ratio combinations of 2,4,5-T and picloram caused higher mortality of honey mesquite than either 2,4,5-T or picloram alone at equivalent rates of application. Bovey *et al*. (12, in nursery and greenhouse studies conducted in 1964 to 1967, reported results similar to those of Robison (62) using 2,4,5-T and picloram. However, paraquat:picloram (1:1) combinations were antagonistic on honey mesquite, indicating that paraquat reduced translocation of picloram in mesquite, huisache, and bean plants. However, uptake and transport of picloram in honey mesquite were increased in the presence of 2,4,5-T, and this may partially explain its increased herbicide effect (26).

Scifres and Hoffman (66) indicated that dicamba controlled about the same percentage of honey mesquite as equivalent rates of 2,4,5-T in the Rolling Plains, Coastal Prairie, and South Texas Plains. Combinations of 2,4,5-T and dicamba controlled no more honey mesquite than either herbicide alone, but dicamba was effectively substituted for 2,4,5-T in combinations with picloram. Three-way combinations were no more effective than dicamba:picloram or 2,4,5-T:picloram mixtures. In East Texas, Meyer and Bovey (50) found dicamba:picloram (1:1) mixtures to be more effective on honey mesquite than dicamba, picloram, and 2,4,5-T, or two-way combinations of dicamba, picloram, or 2,4,5-T.

Beck *et al*. (6, 7) indicated that 2,4,5-T:picloram (trimethylamine salts) mixtures were more effective than either the ester or amine of 2,4,5-T when applied to mesquite resprouts of different ages (6) and in controlling freshly shredded mesquite (7) at all dates of application. These data confirm earlier work on the effectiveness of the 2,4,5-T:picloram mixture compared to 2,4,5-T alone for honey mesquite control (12, 26, 35, 49, 50, 62, 66).

Influence of Soil Temperature

In 1971, Dahl *et al*. (25) reported soil temperature at the 18-inch depth was the most important factor affecting control of honey mesquite with aerial sprays of 2,4,5-T, and that best results occurred if soil temperatures were over 80°F. Sosebee *et al*. (71) indicated that soil temperature (18-inch depth) above 75°F, relatively low soil water content (0- to 6-inch depth), and tree height (less than 8 feet) were most influential in mesquite mortalities using triethylamine salt of 2,4,5-T:picloram (1:1 ratio).

Influence of Other Variables

Meyer *et al*. (52), however, found that soil moisture at a depth of 2 to 3 feet was the most important environmental variable of those measured, relative to mesquite control with 2,4,5-T, picloram, or picloram:2,4,5-T mixture. Plant characteristics most closely associated with control were widest translocating phloem thickness, most rapid rate of new xylem ring radial growth, and lowest predawn leaf moisture stress. In other studies (49), rate of new xylem ring radial growth and thickness of translocating phloem were the factors appearing most often in predictive equations for mesquite control with either 2,4,5-T or 2,4,5-T:picloram (1:1) mixtures.

Wilson *et al*. (75) predicted that best beginning dates for application of 2,4,5-T in West Texas were generally May 15 to June 15, and ending dates were from July 1 to July 15. The prediction was based on carbohydrate concentrations found in mesquite roots and the fact that phenoxy herbicides such as 2,4,5-T are translocated to the roots when carbohydrates are accumulating there.

In 1974, Fisher *et al*. (34) reported that low volume applications of 2,4,5-T or 2,4,5-T:picloram combinations at 0.25 to 0.5 pounds per acre of total herbicide were possible by aircraft for honey mesquite control. Variation in carrier volume from 0.5 to 4.0 gallons per acre did not significantly alter plant mortality.

New Herbicides

More recently, Jacoby *et al.* (46, 47) in field studies and Bovey and Meyer (18) in greenhouse research have indicated that triclopyr [(3,5,6-trichloro-2-pyridinyl)=oxyacetic acid] and 3,6-dichloropicolinic acid applied as foliar sprays have given excellent control of honey mesquite. Studies are being continued to define the parameters affecting results. The remainder of this paper explores details of the mode-of-action of herbicides and the influence of environmental factors on the physiology and effectiveness of foliar and soil-applied herbicides on honey mesquite.

FACTORS AFFECTING HERBICIDE RESPONSE

Stage of Growth

Honey mesquite is treated with herbicides at various stages of growth and in various forms. The two most common forms are the large, single-stemmed tree and the many-stemmed brush or small tree (54). Probably the many-stemmed plant is the most common form and may result from above or below ground growth from crown stem buds after damage from fire, grazing animals, mowing, drought, or herbicide injury. A third type of growth is the more or less decumbent or "running" type brush or shrub.

Most stands of mesquite are composed of distinct size and age classes. Such plants become established from seed during periods favorable to germination and establishment, often following severe overgrazing or other factors, such as drought, that reduce herbaceous vegetative cover.

The life cycle of mesquite is characterized by three distinct stages: seed germination and seedling establishment, juvenile plant, and mature plant (39). During herbicide spraying operations, one or more life stages may be present in the same pasture. Mesquite in different stages of growth can respond differently to the same herbicide treatment. Fisher *et al.* (32) indicated young plants with stems less than 3 inches in diameter were more effectively controlled with 2,4,5-T than older trees. Lack of vigor and poor foliage cover may be responsible for lower percentage mortality obtained on old trees. Fisher *et al.* (32) also indicated control of regrowth with 2,4,5-T originating from the crown buds (above-ground growth from damaged trees) was effective when new growth reached a height of 4 feet or more and attained heavy foliage. They indicated that there must be a balance of above-ground growth with that of the root system for most effective control. In other words, aerial growth (leaves) must be sufficient to intercept and translocate lethal quantities of herbicide to the crown zone. A single application of 2,4,5-T usually controls the plant population for 5 to 7 years before retreatment is necessary because of resprouting and recovery of the original plants. Plant mortality is typically 20 to 30 percent in northwest Texas with 2,4,5-T aerial sprays (35).

Control of creeping or running mesquite in Texas requires application of 2,4,5-T for 3 successive years (40). Apparently, the vigorous growth and extensive root system requires repeated 2,4,5-T exposure for adequate translocation to the roots. Velvet mesquite in Arizona requires two treatments for best control, which may be in consecutive years or 2 years between treatments, depending upon rate of regrowth following the initial application (72).

Greenhouse-grown and nursery plants respond to herbicides as does mesquite growing in natural stands (3, 9, 12, 15, 16, 17, 18, 26, 27, 28, 29, 53, 63, 67). Seedlings growing under field conditions are also susceptible to herbicides unless shoot:root ratios are such that aerial growth is inadequate to intercept and transport lethal amounts of herbicide to the crown zone. Large root biomass to aboveground biomass ratios occur if aerial growth has repeatedly been removed either by grazing (livestock, wildlife, or rodents), fire, or mechanical means. However, mesquite seedling mortality occurs if the stem is severed below the cotyledonary node (17, 54, 65). The younger the seedlings, the higher the mortality of mesquite from 2,4,5-T or picloram (17). For example, picloram or 2,4,5-T at 0.25 pound per acre killed 100 and 92 percent of 1-week-old plants and 37 and 17 percent of 16-week-old plants, respectively (17).

Beck *et al.* (6) studied the effect of 2,4,5-T amine, 2,4,5-T ester, and the trimethylamine salts of 2,4,5-T plus picloram (1:1) on honey mesquite resprouts 1, 7, and 14 years old under field conditions. No consistent differences were obtained between age of regrowth and level of control; however, the 2,4,5-T:picloram mixture was most effective at all dates of application (May, June, July or August). Beck *et al.* (6) suggested that equally effective control at some dates of application on 1-year-old resprouts and possibly some of the 7-year-old resprouts was due to absorption and translocation of herbicide by the green, succulent stems of the new growth and the close proximity of application to the crown zone.

Beck *et al.* (7) also reported excellent control of honey mesquite by simultaneous shredding and spraying. The 2,4,5-T:picloram mixture (trimethylamine salts) was consistently more effective than the amine or ester of 2,4,5-T. May treatments were more effective than those applied in June, July, August, or October 1972. Herbicide rate was not given.

Time and Types of Herbicide Treatment

The pioneering work of Fisher *et al.* (32) established that mesquite was most susceptible to 2,4,5-T sprays 50 to 90 days after bud break which usually occurs from May 15 to the first week in July. This period corresponds to cessation of leaf and twig growth (full leaf development) and the beginning of radial stem, trunk and root growth in the tree (39). Other researchers using foliar sprays of 2,4,5-T, picloram, and dicamba or various mixtures of these herbicides have confirmed Fisher's findings (6, 7, 12, 25, 40, 49, 50, 61, 62, 66, 71, 72, 73, 74). Application of herbicides to the foliage at other times during the year is usually not very effective unless it is a drenching spray made during the summer months to individual plants.

The cut-stump method involves treating the freshly-cut stump surface with herbicide (64). Hoffman (40) suggested using 8 pounds of 2,4,5-T in 100 gallons of diesel oil or kerosene and applying the mixture to the cut surface until the solution runs down the bark to the root crown. Using the cut-stump method, the herbicide may be poured on the stump or applied with various types of hand or power sprayers. Although the cut-stump method is effective, considerable time and expense may be saved by using the basal treatment method (64). The basal treatment consists of spraying or wetting the trunk with adequate liquid or spray to cause runoff from a height of 12 inches to the ground line, with enough solution to soak into the crown zone (40). Mesquite with a trunk diameter of 5 inches or less can be treated with basal herbicide sprays as used with the cut-stump method. Kerosene or diesel oil is also effective when the crown zone is throughly soaked. Trees with trunks greater than 5 inches in diameter should be frilled with an axe or similar tool and herbicide applied into the cuts.

Cut-surface, trunk-base, or frill treatments can be applied any season of the year, but best results are from summer or winter applications (40). Applications to cut-surfaces and trunk bases are more effective during dry periods when the soil is not fused to the tree trunk and liquid can penetrate to the root crown. Better control is obtained on sandy, rocky, or porous soils than on clay soils.

Soil-applied herbicides can be applied any time of the year but are most efficient in killing mesquite when applied prior to a sufficient amount of rainfall to leach the herbicide into the root zone. Mesquite, however, is difficult to kill with soil-active herbicides, especially when growing in clay soils.

Types of Herbicides Used

Types of herbicides applied, methods of application, and the response of honey mesquite to the treatments are shown in Table 1. In actual field use, foliar sprays include 2,4,5-T, 2,4,5-T:picloram, or 2,4,5-T:dicamba in 1:1 combinations usually applied at a total rate of 0.5 to 1.0 pound per acre of herbicide. More recently, triclopyr and 3,6-dichloropicolinic acid are showing promise as foliar sprays for honey mesquite control (16, 18, 46, 47). All these herbicides are hormone-like, growth regulator compounds, which are absorbed through leaf and stem tissue and are translocated to other plant parts from the point of application. Picloram, dicamba, triclopyr, and 3,6-dichloropicolinic acid are also effective herbicides via root absorption on many species and honey mesquite in the greenhouse (3, 9, 15, 16, 20, 64). However, under actual field conditions, the control of honey mesquite via root uptake from picloram and dicamba applied to the soil has not been effective (9, 10, 20, 51, 64).

One of the most effective soil-applied herbicides, especially in sandy soils, for control of honey mesquite is karbutilate (Table 1). Unfortunately, the compound is no longer commercially available for use on rangeland in the United States. Other soil-applied herbicides that have been investigated include diuron, fenuron, monuron, sodium arsenate, sodium chlorate, tebuthiuron, and hexazinone [3-cyclohexyl-6-(dimethylamino)-1 methyl-1,3,5-triazine-2,4(1*H*,3*H*-dione] (10, 20, 33, 51, 57, 64, 69, 74).

Basal sprays and the injection/cut surface treatments are discussed above. Chemicals used for both methods are listed in Table 1. Basal sprays or pours with kerosene, diesel oil, or diesel oil plus 2,4,5-T ester are a common practice to kill scattered trees of honey mesquite.

Foliar Absorption

Foliar-applied herbicides must be absorbed by leaf and stem tissue and translocated to the crown zone of honey mesquite to kill the plant. Factors affecting foliar absorption are examined in the discussion that follows.

Herbicide Type

Herbicides vary in rate of foliar penetration. Davis *et al*. (27) studied the uptake of picloram and 2,4,5-T in leaves of 10 woody species including honey mesquite and found that in most species picloram entered faster and accumulated at higher concentrations than 2,4,5-T. In other studies (28), honey mesquite leaves also absorbed picloram more rapidly and extensively than 2,4,5-T, but moisture stress reduced foliar uptake of picloram, whereas absorption of 2,4,5-T was unaffected. More recently, Bovey and Mayuex (16) found higher concentrations of 3,6-dichloropicolinic acid than 2,4,5-T, triclopyr or picloram in honey mesquite stems and roots 3, 10, and 30 days after application to soil or foliage in the greenhouse.

Herbicide Formulation

Morton *et al*. (56) found larger amounts of 2,4,5-T in honey mesquite leaves treated with the butoxyethyl esters of 2,4,5-T than with the ammonium salts. Concentration of 2,4,5-T translocated to the stems, however, was similar. Most data suggest that ester formulations of the phenoxy herbicides penetrate leaf surfaces more readily than amine salts (43). This may or may not result in greater accumulation of herbicide in the roots, since the esters are not translocated as readily as the amine salt formulations (22, 42).

Carriers and Adjuvants

Fisher *et al*. (32) evaluated a wide range of oils and oil-water emulsions as well as water as 2,4,5-T spray carriers for control of honey mesquite. The 1:3 diesel fuel oil-water emulsion was considered equally effective and more economical to use than specially formulated oils. In some instances, use of water alone as the carrier reduced the effectiveness of the 2,4,5-T application. Hull (42) indicated similar results on velvet mesquite. A nontoxic oil in a 1:4 oil-water emulsion as a carrier for 2,4,5-T resulted in considerably greater injury to the nontreated distal foliage than diesel oil as a carrier. Behrens (8) found that when diesel fuel alone was used as the carrier on greenhouse-grown plants at spray volumes of 12.5 and 32 gallons per acre, effectiveness was reduced compared to 4 gallons per acre. The reduced effectiveness was attributed to the phytotoxicity of the diesel fuel, which caused rapid killing of the leaves, limiting 2,4,5-T translocation. More recently, Scifres *et al*. (63) found that absorption of 2,4,5-T ester was more rapid in a paraffin oil carrier than in diesel fuel, water, or emulsions of the oils in water carriers. No significant differences in percentage mesquite control have resulted from foam carriers (68) compared with conventional sprays or addition of sufactants to the spray solution (19). Most commercial herbicide formulations have sufficient surfactant and wetting properties for wetting plant surfaces, and the addition of most surfactants or emulsifiers to the spray solution may have limited effect.

Spray carrier volume may influence herbicide results. Carrier volumes equivalent to 4, 20, and 100 gallons per acre [oil-water (1:3v/v)] with 0.5 pound per acre of the 2-ethylhexyl ester of 2,4,5-T were applied to nursery-grown honey mesquite (19). Herbicide applied at 20 gallons per acre using hand-carried sprayers reduced the canopy more than when applied at 4 or 100 gallons per acre. Compared to 20 gallons per acre, 4 gallons per acre may have resulted in insufficient coverage of the foliage whereas 100 gallons per acre may have resulted in loss of the herbicide from plant surfaces in excessive runoff.

Variation in carrier volume from 0.5 to 4.0 gallons per acre containing 0.25 to 0.5 pound of 2,4,5-T per acre of 1:1 combination of 2,4,5-T and picloram when applied by aircraft did not significantly affect honey mesquite mortality (34).

Meyer *et al*. found that mesquite leaves were functional in herbicide uptake for about 4 days after application. However, maximum absorption apparently occurred the day of spraying. Thus, any agent or force which causes leaf removal too quickly after spraying reduces control. In most cases, it is important to use a carrier which will penetrate the waxy surface of the leaf but will not kill the leaves or cause abscission soon after spraying (64).

Acidity

Uptake of 2,4,5-T-1-^{14}C by immersion of honey mesquite leaflets into solutions rapidly diminished as pH was increased from 3.5 to 5 in the treating solution (4). Leaves treated with droplets at pH 3.5 and kept moist absorbed about 92 percent of available 2,4,5-T-1-^{14}C during the first 3 hours of exposure, with no additional uptake between 3 and 5 hours. Comparable leaflets treated with droplets that were allowed to evaporate absorbed only 30 percent of available 2,4,5-T-1^{14}C during the first 3 hours and an additional 10 percent between 3 and 5 hours. Leaflets continued to absorb 2,4,5-T-1-^{14}C for about 14 to 24 hours after treatment with pH 3.5 droplets that were allowed to evaporate, but those kept moist did not absorb 2,4,5-T-1-^{14}C after 3 hours, presumably because of lack of available 2,4,5-T-1-^{14}C. Under laboratory conditions, weak acids penetrate best at low pH values where the molecules are largely in the undissociated form (22). In this state, they more readily penetrate the lipoidal phases of the cuticle and leaf cells. However, under field conditions, little benefit of improved control has been shown by adjusting pH of the spray solution.

Spray Characteristics

Spray droplet size affects phytotoxicity depending upon species studies. In some species, herbicidal efficiency decreases as droplet size increases above 500 micrometers in diameter (43). An average droplet deposition of 72 droplets per square inch is considered the maximum spacing that maintains a high level of herbicidal effectiveness when 2,4,5-T is applied to honey mesquite and cotton (8). Droplet size, spray volume, and herbicide concentration have no direct influence (8).

Air Temperature and Relative Humidity

Morton (55) treated honey mesquite seedling leaves with 5 µg of carboxyl-labeled 2,4,5-T and found more 2,4,5-T absorbed at 100°F than at 70° or 85°F after 72 hours. Approximately 50 percent of the 2,4,5-T applied to a single leaf was absorbed. Only slight differences in absorption were found at different humidity levels.

Rainfall

Bovey and Diaz-Colon (13) found that oil-soluble formulations (esters) of 2,4,-D and 2,4,5-T, and picloram were less affected by artificial rainfall than water-soluble herbicides such as paraquat (1,1'dimethyl-4,4'-bipyridinium ion) and cacodylic acid (hydroxydimethylarsine oxide) on guava (*Psidium guajava* L.) and mango (*Mangifera indica* L.). The oil-soluble phenoxy herbicides usually retained their effectiveness even when leaves were washed within 15 minutes after treatment. Field-grown honey mesquite leaves showed complete leaf necrosis even when leaves were washed 20 minutes after treatment with paraquat, indicating rapid absorption (11). Winged elm (*Ulmus alata* Michx.) and live oak (*Quercus virginiana* Mill.) showed little injury under the same conditions.

Moisture Stress

Merkle and Davis (48) showed that foliar absorption of 2,4,5-T and picloram in beans (*Phaseolus vulgaris* L. var. Black Valentine) was unaffected by extreme moisture stress. Moisture stress reduced foliar uptake of picloram in honey mesquite but not in winged elm (28). Moisture stress did not affect absorption of 2,4,5-T in honey mesquite.

Light

Light assists herbicidal penetration by stimulating stomatal opening in most species (1). Measurement of herbicide absorption by honey mesquite as influenced by quality and intensity of light has not been determined. Brady (24), however, found that the absorption of the isooctyl ester of 2,4,5-T increased as light intensity increased up to 2,680 foot candles, but it decreased thereafter in post oak (*Quercus stellata* Wangenh) and water oak (*Quercus Nigra* L.). Absorption of 2,4,5-T increased as light intensity increased up to 6,000 foot candles in long leaf pine (*Pinus palustris* Mill.) and American holly (*Ilex opaca* Ait). Davis *et al*. (27) found that uptake of picloram by live oak leaves decreased as light intensity increased.

Scifres *et al*. (67) found that honey mesquite seedlings which developed under shade (low-light intensity) were more easily killed by 2,4,5-T sprays than seedlings grown in sunlight. The increased effectiveness under shade may have been due to limited cuticle development (45) and, hence, greater herbicide uptake. Baur and Swanson (5) found that honey mesquite grown during short days was more susceptible to 2,4,5-T or picloram than that grown during long days. The reason for this difference is not clear but may be related to cuticular development.

Leaf Structure and Development

As indicated earlier, the best time for application of foliar herbicides for honey mesquite control is during a 50- to 90-day period after the first leaves emerge in the spring. By May 20, leaflets of honey mesquite in Brazos County have usually attained full maturity (54). The upper cuticle is usually 5 to 8 microns thick and the lower cuticle is usually 2 microns thick; however, penetration of the cuticle by herbicides appears sufficient for herbicidal effect and translocation to other parts of the plant. In most plants there is a relationship between cuticular development and composition, and foliar absorption of herbicides (45). The more mature the leaf, the greater the cuticular development, and that may partially explain the resistance of honey mesquite to herbicide sprays applied late in the growing season, even though limited stomatal penetration can occur when cuticules become very thick (45).

Metabolism and Degradation

Morton (55) found that approximately 80 percent of the 2,4,5-T absorbed by leaves of honey mesquite seedlings was metabolized after 24 hours. Metabolism was completely inhibited at 50°F, and a lower rate of metabolism was noted at 100° than at 70° and 85°F. Picloram, however, is more resistant to degradation in plants than 2,4,5-T (21).

Root Penetration

Field Studies

As indicated earlier, control of honey mesquite by soil-applied herbicides has not been highly effective in the field. However, triclopyr, picloram, and 3,6-dichloropicolinic acid are highly effective when applied to soil in pots supporting honey mesquite under greenhouse conditions. Possibly the extensive root system of honey mesquite and impermeable heavy clay soils in some areas may partially preclude effective control under field conditions. However, honey mesquite was more effectively controlled in the field when liquid formulations of karbutilate and tebuthiuron were applied subsurface, than on the soil surface (51).

Laboratory Studies

Baur and Bovey (3) studied changes in the concentration of picloram in roots, stems, and leaves of 20-day-old huisache and honey mesquite plants exposed for different lengths of time. Exposing roots to aqueous solutions of picloram for 24 hours killed about 60 percent of the treated plants. It took 10 times more herbicide to give the same response in honey mesquite (10 ppm) as huisache (1 ppm). In honey mesquite, picloram was redistributed and eventually lost from the plant into the rooting solution over a 5-day period, whereas huisache, a more susceptible plant, showed no redistribution or loss of picloram.

Translocation

Once an herbicide is absorbed by leaves and stems, a key factor in killing mesquite is translocation of the phytocide to the base of the stem. The phloem is the principal food-conducting tissue in vascular plants. Compounds like 2,4,5-T are translocated through the phloem from regions of carbohydrate synthesis (leaves) to sugar-importing tissues such as roots, buds, shoot tips, seeds and fruit, and other leaves. The direction of herbicide movement is determined by the patterns of food distribution and utilization within the plant, since translocation of food may also occur from roots to leaves or between other plant parts (22). Ideally, at least for the phenoxy herbicides, it is best to apply foliar sprays when food transport is occurring from the leaves (basipetal) to other plant parts (roots) so as much herbicide as possible is translocated to the base of the stem. In the case of honey mesquite, this occurs under springtime conditions after foliage is mature enough to export sugars and the plant is rapidly growing radially. If the herbicide is applied at other times during the year, results may be unsatisfactory since assimilate (food) movement may be limited. For successful chemical control of honey mesquite, movement of phytotoxic materials to regenerative tissues (buds) is necessary to eliminate their growth potential. The greatest concentration of buds occurs on the trunk in the first foot below soil line (31, 32, 35, 54, 64). Fisher and Young (36) reported in 1948 that sodium arsenite, sodium arsenate, sodium chlorate, ammonium sulfomate, sulfuric acid, ammonium thiocyanate, 2,4-D, and 2,4,5-T were the only chemicals out of several hundred tested that were absorbed by the foliage and translocated in sufficient amounts to kill dormant buds on the underground stem. Increasing chemical concentration of leaf surfaces above minimum lethal concentrations did not improve translocation. In 1949, Young and Fisher (77) reported that the ester of 2,4,5-T was a more effective treatment than several formulations of 2,4-D or other chemicals.

Early in the 1960's, picloram was discovered to be an effective herbicide for controlling honey mesquite and other woody species (9). The picloram:2,4,5-T combination (12, 62) was particularly useful. Davis *et al.* (26) in 1968 found that transport of picloram to the lower stem in honey mesquite was increased in the presence of 2,4,5-T whereas the uptake and transport of 2,4,5-T was decreased in the presence of picloram. Increasing ratios of 2,4,5-T:picloram in mixtures up to 16:1 continued to increase uptake and transport of picloram; the reverse effect occurred for 2,4,5-T when 2,4,5-T:picloram ratios were decreased. More total herbicide was transported when the 2,4,5-T:picloram combination was used than either herbicide used alone at equal rates. This may help to explain the greater effectiveness of the herbicide combination in controlling honey mesquite. When paraquat was combined with picloram on honey mesquite, huisache, and bean, transport of picloram to the lower stem was reduced because of damage of the transport system by paraquat.

In field studies, Davis *et al*. (29) found that highest concentrations of 2,4,5-T, picloram, or combinations of 2,4,5-T:picloram in phloem were associated with dates of best control of honey mesquite established by numerous investigations. Adding 2,4,5-T to picloram caused an increase in the amounts of picloram in the phloem in four of five dates of application (29). These data agree with the laboratory and greenhouse investigations described above (26). Therefore, the combination of picloram and 2,4,5-T is generally more effective than either herbicide applied alone.

More recently, Bovey and Mayuex (16) studied the effectiveness and transport of 2,4,5-T, picloram, triclopyr, and 3,6-dichloropicolinic acid in honey mesquite. Higher concentrations of 3,6-dichloropicolinic acid than 2,4,5-T, triclopyr, or picloram usually were found in honey mesquite stems and roots 3, 10, and 30 days after application to soil, foliage, or both. This may be one reason why 3,6-dichloropicolinic acid is highly effective in controlling honey mesquite.

Herbicide Formulation

Although Morton *et al*. (56) found larger amounts of 2,4,5-T in honey mesquite leaves treated with butoxyethyl ester than the ammonium salt, concentrations of 2,4,5-T in the stem were equal. Hull (42) reported in velvet mesquite that when carried in a nontoxic oil emulsion, the free acid, and the triethylamine and sodium salts of 2,4,5-T all demonstrated a greater tendency to be translocated to more distant portions of the plant than did ester formulations, even though contact injury to the treated leaves was less. Tschirley and Hull (73) however, found the ester of 2,4,5-T consistently more effective than the amine formulation on velvet mesquite under field conditions. Research data of Fisher *et al*. (32) on honey mesquite agree with that of others (73) in that the low volatile esters and suspended acids were more consistent in killing mesquite than either the high volatile esters or the amine formulations. The reasons for the superior performance of the ester of 2,4,5-T over the amine formulation has not been clearly established, but the ester formulation probably penetrates the wax and cuticle on the leaf more readily than the amine. However, Beck *et al*. (6, 7) showed little difference in effectiveness between the ester and amine formulations of 2,4,5-T on honey mesquite. Differences in formulation may have been masked by high rate of application or by the fact that sprays were applied to the base of the plants.

Carriers and Adjuvants

Scifres *et al*. (63) compared water, diesel oil, water: diesel oil (1:4) emulsion, paraffin oil, and water:paraffin oil (1:4) emulsion for carriers of 0.5 pound per acre of the butyl ether esters of 2,4,5-T. No differences related to carrier occurred in the amount of 2,4,5-T translocated to the stem and roots, although greater amounts of herbicides were absorbed by leaves treated with diesel or paraffin oil carriers.

Temperature and Relative Humidity

Translocation of 2,4,5-T in honey mesquite seedlings was primarily basipetal (downward) from the point of application at 70°F, both acropetal (upward) and basipetal at 85°F, and only a short distance acropetal at 100°F (55). The quantities of 2,4,5-T translocated into untreated tissues at 100°F were less than at 70° and 85°F. The highest concentrations of 2,4,5-T were found in tissues with highest soluble sugar concentrations. From 3 to 27 percent of the 2,4,5-T absorbed by honey mesquite leaves was subsequently detected in untreated stem, leaf, and root tissues. Total amounts of C^{14} (carboxyl-labeled 2,4,5-T) detected in the untreated tissues of the seedlings tended to increase, particularly in the roots and lower stems, with increasing humidity.

Radosevich and Bayer (59) found that 2,4,5-T, triclopyr, and picloram transport was greater in periods of warm temperatures (84° and 55°F day and night) and long days (16-hour photoperiod) than cool temperatures (55° and 35°F day and night) and a 12-hour photoperiod in five plant species as revealed by autoradiographs. They found little metabolism of any herbicide, and each herbicide moved readily in the symplast (phloem); however, root application revealed limited apoplastic (xylem stream) mobility.

Light

Light intensity affected translocation of 2,4,5-T to the roots of woody plants (24). There was a negative linear relationship between light intensity and 2,4,5-T content of post oak roots. In water oak roots, however, herbicide levels increased as light intensity increased. In longleaf pine and American holly, translocation was not significantly influenced by light intensity. Herbicide translocation in honey mesquite as influenced by light has not been measured.

Moisture Stress

Moderate moisture stress in beans did not have a significant effect on the translocation of picloram but did have on the translocation of 2,4,5-T (48). Advanced stress significantly reduced the translocation of both herbicides. However, translocation of 2,4,5-T was apparently more sensitive to changes in moisture stress than was translocation of picloram. Picloram was more mobile than 2,4,5-T at all moisture stress levels studied. After 4 hours, as much picloram was translocated to the apex and central stem of bean plants from a 24 microgram application as there was 2,4,5-T at 8 hours after a 50 microgram application. This agrees with studies on honey mesquite in which both herbicides were detected in the apex only 4 hours after treatment, but only picloram occurred in the roots (28). After 24 hours, the apex and roots contained more picloram than 2,4,5-T. The phloem-cortex accumulated greater quantities of picloram than the xylem-pith, indicating major transport via the symplast. After 90 hours, herbicide concentrations in most tissues were unchanged or higher than after 24 hours. These data support observations by Meyer *et al*. (53) which indicated a period of 3 to 4 days was required for honey mesquite to absorb and translocate herbicide for maximum killing of stems. Moisture stress sufficient

TABLE I. GENERAL RESPONSE OF HONEY MESQUITE TO VARIOUS HERBICIDES[1]

Herbicide	Chemical name	Application method[2]			
		BS	FS	I/CS	ST
AMS	Ammonium sulfamate		S[3]		
Bromacil	5-bromo-3-*sec*-butyl-6-methyluracil	R			R
Cacodylic acid	Hydroxydimethylarsine oxide			S-I	
Dicamba	3,6-dichloro-*o*-anisic acid		S	S	R
2,4-D	(2,4-dichlorophenoxy)acetic acid		S-I	S-I	
3,6-DPA	3,6-dichloropicolinic acid		S		
Dichlorprop	2-(2,4-dichlorophenoxy)propionic acid		I		
Diesel oil		S			
Diuron	3-(3,4-dicholorophenyl)-1-1-dimethylurea				I-R
DSMA	disodium methanearsonate			S	
Fenuron	1,1-dimethyl-3-phenylurea				I-R
Glyphosate	*N*-(phosphonomethyl)glycine		I-R		
Hexazinone	3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1*H*,3*H*)-dione				I-R
Karbutilate	*tert*-butylcarbamic acid ester with 3(*m*-hydroxyphenyl)-1, 1-dimethylurea				S-I
Monuron	3-(*p*-chlorophenyl)-1,1-dimethylurea				I-R
Paraquat	1,1′-dimethyl-4,4′-biphyridinium ion		I-R		
Picloram	4-amino-3,5,6-trichloropicolinic acid		S		R
Prometon	2,4-bis(isopropylamino)-6-methoxy-*s*-triazine				I-R
Silvex	2-(2,4,5-trichlorophenoxy)propionic acid		S		
Sodium arsenite					S
Sodium chlorate					I-R
2,3,6-TBA	2,3,6-trichlorobenzoic acid				R
Tebuthiuron	*N*-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-*N*,*N*′-dimethylurea				I-R
2,4,5-T	(2,4,5-trichlorophenoxy)acetic acid	S	S	S-I	
Triclopyr	[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid		S		
2,4-D + 2,4,5-T			S-I		
2,4-D + picloram			S-I		
2,4,5-T + dicamba			S		
2,4,5-T + picloram			S		
Picloram + dicamba			S		

[1] References: 6, 7, 9, 10, 12, 16, 18, 19, 20, 21, 31, 33, 35, 36, 37, 38, 40, 46, 47, 49, 50, 51, 52, 57, 62, 64, 66, 69, 71, 74, 76, 77.

[2] BS, FS, I/CS and ST = basal spray, foliar spray, injection (cut surface treatment, and soil treatment, respectively.)

[3] S, S-I, I, I-R, and R = susceptible, susceptible to intermediate, intermediate, intermediate to resistant, and resistant, respectively, to honey mesquite.

to slow growth markedly reduced transport of picloram and 2,4,5-T into untreated tissues. Bovey *et al*. (14) found that 1:1 combination of the triethylamine salts of picloram:2,4,5-T was more effective on huisache and Macartney rose when applied in the evening than in the morning or at midday in field studies. Internal water stress of the plants was less at night after the 6:00 p.m. treatment than after the 6:00 a.m. or 1:30 p.m. treatment, allowing more favorable environment for absorption and translocation of the herbicide.

Other Factors

Meyer *et al*. (52) sprayed honey mesquite in the field with three herbicides at 14 different dates during 1969 and 1970. Most effective control of honey mesquite occurred from treatments applied between April 30 and July 6. Picloram and a picloram:2,4,5-T (1:1) mixture were the most effective herbicides. Plant characteristics most closely associated with control included widest translocating phloem thickness, most rapid rate of new xylem ring radial growth, and lowest predawn leaf moisture stress. Environmental variables most clearly associated with honey mesquite control were lower maximum air temperatures of 77° to 96°F 1 week before treatment, maximum soil temperature of 63° to 79°F at a depth of 3 feet 1 week before treatment, and decreasing percent soil moisture from 25 to 18 percent at a depth of 2-3 feet 1 week before treatment. In subsequent studies (49) of responses to spraying on 36 dates from March to October during a 4-year period, percent honey mesquite canopy reduction was directly correlated with total phloem thickness, rate of new xylem ring radial growth, and rate of upward methylene dye movement in the xylem and was inversely correlated with minimum leaf moisture stress. Rate of new xylem ring radial growth and thickness of translocating phloem appeared most often in the equations.

Dahl (25) indicated soil temperature at the 18-inch depth was the most important factor affecting response of honey mesquite to 2,4,5-T application in the spring. Temperatures at this depth in the high 60°'sF or low 70°'sF resulted in no mesquite mortality; best results occurred when temperatures were over 80°F. Proper phenological development of mesquite and soil moisture were important factors in combination with other variables. Mesquite trees on upland and sandy sites were easier to kill with 2,4,5-T than those growing on bottomland and clay sites because the soil is usually several degrees F warmer on upland and sandy sites.

Nitrogen fertilizer did not enhance the control of honey mesquite when sprayed with 2,4,5-T after fertilizer application (2). Ammonium nitrate fertilizer has no effect on the nitrogen or the niacin levels in honey mesquite.

RESEARCH NEEDS

The following areas need serious investigation if we are to improve present mesquite control measures with herbicides and increase our understanding of the physiology, biochemistry, and mode-of-action of herbicides and growth regulators:

1. in-depth understanding of assimilate and water movement in honey mesquite under well-defined conditions
2. better understanding of the mode-of-action, metabolism, absorption, and translocation of herbicides presently used for honey mesquite control
3. investigation of methods to modify the susceptibility of honey mesquite to herbicides by use of growth regulators, surfactants, herbicide combinations, antitranspirants, and other adjuvants
4. determination of the most important environmental factors affecting the susceptibility of honey mesquite to herbicides
5. search for more effective and efficient chemicals for honey mesquite control
6. research on integrated honey mesquite management systems where two or more control methods are applied in a well-planned sequence.

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