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Factors influencing broadcast-herbicide control of huisache (*Vachellia farnesiana*)

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Abstract

Huisache is a major brush problem on native rangelands and pastures in South Texas. Although herbicide applications to foliage provide very high plant-kill levels, the same herbicides have not proven reliable when applied as broadcast ground or aerial foliar treatments. Aerial and ground broadcast herbicide foliar treatments were applied to 31 huisache sites. Soil temperature and soil moisture were measured at a depth of 30 cm at the time of herbicide application. Cumulative rainfall before herbicide application was recorded. Across all aerial treatments, plant mortality was 69% for plants shorter than 2 m versus 40% for plants taller than 2 m. Across all aerial- and ground-treated sites, plants shorter than 2 m had an average 89% mortality when cumulative 2-wk rainfall was at least 50 mm, versus 72% mortality with cumulative rainfall less than 50 mm. Average plant mortality was 84% when 4-wk cumulative rainfall was at least 76 mm, versus 71% with rainfall less than 76 mm; and 85% when, on a dry-to-wet scale of 0 to 10, soil moisture measured at least 8, versus 71% when soil moisture measured less than 8. In a separate aerial trial, plant-mortality effects of spray droplet size (417, 630, and 800 μm) and spray volume (37.4 L ha^{-1} and 93.5 L ha^{-1}) were replicated and tested at a single study site in 2014. Plant mortality was lowest for the 93.5 L ha^{-1} and 800 μm treatment. Plant mortality rates for other treatments were similar, demonstrating a greater importance of droplet size than spray volume. Targeting huisache trees shorter than 2 m, when cumulative rainfall has reached at least 50 mm or at least 76 mm 2 or 4 wk before application, respectively, as well as maintaining spray droplet sizes no larger than 630 μm can increase herbicide efficacy with foliar broadcast applications.

Introduction

Huisache is a single- to multi-stem shrub or tree usually less than 6 meters tall and occasionally up to 10 meters tall. It is often found in the multi-stem growth form, because of disturbance. It is characterized by fragrant orange-yellow to orange flowers appearing in February to March. Fruit is a straight to slightly curved legume. Leaves are pinnately compound and deciduous; defoliation occurs only with hard freezes (Clayton et al. 2014).

Huisache infests approximately 3.3 million acres in south and central Texas (Texas State Soil and Water Conservation Board 1987). Huisache canopy cover can reduce forage available for livestock, and high stem densities can reduce physical access to grazing areas. Heavily infested areas also decrease plant diversity, creating unsuitable habitat for many wildlife species.

Reliable criteria, including soil temperature, leaf color, flower color, and bean elongation, have been developed for honey mesquite (*Prosopis glandulosa Torr*. var. *glandulosa*) foliar herbicide applications (Dahl et al. 1971; Fisher et al. 1972; Sosebee and Dahl 1991). Previous experience has suggested that fall is the best time to apply foliar spray to huisache; however, specific criteria have not been developed. Individual-plant herbicide treatments are typically successful at controlling huisache, whereas foliar broadcast applications have generally yielded inconsistent control and are not well understood (Lyons et al. 2019).

Although little is known about the conditions supporting greater control of huisache with broadcast herbicide foliar applications, previous plant mortality observations have suggested that huisache could be particularly sensitive to soil moisture. Bovey et al. (1972) reported poorest huisache control when internal water stress was highest. With honey mesquite and winged elm (*Ulmus alata* Michx.), Davis et al. (1968) reported that moisture stress sufficient to slow growth markedly reduced herbicide transport. Wills and Basler (1971) found that decreased soil moisture reduced translocation from winged elm leaves to roots. Badiel et al. (1966) reported that herbicide translocation in natural stands of blackjack oak (*Quercus marilandica* Münchh.) was inversely related to soil moisture stress.

In a recent study, Teveni (2017) investigated the potential relationship of huisache plant mortality from individual-plant herbicide foliar applications to factors including soil moisture, cumulative rainfall, root carbohydrate dynamics, soil temperature, plant growth relative to long-shoot/short-shoot phenological stages, and month of application. Significant relationships were found for plant mortality to soil temperature, soil moisture, cumulative rainfall, and month of

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application, but stable relationships to root carbohydrates or long-shoot/short-shoot growth were not found. However, Teveni (2017) did report high plant mortality for plants treated in the full-canopy phenological stage.

Although results conflict, herbicide spray-droplet size is thought to be an important consideration in broadcast foliar applications and may be even more important with huisache because coverage of the small but dense leaves is difficult. Whisenant et al. (1993) reported honey mesquite plant mortality relative to droplet size becomes less important with larger spray volumes. However, Lyons and Rector (2018) reported decreased plant mortality among honey mesquite plants treated with large droplet sizes and large spray volumes of herbicide. Therefore, increasing spray volume alone may not equate to better coverage and greater control, and a study investigating droplet size specifically on huisache is needed.

A treatment-factor study was conducted to examine the relationship of plant height, soil temperature, cumulative rainfall, and soil moisture to huisache plant mortality with ground-broadcast and aerial herbicide foliar applications. A second study was conducted to examine the effect of spray volume and spray droplet size on huisache plant mortality.

Materials and Methods

Field trials (n = 32) were conducted from 2013 to 2018 in South Texas to examine factors affecting huisache mortality with aerial (n = 10) and ground broadcast (n = 22) herbicide foliar applications (Table 1). All treatments were applied during fall, except half of the 2017 ground broadcast foliar treatments (n = 8) in Atascosa and Nueces counties that were applied earlier in the year to test the spring treatment window suggested by Teveni (2017). Sites were selected randomly from locations supporting 120 to 160 trees ha^{-1}, a commonly accepted density threshold for using broadcast chemical applications instead of individual plant treatments.

Treatment-Factor Study

The first study investigating the relationship of plant height, soil temperature, soil moisture, and cumulative rainfall to huisache plant mortality included a combination of aerial and ground-broadcast foliar applications (n = 31). Aerial herbicide treatments (n = 9) were applied to 4-ha blocks at 93.5 L ha^{-1} spray volume by helicopter, except for the Webb County site, where a fixed-wing aircraft was used. Ground broadcast treatments (n = 22) were applied in swaths covering a minimum of 15 huisache trees with all-terrain and utility vehicles equipped with electric pumps using Model 140 or 187 Boom Buster™ boomless nozzles (Evergreen Products, Richmond Hill, GA), at 206.8 kPa and a 187.1 L ha^{-1} spray volume.

A single treatment composed of a combination of two herbicides was selected for evaluation of factors affecting huisache plant mortality: Sendero® (2.05 L ha^{-1}; Corteva Agriscience, Indianapolis, IN), which contains aminopyralid (0.12 kg ae ha^{-1}) and clopyralid (0.56 kg ae ha^{-1}) plus Tordon 22K (2.34 L ha^{-1}; Corteva Agriscience), which contains picloram (0.23 kg ae ha^{-1}), plus nonionic surfactant (0.25% vol/vol; 90% ai). Control plants were located in unsprayed plots directly adjacent to treatment plots at all sites.

Plant mortality rates determined 2 yr after treatment were used in analyses, except for the 2017 studies, for which only mortality rates for 1 yr after treatment were available. Apparent plant mortality was determined by examining individual plants for basal resprouting or leaf presence on stems. If any resprouting or leaf was found, the plant was considered alive. Plants without basal resprouting or leaves on stems were counted as dead and the number of dead plants was averaged by site to obtain apparent plant mortality, reported as ± SE.

Table 1. Year and locations of aerial and ground broadcast huisache field trials conducted in South Texas.

Year	County	Application method	Longitude (W)	Latitude (N)
2013	Atascosa	Aerial	98.456	28.74
2013	Medina	Aerial	98.859	29.292
2013	Uvalde	Aerial	99.499	29.451
2013	Jim Wells (2 applications)	Aerial	98.048	27.336
2014	Atascosa (2 applications)	Aerial	98.251	28.723
2014	San Patricio (droplet-size study)	Aerial	97.446	28.113
2016	Atascosa	Aerial	98.394	28.723
2016	Webb	Aerial	99.064	27.744
2013	Guadalupe	Ground	97.864	29.566
2014	Gonzales	Ground	97.602	29.181
2015	Atascosa	Ground	98.245	28.712
2015	Guadalupe	Ground	98.125	29.587
2016	Guadalupe	Ground	97.864	29.567
2016	Guadalupe	Ground	97.869	29.567
2017	Atascosa (8 applications)	Ground	98.285	28.731
2017	Nueces (8 applications)	Ground	97.874	27.892

For evaluation of aerial sites, transects were walked through the middle of each treatment block, with a minimum of 100 trees recorded per treatment. Aerial plant mortality was stratified between trees taller and shorter than 2 m, based on an observed difference in early trials. Apparent plant mortality was calculated by averaging all site averages in the taller than 2-m or shorter than 2-m categories independently, and these also are reported as ± SE.

For evaluation of ground broadcast sites, a minimum of 15 trees per treatment were marked and recorded. All ground broadcast applications were made to plants less than 2 m tall. For huisache trees shorter than 2 m, plant mortality rates resulting from ground broadcast and aerial foliar applications were used in the analyses of other treatment factors, including soil temperature, soil moisture, and cumulative rainfall, to remove the height effect.

Soil temperature at a depth of 30 cm at the time of herbicide application was measured with a REOTEMP soil thermometer (REOTEMP Instruments, San Diego, CA). Cumulative rainfall measurements at 2, 4, and 8-wk intervals before each herbicide application were estimated using the FarmLogs software application (Ann Arbor, MI). Exact research locations were saved in the FarmLogs application, which determined rain accumulation using hourly data from the U.S. National Weather Service.

Soil moisture was measured at the time of herbicide application using a Lincoln Soil Moisture Meter (Lincoln Irrigation, Lincoln, NE) with a relative scale of 0 to 10 (dry to wet). This meter was calibrated to saturated soil at each site and measurements were taken at a depth of 30 cm. Although this may not be the most scientific instrument, because soil moisture is measured on a relative scale, it was selected for its low cost and ease of use, making it a reasonable, replicable measure for landowners and management professionals to use on-site.

Correlation analyses were conducted to determine relationships among treatment factors and plant mortality using the PROC CORR procedure in SAS, version 9.4 (SAS Institute, Cary, NC). To test for treatment thresholds for cumulative rainfall and soil

Table 2. Huisache droplet-size study treatments with spray volume and nozzle specifications as applied in San Patricio County, TX, in October 2014.

Treatment	Droplet-size goal	Spray volume	Nozzle	Orifice	No. of nozzles	Pressure	Deflection
	µm	L ha^{-1}				kPa	°
1	417	37.4	CP03	0.078	23	275.79	90
2	417	93.5	CP03	0.078	44	344.74	90
3	630	93.5	CP03	0.125	23	275.79	30
4	800	93.5	Accu-flo	0.028	23	275.79	30

moisture, sequential ANOVA procedures were conducted. Cumulative rainfall amounts (at 2 and 4 wk before herbicide applications) were plotted along with the average plant mortality rate during intervals of approximately 25 mm (e.g., <25 vs. ≥25 mm) to determine cumulative rainfall needed for greatest plant mortality. Cumulative rainfall amounts at 2 and 4 wk before herbicide applications were also used with average soil moisture readings during those intervals to determine when soil moisture readings stabilized, based on the SD closest to 1. This soil moisture reading could be used as a threshold required to obtain greatest plant mortality.

Droplet-Size Study

On October 29, 2014, a helicopter was used to apply herbicide on huisache trees of variable size at a spray volume of either 37.4 L ha^{-1} or 93.5 L ha^{-1} (Table 2). The herbicide mix used for all foliar treatments included the following: aminocyclopyrachlor 50 SG (210.16 g ai ha^{-1}) and metsulfuron (31.52 g ai ha^{-1}; Bayer CropScience LP, Research Triangle Park, NC) plus nonionic surfactant/methylated seed oil blend (Aero Dyne-Amic, 292.31 mL ha^{-1}; Helena Agri-Enterprises, Collierville, TN). Spray-swath width was 12.2 m and applied at 104.6 kph. Three different droplet sizes were tested: 417, 630, and 800 µm. Each treatment (Table 2) was replicated three times at a single study site near Sinton, TX, on the same day.

Results and Discussion

Treatment-Factor Study

Plant height

The plant mortality for huisache plants taller or shorter than 2 m was evaluated for nine aerial sites. Plant mortality (% ± SE) was greater (P = 0.0155) for plants shorter than 2 m (69 ± 6.68) than taller than 2 m (40 ± 8.56), likely because it is more difficult to achieve consistent herbicide leaf coverage on larger plants with more stems, and taller plants may shade a portion of the canopy below (Jacoby et al. 1990). Jacoby et al. (1990) also found shorter honey mesquite plants were more susceptible to herbicide; they reasoned that there is less distance to translocate the chemical to the basal bud zone and younger stem tissue may absorb more herbicide, contributing to greater plant mortality rates. This information is valuable for setting plant mortality expectations with broadcast herbicide applications and may encourage treatment before plants are taller than 2 m.

Soil temperature

Soil temperature was not correlated (P = 0.545) with plant mortality. Temperatures ranged between 22 C and 31 C at all sites except Atascosa in 2016 (15.6 C). Teveni (2017) reported optimum individual-plant foliar huisache control at or near a peak of 24.5 C, with at least 80% mortality from 20 to 30 C at 30-cm depth during the full-canopy phenological stage, which would indicate that plants have enough leaf material for consistent movement of herbicide to the bud zone to kill the plant. Teveni (2017) reported a total soil temperature range of approximately 12 C to 33 C and a range of plant mortality rates from 0% to 100%. In the current study, soil temperatures did not exhibit wide variation, which could account for the lack of correlation.

Table 3. Average plant mortality rates above versus below cumulative rainfall thresholds for huisache shorter than 2 m in South Texas.

Cumulative rainfall	2-Wk cumulative rainfall		4-Wk cumulative rainfall	
	Plant mortality	P value	Plant mortality	P value
mm	%		%	
<25	75	0.324	70	0.195
≥25	82		80	
<50	72	0.0369	71	0.130
≥50	89		82	
<76	72	0.00614	71	0.0459
≥76	96		84	
<102	74	0.00821	73	0.0339
≥102	96		88	

Cumulative rainfall

Only cumulative rainfall amounts at 2 and 4 wk were positively correlated with plant mortality (P = 0.0160 and 0.0270, respectively). Huisache mortality was not correlated with 8-wk cumulative rainfall (P = 0.708), in contrast to findings by Teveni (2017). Plant mortality averaged for sites with cumulative rainfall amounts above and below every 25-mm interval indicated greatest plant mortality with rainfall higher than a 50-mm to 76-mm threshold for 2-wk cumulative rainfall and higher than a 76-mm threshold for 4-wk cumulative rainfall (Table 3). These rainfall thresholds could be helpful for land managers when deciding if a treatment should be applied to control huisache, especially during drought years.

Soil moisture

Soil moisture was not correlated with plant mortality (P = 0.165). However, soil moisture was positively correlated with 2-wk cumulative rainfall amounts (r = 0.63; P = 0.0003), 4-wk cumulative rainfall (r = 0.64; P = 0.0002), and 8-wk cumulative rainfall (r = 0.49; P = 0.0071). Because only cumulative rainfall amounts at 2 and 4 wk were positively correlated with plant mortality, we focused on these two time intervals to determine if soil moisture readings could be used to predict plant mortality after reaching a certain amount of rainfall.

A plot of 2-wk cumulative rainfall versus soil moisture readings showed high variability in readings at lower rainfall amounts and stabilization of these readings as rainfall amounts increased (Figure 1). A similar but more variable polynomial pattern was observed for 4-wk cumulative rainfall (Figure 2). Therefore, during times of higher rainfall amounts, soil moisture might be used as an indicator of potential plant mortality if a soil moisture threshold for increased plant mortality can be determined.

Soil moisture threshold analyses (Table 4), based on SDs close to 1, indicated a stable level for 2-wk cumulative rainfall greater than 50 mm when mean soil moisture was approximately 9. The 4-wk cumulative rainfall came closer to stabilizing with twice the amount of rainfall (≥102 mm) and soil moisture readings

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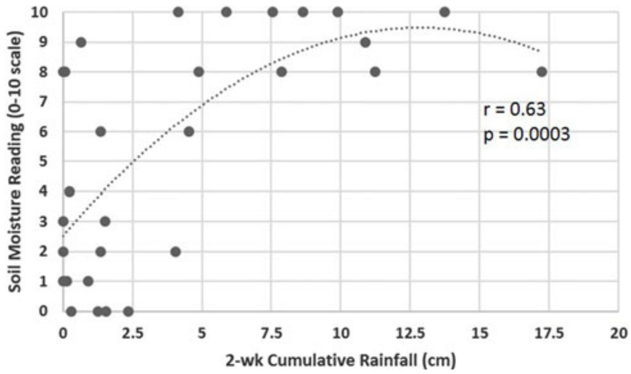

Figure 1. Polynomial relationship of 2-wk cumulative rainfall prior to huisache herbicide application to soil moisture readings at the time of application.

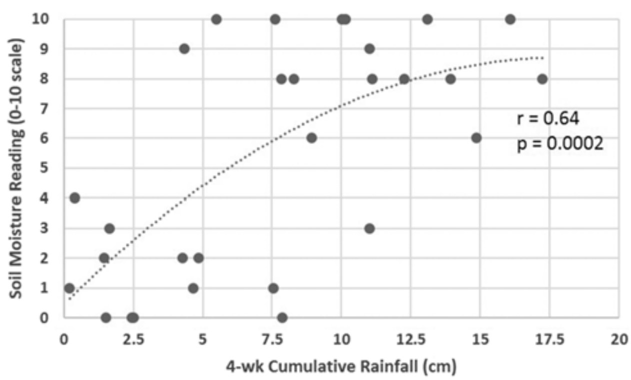

Figure 2. Polynomial relationship of 4-wk cumulative rainfall prior to huisache herbicide application to soil moisture readings at the time of application.

Table 4. Cumulative rainfall at 2- and 4-wk pre-application of herbicide on huisache in South Texas relative to soil moisture thresholds.

Cumulative rainfall	2-Wk cumulative rainfall		4-Wk cumulative rainfall	
	Mean soil moisture[a]	SD	Mean soil moisture[a]	SD
mm				
<25	3	3.1	1.4	1.6
≥25	8.4	2.3	6.7	3.5
<50	3.7	3.4	2.1	2.8
≥50	9.2	0.97	7.4	3.1
<76	4.3	3.7	2.7	3.5
≥76	9	1	7.6	2.8
<102	4.7	3.8	3.7	3.7
≥102	9	1	8.2	2.1

[a]On a dry-to-wet scale of 0 to 10.

around 8 (Table 4). Taking these soil moisture thresholds into consideration, plant mortality averages were calculated for trees shorter than 2 m at sites with soil moisture readings of at least 8 (n = 14; 85% ±4.79%) and less than 8 (n = 15; 71% ± 4.05%) and were significantly different (P = 0.0345).

Huisache mortality was significantly lower with less cumulative rainfall prior to herbicide treatments and mortality tended to be lower with low soil moisture readings. In support of our findings, Bovey et al. (1972) found huisache control was poorest when internal water stress was highest. In studies involving other woody species (Badiel et al 1966; Davis et al. 1968; Wills and Basler 1971), reduced herbicide translocation was reported in relation to moisture stress and decreased soil moisture. The importance of moisture for increased plant control could be the effect of either herbicide translocation rates and/or leaf-growth differences.

On the basis of our research, efforts should be made to treat huisache trees before they exceed 2 m in height to achieve increased mortality. Cumulative rainfall should be monitored either 2 or 4 wk before huisache herbicide applications to reach at least 50 or 76 mm, respectively. Soil moisture level (preferably ≥8 on a scale of 0 to 10) could be an additional factor to monitor just before the spray application to ensure conditions are favorable for greatest plant mortality. Teveni (2017) reported increased mortality of plants treated in the full-canopy phenological stage and soil temperatures between 20 C and 30 C. For improved herbicide uptake of foliar herbicide applications, healthy leaves are necessary and may be a result of increased soil moisture.

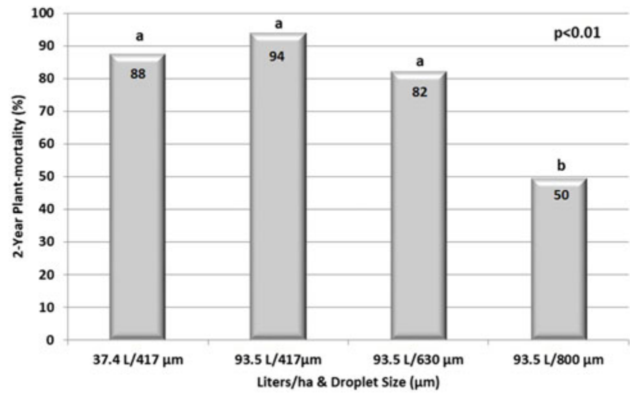

Figure 3. Two-year post-application plant mortality for all huisache tree heights by spray volume and droplet-size treatment in South Texas.

Droplet-Size Study

Huisache mortality was similar (Figure 3) for droplet-size treatments using 37.4 L ha^{-1} and 417 µm, 93.5 L ha^{-1} and 417 µm, and 93.5 L ha^{-1} and 630 µm. However, mortality resulting from the 93.5 L ha^{-1} and 800-µm droplet treatment was lower ($P < 0.01$) than from all other treatments (Figure 3). Surprisingly, huisache mortality for plants taller than 2 m compared with shorter than 2 m at this site was not different (P = 0.660) across treatments.

Although the 93.5 L and 630-µm treatment was not statistically different from the two 417-µm treatments, the treatments using a smaller droplet size had a higher minimum plant mortality rate, with ranges of 84% to 90% and 85% to 99% for spray volumes of 34.7 L and 93.5 L, respectively, compared with a range of 74% to 86% for the 630-µm treatment (Figure 4). Although treatments with 37.4-L spray volume and 417-µm droplets and 93.5-L spray volume with 417-µm droplets treatments exhibited similar efficacy, the 37.4-L treatment would be easier to apply and more economical, because the lower spray volume would allow an applicator to carry more spray load, assuming the ability to maintain droplets of approximately 417 µm. If an applicator cannot achieve a 417-µm average droplet size because of nozzle configuration or drift concerns, the 93.5-L and 630-µm treatment appears to be a viable option.

Although these treatments were replicated at the research site, this study has not been repeated at additional sites or during different years. However, Whisenant et al. (1993) examined honey mesquite mortality in relation to combinations of 325-µm, 425-µm, and 625-µm droplet sizes with 19, 37, and 75 L ha^{-1} spray

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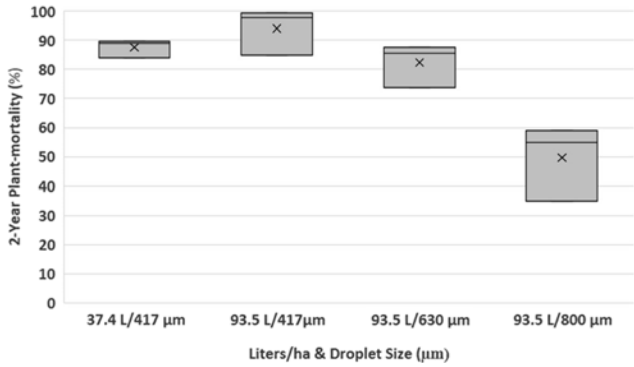

Figure 4. Box-and-whisker graph of spray volume and droplet size versus 2-yr post-application plant mortality for huisache in South Texas.

volumes. They reported lower mortality rates when large droplet size was combined with low spray volume, but similar relative mortality for all droplet sizes with a high spray volume (75 L ha^{-1}) and suggested spray drift could be reduced by using the largest droplet size (625 µm in their study). However, Lyons and Rector (2018) reported a study showing a marked drop in mesquite mortality rate with droplet size of at least 600 µm and a 93.5 L ha^{-1} spray volume. Interestingly, the results of the current study on huisache and these two earlier studies on honey mesquite report similar findings in respect to droplet size, where there appears to be a similar droplet-size threshold at approximately 600 to 630 µm.

Huisache leaf coverage with herbicide appears to be sensitive to droplet sizes, with droplets larger than 630 µm resulting in decreased plant mortality. Often, spray volume is discussed prior to aerial herbicide applications, but these data demonstrate a heightened importance of droplet size, because spray volume cannot make up for droplet-size deficiencies. Applicators must be knowledgeable of the capabilities of their sprayer system and make appropriate changes to maintain smaller droplet sizes to achieve desirable huisache mortality levels.

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