Weed Science. 1988. Volume 36:810–817

Conditions Influencing Turbinella Oak (*Quercus turbinella*) Mortality from Picloram or Picloram and 2,4-D[1]

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Abstract. Turbinella oak was sprayed with picloram-containing herbicides on 90 dates throughout 81 months. A mixture of triisopropanolamine salts of picloram and 2,4-D was compared to the potassium salt of picloram on 44 dates, and to a mixture of isooctyl ester of picloram and propylene glycol butyl ether esters of 2,4-D on 42 dates. Low rates of herbicide treatments were used to increase the sensitivity to environmental factors and plant growth stages. Turbinella oak mortality was greater with the mixture of picloram and 2,4-D amines than with picloram alone or the mixture of picloram and 2,4-D esters. The mixture of picloram and 2,4-D esters did not kill any plants. The combination of available soil moisture at the 60-cm depth, no senescent or falling leaves, and full-sized leaves was the best indicator of when to apply picloram or the mixture of picloram and 2,4-D amines. No turbinella oak were killed when soil at the 60-cm depth was dry or leaves were falling at the time of treatment. Nomenclature: Picloram, 4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid; 2,4-D, (2,4-dichlorophenoxy)acetic acid; turbinella oak, *Quercus turbinella* Greene #[3] QUETB.

Additional index words. Herbicide translocation, soil water content, plant growth.

INTRODUCTION

Although many attempts have been made to control hard-to-kill woody plants, their responses to herbicides are still uncertain (9, 21, 23), indicating that each species has its own specific requirements for optimal control (14, 18). The development of safe and efficient control methods would be advanced by determining how different woody species respond to various herbicides under a variety of climatic and edaphic conditions.

Turbinella oak, a hard-leaved, multistemmed, evergreen shrub has numerous dormant buds on the stems and root crown that develop after shoot damage. Turbinella oak is found from southeastern California to southern Colorado, Utah, Nevada, western Texas, and northern Mexico. The species is most common in the Arizona interior chaparral (13) but it also grows in oak woodlands, pinyon-juniper woodlands, pine forests, and shrub deserts. Control of this species increases water yield, reduces fire hazard, protects soil, increases forage for livestock and wildlife, improves timber production, and provides access for grazing and recreational uses (3).

Methods that consistently control turbinella oak and that can be widely used are not available. Root plowing has been successful only in areas with deep, rock-free soils (10). Burning followed by herbicide spraying provides only temporary control (10).

Picloram, one of the few herbicides still available for use on southwestern rangelands, kills several oak species (2). Turbinella oak was killed by picloram in some trials (5) but not in others (7). Wagle and Baker (22) believed that erratic responses to herbicides were caused by genetic variation within the turbinella oak complex. The responses of woody species to herbicides have been related to growth stage, soil moisture, timing of application, photosynthesis, movement of solutes in the xylem, and xylem water potential (11, 14, 15). The conditions that determine turbinella oak response to picloram are unknown.

The objectives of this study were primarily to identify environmental and phenological conditions that influence turbinella oak mortality from picloram-containing herbicide sprays, and secondarily to compare the efficacy of a mixture of amine salts of picloram and 2,4-D to: a) the potassium salt of picloram alone, and b) a mixture of esters of picloram plus 2,4-D for turbinella oak control with low-rate applications.

MATERIALS AND METHODS

Study area. The study was done at Blue Grade, 59 km southwest of Flagstaff, AZ, on the Coconino National Forest. The original overstory of Utah juniper [*Juniperus osteosperma* (Torr.) Little] and pinyon (*Pinus edulis* Engelm.) was removed by cabling, bulldozing, and slash burning in the late 1950's. An understory of scattered turbinella oak about 1 m tall remained.

More than half of the 41-cm average annual precipitation occurred in the winter. Winter precipitation was usually from general, low-intensity, frontal storms; summer precipitation was usually from localized, high-intensity, convection thunderstorms. Spring and fall seasons were dry.

The elevation is 1650 m, and the topography is flat. The soil is Springerville clay classed as fine, montmorillontic, mesic Typic Chromusterts ranging from 90 to 150 cm deep, underlain by basalt. The soils were normally dry during the spring.

[1] Received for publication February 5, 1988, and in revised form July 2, 1988.

[2] Res. Agron., Agric. Res. Serv., U.S. Dep. Agric., 2000 E. Allen Rd., Tucson, AZ 85719.

[3] Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Weed Sci. 32, Suppl. 2. Available from WSSA, 309 West Clark Street, Champaign, IL 61820.

Herbicide treatments. Picloram-containing herbicide sprays were applied on 90 dates throughout the years over 81 months. The herbicide treatments were: 1) picloram as the potassium salt (picloram alone), 2) a mixture of 1:3.7 (w/w) picloram and 2,4-D as triisopropanolamine salts (picloram and 2,4-D amines), and 3) a mixture of 1:1 (w/w) picloram as isooctyl ester and 2,4-D as propylene glycol butyl ether esters (picloram and 2,4-D esters). Herbicides were applied with a motorized backpack mist blower to individual shrubs 0.7 to 1.3 m tall and having crown covers of 1 to 16 m^2. The foliage was thoroughly covered to the point of runoff.

All sprays contained 2.4 g ae picloram/L in water, which is less than needed for uniformly killing turbinella oak as determined in preliminary trials. This low rate was used to increase sensitivity to conditions other than herbicide rates; limited space and materials did not allow rate comparisons. In addition to the 2,4 g picloram/L, the mixture of picloram and 2,4-D amines contained 8.9 g ae 2,4-D/L, and the mixture of picloram and 2,4-D esters 2.4 g 2,4-D/L. The mixture of picloram and 2,4-D esters was emulsified with 9.7 g of a nonionic emulsifier [4] /L of solution.

The mixture of picloram and 2,4-D amines and picloram alone were compared on 44 dates during the initial 40 months; the mixture of picloram and 2,4-D amines and the mixture of picloram and 2,4-D esters were compared on 42 dates during the final 41 months. The total number of application dates for each herbicide treatment was, however, 87 for the mixture of picloram and 2,4-D amines, 47 for picloram alone, and 42 for the mixture of picloram and 2,4-D esters.

Individual plots consisted of 10 adjacent tagged turbinella oak clumps; plots were paired and herbicide formulations applied in random order on each date. The paired plots were in randomized complete blocks of prenumbered, tagged turbinella oaks with two replications in a split-plot experimental design.

Plant response. Responses to the herbicides were determined visually by estimating percent shoot damage at monthly intervals for 1 yr after treatment and then at 24 and 36 months after treatment. Additional estimates were made at the end of each growing season for up to 8 yr after treatment. When live tissue was not observed for 2 successive yr, shrubs were considered dead.

Plant conditions. Observations and measurements of turbinella oak growth, development, and physiological status were conducted weekly at a prescribed site in the study area on the same five untreated shrubs. Observations included bud development, flowering, fruiting, stages of leaf growth, leaf senescence, leaf fall, stem growth, and root growth. Root growth was determined before treatment by examining roots in the surface 30 cm of soil near five randomly selected shrubs for the presence of new, unsuberized rootlets. Foliage water content was determined at the time of treatment. Before applications, leaves on five randomly selected plants were hand stripped from branches, weighed, oven dried, and reweighed to determine water content as a percentage of dry weight.

[4]An unidentified experimental product, Dow-M 3349, provided by the Dow Chem. Co., Midland, MI. Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the U.S. Dep. Agric. and does not imply its approval to the exclusion of other products that may also be acceptable.

Stem xylem translocation rate was determined by measuring ammonium thiocyanate movement in 1.0- to 1.5-cm-diam main shoots collected before treatment from seven randomly selected shrubs. Immediately after collection, the shoot cut end was immersed in degassed tapwater and the shoot was cut several cm above the initial cut. The shoot was then placed in a saturated aqueous ammonium thiocyanate solution for 10 min, removed, and cut into 10- to 15-cm-long sections starting near the top end. Section ends were brushed with saturated aqueous ferric chloride to detect ammonium thiocyanate. When ammonium thiocyanate was detected, the section immediately above was cut into 1-cm-long segments to find the highest point reached. The distance of movement was then measured.

Phenology of other species, such as blue grama [*Bouteloua gracilis* (H.B.K.) Lag.] and broom snakeweed [*Gutierrezia sarothrae* (Pursh.) Britt. & Rusby] growing near the turbinella oaks being treated, was also recorded to determine if such information could aid prediction of herbicide effects.

Environmental condition. Environmental conditions were measured at the prescribed site in the study area where phenological observations were made and between shrubs at the treatment sites during treatments. At the prescribed site, air temperature, relative humidity, and air movement were recorded 137 cm above the soil surface. Soil temperatures at 5 cm were recorded also. Rainfall was measured with recording and storage rain gauges. Weather records from nearby weather stations were used to determine relations to long-term weather trends in the area. Soil moisture potential was estimated with duplicate sets of calibrated electrical resistance gypsum blocks at depths of 1, 5, 15, 30, 45, and 60 cm. Gravimetric soil moisture samples were taken annually to calibrate the gypsum blocks. Comparisons of soil moisture were generalized to dry (−1.5 MPa or lower), moist (−0.03 to −1.5 MPa), and wet (higher than −0.03 MPa) to simplify this discussion.

Other environmental measurements and observations were made weekly at the prescribed site and before, during, and after herbicide applications at the treated site. Measurements included were air temperatures from maximum-minimum indicating thermometers shielded from direct radiation at 6, 30, 60, and 137 cm above the ground; wet and dry bulb temperatures at 137 cm above the ground; barometric pressures; wind speed and direction; cloud cover; rainfall; soil surface conditions like frost, standing water, or cracking; soil water content from depths of 0 to 7 and 7 to 15 cm and at irregular interval depths of 15 to 30, 30 to 45, and 45 to 60 cm; and soil temperatures at depths of 5, 20, 30, 45, and 60 cm.

Statistical analyses. Turbinella oak responses are based on shrub mortality and maximum shoot damage. The two herbi-

Table 1. Percent of applications in which some turbinella oaks are killed (frequency of mortality) by 47 applications of picloram or 44 applications of a mixture of picloram plus 2,4-D amines as related to limiting plant and environmental conditions during a 40-month period.

Limiting condition[a]	Picloram		Picloram + 2,4-D		Significance[b]
	(%)	(no.)	(%)	(no.)	
None	49	47	66	44	*
Soil moist	55	42	74	39	*
No leaf fall	79	28	93	27	NS
Shoot growth	68	28	81	27	*
SM + SG	68	27	81	27	*
SM + NF	79	28	93	27	NS
SM + NF + SG	77	22	91	22	NS
SM + NF + FL	78	27	93	27	NS

[a]SM = soil moist, SG = shoot growth, NF = no leaves falling or senescent, and FL = full-sized leaves.

[b]Comparison of frequency of mortality in rows; * = 0.05, ** = 0.01, and NS = not significant according to paired chi-squared tests.

cide treatment comparison trials were evaluated separately by analysis of variance. The mixture of picloram and 2,4-D esters caused no mortality and was not evaluated further.

Data obtained for the total number of application dates, 87 for the mixture of picloram and 2,4-D amines and 47 for picloram alone, were used to evaluate effects of environmental, phenological, and physiological conditions on turbinella oak mortality for each formulation unless stated otherwise. Environmental and physiological conditions, singly and in combinations, were evaluated by regression analyses for each formulation. Phenological conditions and environmental condition classes were evaluated by chi-square tests of independence in which treatment responses were classed as having or not having caused any turbinella oak mortality. Mortalities for condition classes are discussed as a percent of the applications made for the condition class in which some turbinella oaks were killed and referred to as "frequency of mortality".

Some data are presented as summaries by Julian dates regardless of year of occurrence to emphasize event occurrences throughout the year. Only probabilities of 0.05 or less were considered significant.

RESULTS AND DISCUSSION

Available moisture at 60 cm in the soil, no leaves senescent or falling, and full-sized leaves were the best combination of conditions for killing turbinella oak with either picloram or a mixture of picloram and 2,4-D amines foliage sprays (Tables 1 and 2). Some conditions, such as shoot growth or available deep soil moisture, by themselves were not dependable indicators (Tables 1 and 2). Long-term testing allowed examination of combinations of conditions to identify those that best indicated when to treat turbinella oak.

Herbicides. The mixture of picloram and 2,4-D amines was superior to the potassium salt of picloram (P = 0.025) and to the mixture of picloram and 2,4-D esters (P = 0.005) for killing turbinella oak (Figure 1). Some turbinella oaks were killed in every month except December, but mortality varied widely (Figure 1).

Picloram killed some turbinella oaks in 49% of 47 applications (Table 1) and half or more of the plants in 13% of the 47 applications. The mixture of esters killed no plants but damaged shoots extensively (Figure 1). The mixture

Table 2. Comparison of frequencies of turbinella oak mortalities (%) from applications of a mixture of picloram and 2,4-D amines in treatment periods of 40, 41, and 81 months.

Limiting condition	Treatment applications and mortality frequency								
	40 months		41 months		Significant[a]	81 months		Significant: 40 & 81 months[b]	Significant: 41 & 81 months[c]
	(%)	(no.)	(%)	(no.)		(%)	(no.)		
None	66	44	14	43	***	40	87	**	***
Soil moist	74	39	25	20	***	58	59	NS	*
No leaf fall	93	27	38	13	***	75	40	NS	*
Shoot growth	81	27	20	25	***	52	52	*	**
SM + SG[d]	81	27	50	10	NS	73	37	NS	NS
SM + NF[d]	93	27	71	7	NS	88	34	NS	NS
SM + NF + SG[d]	91	22	71	7	NS	86	29	NS	NS
SM + NF + FL[d]	93	27	100	5	NS	94	32	NS	NS

[a]Row comparison of percent frequency of mortality of picloram plus 2,4-D amines 40 and 41 months; * = 0.05, ** = 0.01, *** = 0.005, and NS = not significant according to paired chi-square tests.

[b]Row comparison of picloram plus 2,4-D amines 40 and 81 months.

[c]Row comparison of picloram plus 2,4-D amines 41 and 81 months.

[d]SM = soil moist at 60 cm, SG = shoot growth, NF = no leaves falling or senescent, and FL = full-sized leaves.

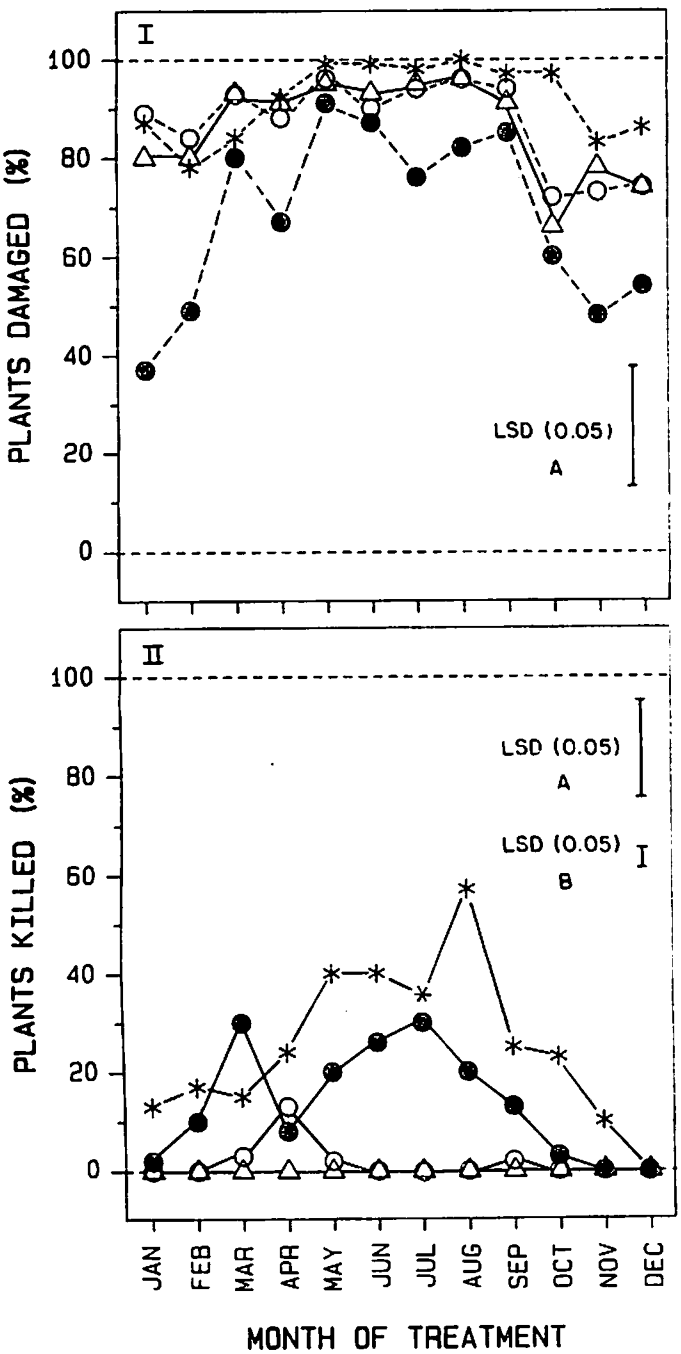

Figure 1. Monthly average percent of turbinella oak plants damaged (I) or killed (II) by picloram alone (●), a mixture of picloram and 2,4-D esters (Δ), a mixture of picloram and 2,4-D amines (•) when applied with picloram, and the mixture of amines (○) when applied with the mixture of esters. The dashed horizontal lines at 0 and 100% indicate these respective levels. LSD A compares the mixture of picloram and 2,4-D amines (•) to picloram alone (●). LSD B compares mortality from the mixture of picloram and 2,4-D amines (○) to that of the mixture of picloram and 2,4-D esters (Δ). There was no significant difference between the mixture of amines and the mixture of esters in plants damaged.

of picloram and 2,4-D esters was not compared to picloram alone, but Bovey et al. (1) found that the potassium salt of picloram was more effective than the ester on live oak (*Quercus virginiana* Mill). The mixture of esters is not included in further discussions.

In the initial 40-month trial comparing picloram and the mixture of picloram and 2,4-D amines, the mixture killed some plants in 66% of 44 applications (Table 1) and half or more of the plants in 30% of the 44 applications. In the second 41-month trial comparing the mixture of picloram and 2,4-D amines and the mixture of picloram and 2,4-D esters, the mixture of amines killed 20% or less of the turbinella oaks in 14% of 43 applications (Table 2). The mixture of picloram and 2,4-D amines killed some turbinella oaks in 40% of 87 applications over the entire 81-month period (Table 2). During the study there were five distinct dry periods lasting from 3 to 9 months, all occurring in the last 50 months. Therefore, the later 41-month trial was drier and less favorable for killing turbinella oak than the preceding 40-month trial (Table 2).

Plant conditions. Elongating stems, new leaves, and acorns indicated favorable times to treat turbinella oak (Figure 2). No shoot growth and senescent or falling leaves indicated unfavorable times for treatment.

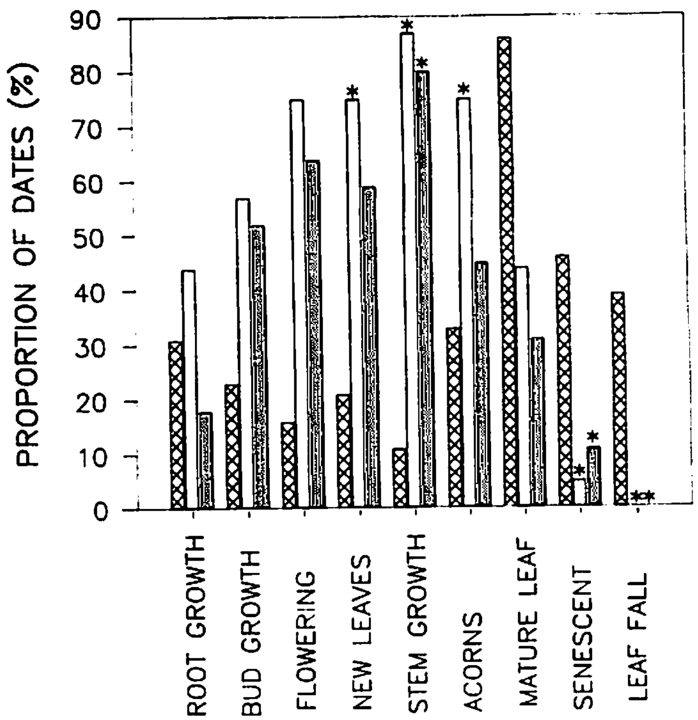

Figure 2. Turbinella oak phenological stages at time of treatment with herbicides showing the frequency that each phenological stage was observed (cross-hatched bar), and percent of the applications in which any turbinella oak was killed by picloram alone (white bar), or by the mixture of picloram and 2,4-D amines (black bar) when the phenological stage was observed. • denotes significant ($P \leq 0.05$) relationship of turbinella oak mortality or lack of mortality from herbicide application and specific phenological state.

Stem elongation, new leaves, and acorns were associated with increased frequency of turbinella oak mortality from both picloram (P = 0.025, 0.05, and 0.025, respectively) and the mixture of picloram and 2,4-D amines (P = 0.005, 0.05, and 0.025, respectively) in the initial 40-month comparison trial. But in the 41-month comparison trial and the 81-month evaluation of the mixture, only stem elongation was so associated (P = 0.005) (Figure 2). Other factors reduced turbinella oak mortality when new leaves or acorns were present in the longer term evaluations, rendering new leaves and acorns unreliable indicators. Stem elongation was observed in applications between April and the end of September (Figure 3). Weekly phenological observations showed stem elongation was infrequent but most likely from mid-May to the end of June.

Leaf senescence, as evidenced by color change or drying, indicated that few turbinella oaks would be killed by either picloram (P = 0.025) or the mixture of picloram and 2,4-D amines (P = 0.005) (Figure 2). Leaf senescence was more common during fall and winter applications (Figure 3). The weekly phenological observations indicated senescence occurred throughout the year but most commonly in June and early fall.

Leaves falling at the time of treatment were associated with no turbinella oaks being killed by picloram (P = 0.005) or the mixture of picloram and 2,4-D amines (P = 0.005) (Figure 2). Falling leaves were most common with fall and winter applications (Figure 3). Weekly phenological observations showed leaf fall occurred throughout the year, but

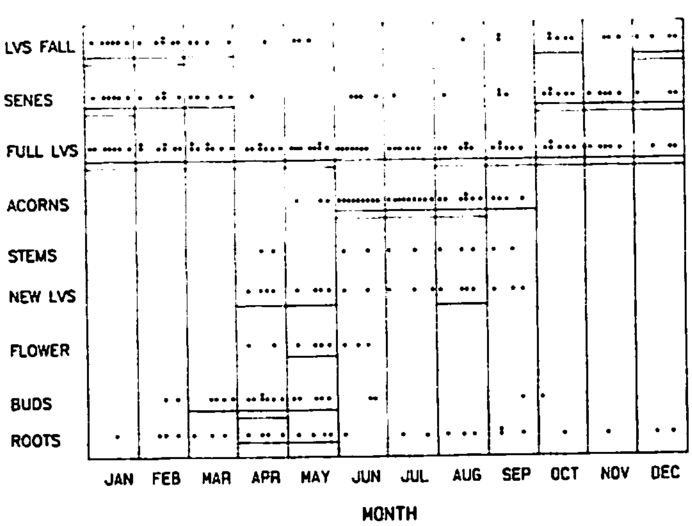

Figure 3. Summary of turbinella oak phenology stages on 90 application dates combining all years. Dots (•) indicate that the event was observed, single underscoring indicates that event was observed on half or more of the observation dates during that month, double underscoring indicates that event was observed on 75% or more of the observation dates during that month. ROOTS = roots growing; BUDS = buds growing; NEW LVS = leaves growing; STEMS = stem elongation; ACORNS = acorns present on the plant; FULL LVS = leaves fully expanded; SENES = leaves changing color or dry; LVS FALL = leaves falling off the shrub.

most commonly from October through December, and could be heavy in May or June following dry winters. Pase (16) reported turbinella oak leaf fall was most common from April through August. Lindemuth and Davis (12) reported leaves can persist longer than a year.

Both herbicides had similar high frequencies of turbinella oak mortality, 79% for picloram alone and 93% for the mixture of picloram and 2,4-D amines, when applications were made while no leaves were senescent or falling in the initial 40-month comparison trial (Table 2). However, frequencies of mortality were significantly less with the herbicide mixture in the second 41-month comparison trial (Table 2). Over the 81-month period, the frequency of mortality from the mixture of picloram and 2,4-D amines applications made when no leaves were senescent or falling was similar to that of the 40-month trial but different from that of the 41-month trial (Table 2). Hence, no leaves senescent or falling alone may not be reliable indicators since other factors may have been more important in determining turbinella oak mortality from these herbicides. Nonetheless, because leaf senescence and fall coincided with reduced mortality, having no leaves senescent or falling was an important consideration.

Turbinella oak mortality was independent of root growth, bud development, and flower development. These factors often coincided with other favorable conditions. However, the infrequency of their occurrence (Figure 3) and the overriding presence of conditions unfavorable to treatment render them individually unreliable indicators. The low frequency for some phenological stages agrees with Pond and Schmutz (17) who reported turbinella oak growth was highly variable between years, sites, and clumps.

Nonetheless, if there was little or no current shoot growth such as bud, flower, acorn, leaf, or stem development, few plants were killed by picloram (P = 0.005) or the mixture of picloram and 2,4-D amines (P = 0.005). However, if treatments were made only when shoots were growing, 68% of the picloram applications and 81% of the mixture of picloram and 2,4-D amines applications killed some turbinella oaks in the initial 40-month trial (Table 2). However, there was significantly less mortality from applications of the mixture of picloram and 2,4-D amines in the second comparison than in the initial 40-month one (Table 2). Also, the frequency of turbinella oak mortality from the mixture of picloram and 2,4-D amines applied when shoots were growing was significantly higher for the 40-month than the 41-month trials with this herbicide (Table 2). Therefore, shoot growth by itself was not reliable as an indicator, because other factors were more important in determining turbinella oak mortality from these herbicides.

Foliage water content and stem xylem translocation rates were not significantly correlated with turbinella oak mortality. Also, the growth and development of associated species, such as blue grama, broom snakeweed, or annual forbs, did not provide information useful for predicting herbicide effectiveness on nearby turbinella oak.

Environmental conditions. Soil at the 60-cm depth was moist or wet at each application during the initial 31 months of the study, a period of high turbinella oak mortality from both picloram and the mixture of picloram and 2,4-D amines. However, when soils were classed as "moist" (−0.03 to −1.5 MPa) or "wet" (above −0.03 MPa) at any depth there was no significant effect on turbinella oak mortality because other factors, such as senescent or falling leaves, often reduced mortality. Nonetheless, soil moisture availability is important to consider. No turbinella oaks were killed from treatments made when soil at the 60-cm depth was classed as dry (−1.5 MPa or less). Soils at the 60-cm depth were dry during 27 of the 87 mixtures of picloram and 2,4-D amines applications, and 5 of the 47 picloram applications. Additionally, some plants were killed in only 16% of 32 applications made when soil at the 45-cm depth was dry. Dry soil at other depths was not related significantly to oak mortality.

Rainfall replenishing deep soil moisture may affect herbicides applied several months later, which is partly why rainfall amount or timing did not correlate with mortality. For example, a December storm that replenished depleted moisture at the 60-cm depth had no effect on turbinella oak mortality from herbicides applied that winter because leaves were falling. The following May, when deep soils were still wet and the plants were growing, turbinella oaks were killed by the herbicides. Davis and Dieterich (8) noted a positive relationship between winter rainfall and leaf water content later in the year, illustrating the delayed effect of winter rains.

Turbinella oak has both widespread, shallow lateral roots and deep taproots, utilizing both shallow and deep soil water (20). If, as Romberger states (19), individual roots of woody plants supply specific parts of the topgrowth, perhaps deep roots of turbinella oak supply the root crown bud zone. If so, deep roots in dry soil and buds in the bud zone would be inactive while other shoots would be growing with moisture obtained by shallow, lateral roots.

Shallow turbinella oak roots were observed growing throughout the year, so deep roots in moist or wet soil may also grow throughout the year (19). Growing roots are carbohydrate and picloram sinks, so it is possible that picloram applied to the foliage would be transported to growing deep roots and from them to developing basal buds, thus killing the sprouts. When bud dormancy is broken, the deep roots are the nearest and most likely carbohydrate and herbicide source (4).

Because picloram and 2,4-D are transported basipetally with carbohydrates in the symplast (18), little herbicide or carbohydrates from the foliage would reach inactive deep roots (4) or dormant buds in the root crown. Therefore, because the deep roots would not contain picloram, shoots developing from root crown buds would not be killed and the plant would survive.

Air and soil temperatures, relative humidity, vapor pressure deficit, dew point, cloudiness, windspeed, and amount and timing of rainfall were not significantly related to turbinella oak mortality. However, the highest mortalities occurred when air temperatures were 21 C or higher and may be related to rapid growth. Davis (6) reported that turbinella oak seedlings grew best when the temperatures were above 21 C. Also, turbinella oak was often killed when the soil temperature at 20 cm was above 7 C (Figure 4), but often concurrent conditions such as leaf senescence, leaf fall, or dry soil reduced the chances of killing turbinella oak. When the surface soil was frozen or frost had damaged the foliage, no oak mortality was observed, but leaf senescence and abscission occurred at the same times.

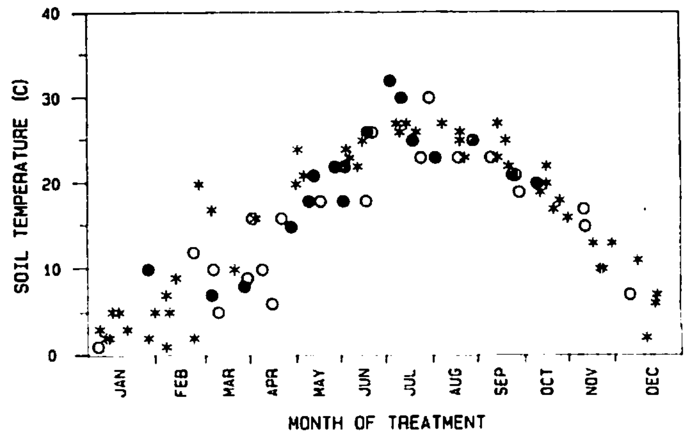

Figure 4. Summary of relative turbinella oak mortality (* = none; o = <50%; ● = >50%) at various noon (12:00) soil temperatures at 20 cm deep for 88 herbicide application dates in an 81-month period, combining different years by Julian dates.

Combinations of conditions. Increased frequency of turbinella oak mortality and the reliability for determining when to apply the herbicides were most closely associated with the combined environmental and phenological conditions.

Those combinations limiting applications to times having soil moisture available at 60 cm and no leaves senescent or falling consistently had significantly higher frequencies of turbinella oak mortality than not limiting treatments (Table 3). There was no significant difference between combinations of conditions containing both soil moisture availability and leaf senescence or fall as limitations for treatment (Table 3).

The best combination for high frequency of turbinella oak mortality appeared to be related to applications when soil moisture was available at 60 cm, no leaves were senescent or falling, and leaves were full size. This is based on the two application times when there were few full-size leaves on the plants, but soil moisture was available at 60 cm and no leaves were senescent or falling. No turbinella oaks were killed. The infrequent occurrence of a few full-size leaves on the plants resulted in statistical nonsignificance, but that was still an important influence on mortality from the herbicides. This combination may also have been the best for applying picloram alone since turbinella oak responses to both herbicides were similar (Table 1).

Soil moisture at 60 cm, as discussed earlier, may be related to movement of herbicides to growing points when regrowth does occur after the initial shoot damage. Herbicides applied to senescent or falling leaves would not be transported from

Table 3. Differences between environmental and phenological factors influencing turbinella oak mortality from a mixture of picloram and 2,4-D amines applied in periods of 40, 41, and 81 months, respectively[a].

Factor[b]	SM	NF	SG	SM/SG	SM/NF	SM/NF/SG	SM/NF/FL
None	N/N/*	*/N/***	N/N/N	N/*/***	*/**/***	*/***/***	*/***/***
SM		N/N/N	N/N/N	N/N/N	N/*/**	N/*/**	N/***/***
NF			N/N/*	N/N/N	N/N/N	N/N/N	N/*/**
SG				N/N/*	N/**/***	N/**/***	N/***/***
SM/SG					N/N/N	N/N/N	N/N/*
SM/NF						N/N/N	N/N/N
SM/NF/SG							N/N/N

[a]In the body of the table: N = no significant difference, * = 0.05, ** = 0.01, *** = 0.005 of factors compared in 40-, 41-, and 81-month periods, respectively, according to paired chi-square tests.

[b]Factor abbreviations: SM = soil moist, SG = shoot growth, NF = no leaves fallings or senescent, FL = full-sized leaves.

the leaves. Broadcast applications on bare stems or shoots with very small leaves would have little herbicide deposition on the plant and hence very little herbicide would move into the plant. Available soil moisture at 60 cm and leaf condition were individually inconsistent indicators, but combined they become associated with high frequencies of turbinella oak mortality from picloram herbicide sprays (Tables 1 and 2).

The earlier 40-month applications, by chance, were made under favorable conditions and responses were promising for each herbicide, but the later 41-month applications of the mixture of picloram and 2,4-D amines were made under unfavorable conditions and responses were unfavorable (Tables 1 and 2). However, by combining information from both sets of applications, the key factors affecting turbinella oak responses were more clearly identified (Table 2), enabling marked improvement for predicting the control of this species with picloram or the mixture of picloram and 2,4-D amines. This increased precision of mortality prediction illustrates the value of conducting herbicide tests for several years at different times of the year when accompanied by notations of environmental, phenological, and physiological factors at the study site, and by considering the activity of all parts of the plant. Such information allowed identification of key factors to monitor and should increase field testing efficiency as well as providing means of predicting treatment success on a practical scale.

Data from this research showed that spraying foliage with picloram or a mixture of picloram and 2,4-D amines can kill turbinella oak. Effective applications were restricted to times when the herbicides would be transported from foliage with full-sized actively metabolizing leaves to the roots (4, 9, 11, 14, 18, 23). Also, effectiveness was limited to conditions that favored herbicide transport from the roots to sprouts growing from dormant buds such as when abundant deep soil moisture was available (4). The chances of killing turbinella oak were improved if the herbicides were applied when the subsoil at the 60-cm depth was moist or wet and the leaves were not senescent or falling.

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