Aerial Spraying of Herbicide to Control Buffelgrass in Southern Arizona: Efficacy, Non-Target Impacts and Application Recommendations

Summary of Efficacy and Vegetation Response

Ground-based buffelgrass control efforts include manual removal using digging bars and picks, as well as herbicide. These methods continue to be effective and successful control of buffelgrass is possible but only at a small scale. These efforts cannot keep pace with the rapid growth and spread of buffelgrass. Infestations can form large, continuous, monoculture patches that are doubling in size every 2-7 years (based on research from the Santa Catalina Mountains in Coronado National Forest). Research has also documented that as buffelgrass patches become larger and denser, native plant diversity and abundance declines. Buffelgrass is present not only in disturbed urban areas but in natural areas, some of which are remote steep and rocky slopes where it can be difficult or impossible to access and where it is unsafe to send field crews.

To address these challenges, local and national public land managers and researchers joined together to evaluate the use of herbicides applied from a helicopter to control buffelgrass. Glyphosate, the active ingredient in the product used in these tests, was applied at 2 concentrations and 2 water carrier rates. In addition to monitoring the effects of the herbicide on buffelgrass, over 1,600 native plants were tagged for monitoring before the experiment and will be monitored for three years following the treatment. Percent greenness of each individual was recorded at each monitoring event.

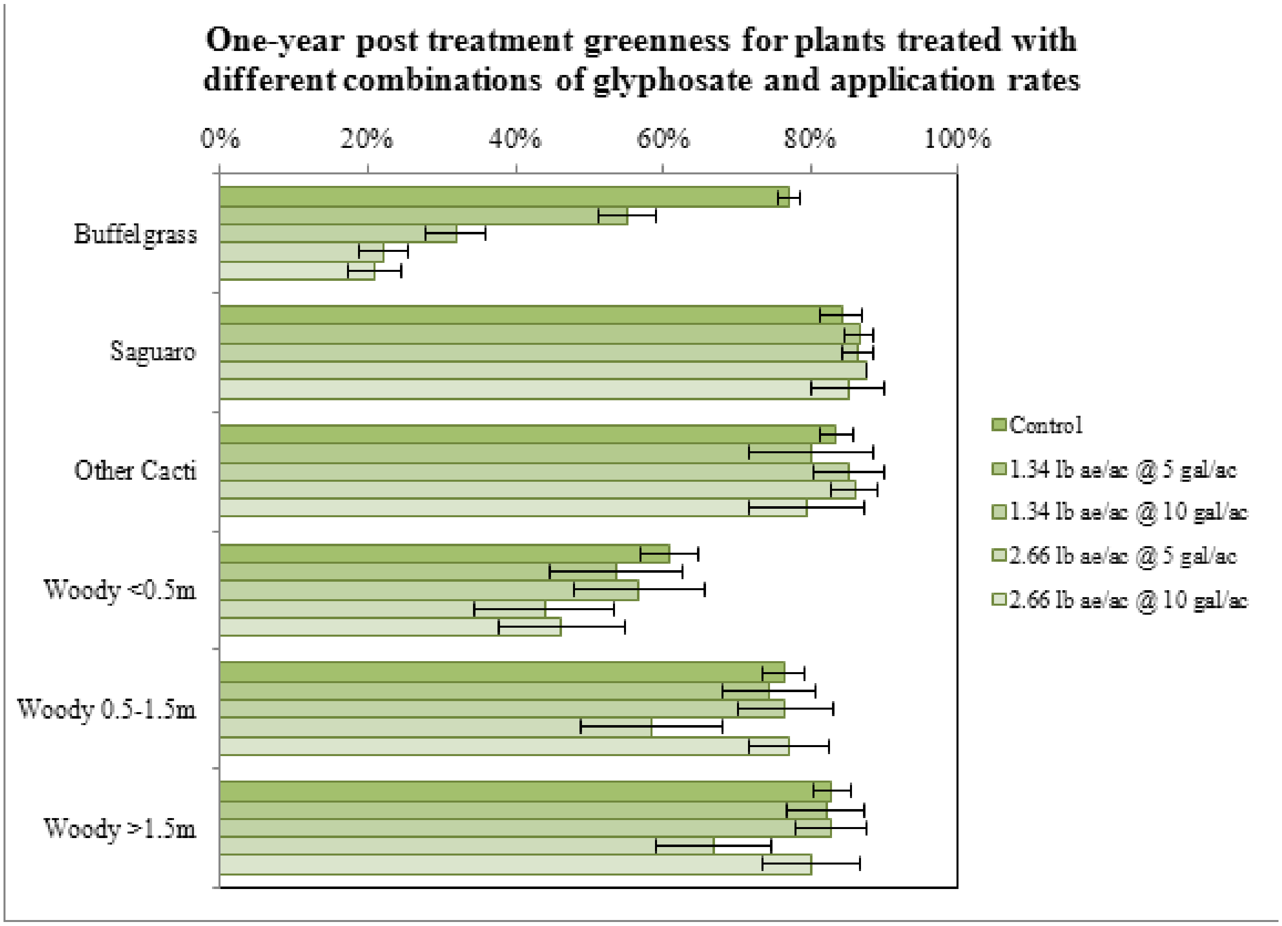
Results from the first year of post-treatment monitoring indicate that the higher concentration of glyphosate at either application rate significantly reduces buffelgrass greenness while saguaros and cacti were unaffected. Large woody species were susceptible to minor damage at higher concentrations and lower carrier rates. Smaller woody species like brittle bush, limber bush and mallows were most sensitive to glyphosate of natives present, also at higher concentration and lower carrier rate. While the areas tested had a high density of native vegetation, this technology will be deployed in areas where buffelgrass dominates and most of the native vegetation is no longer present.

Vegetation Response

Vegetation in twelve plots (each approximately one acre in size) was monitored for effects of aerially applied glyphosate (Roundup Pro®) herbicide treatments at two concentrations (1.34 pounds acid equivalent/acre and 2.66 pounds acid equivalent/acre) and two carrier (water) rates (5 gallons/acre and 10 gallons/acre). Each plot was paired with a control transect. Plots were purposefully chosen to have a mix of buffelgrass (<50% cover) and native vegetation to allow for the evaluation of any potential damage to native vegetation. This scenario does not represent a situation where aerial boom spraying would occur. To that end, over 1,600 individual native plants were tagged and then monitored prior to treatment, one year after treatment, and two years after treatment. This discussion presents the one-year post treatment data results. Data analysis for two- year post treatment vegetation response is ongoing.

Herbicide effects are measured as percent greenness of a plant. Greenness was visually estimated as the proportion of green actively growing tissue to dead or dormant tissue. The greenness categories were <10%, 10-40%, 41-75%, and >75% for non-target native plants and <10%, 10-75%, and > 75% for buffelgrass. The actual amount of herbicide that reached the plots was less than that released from the helicopter because of evaporation, drift and targeting issues and the amount decreased as the humidity lowered and thermal convection increased over the course of the day. Some material landed off-target due to both drift and difficulty in hitting small target plots in broken terrain. Buffelgrass was suppressed most effectively with the higher application rates of glyphosate (2.66 pounds acid equivalent/acre) at either carrier rate. However, higher rates will be required if mortality of mature buffelgrass plants is the objective. In general, mean greenness for the untreated buffelgrass was 77%, which was significantly greener than any of the treatments (Figure 1). Mean buffelgrass greenness for the low concentration and low carrier rate treatment was 58% and was significantly greener than other treatments. Mean greenness for the low concentration and high carrier rate and high concentration-low carrier treatments were 28% and 25%, respectively. These were not significantly different from each

Figure 1: One-year post treatment greenness for target and non-target life forms. Error bars indicate 95% confidence intervals for least squares means.



other, though they were significantly greener than the high concentration and high carrier treatment for which the mean greenness was 19%. Greenness measurements of non-target plants by treatment type are summarized in Figure 1 and 2.

Some treatment combinations affected various native plant species; however, there was no consistent pattern (Figure 1).

A comparison of the controls to combined treatments showed significant differences which were dependent upon life form, species, and rates for glyphosate and the carrier (Table 1). No significant differences were observed among the control and treatments for saguaros and other cacti. Cacti and most other desert plants have epicuticular waxes that extrude from the leaf surface in addition to the membranous cuticle layer . This waxy coating makes absorption of herbicide difficult.

Recommendations: Given the effect of glyphosate on native vegetation, although minor and species specific, only areas with a high percent cover of buffelgrass should be considered for aerial boom treatments. Higher deposition rates or multiple applications are needed to achieve mortality in mature buffelgrass plants. It is not known what the effects from multiple applications of glyphosate would be for Sonoran Desert vegetation, and further research on vegetative impacts from continuous applications of glyphosate or other herbicides should be a priority.

Figure 2. Native plants and buffelgrass greenness as a response to the different herbicide treatments and control. Error bars indicate 95% confidence intervals for least squares means.

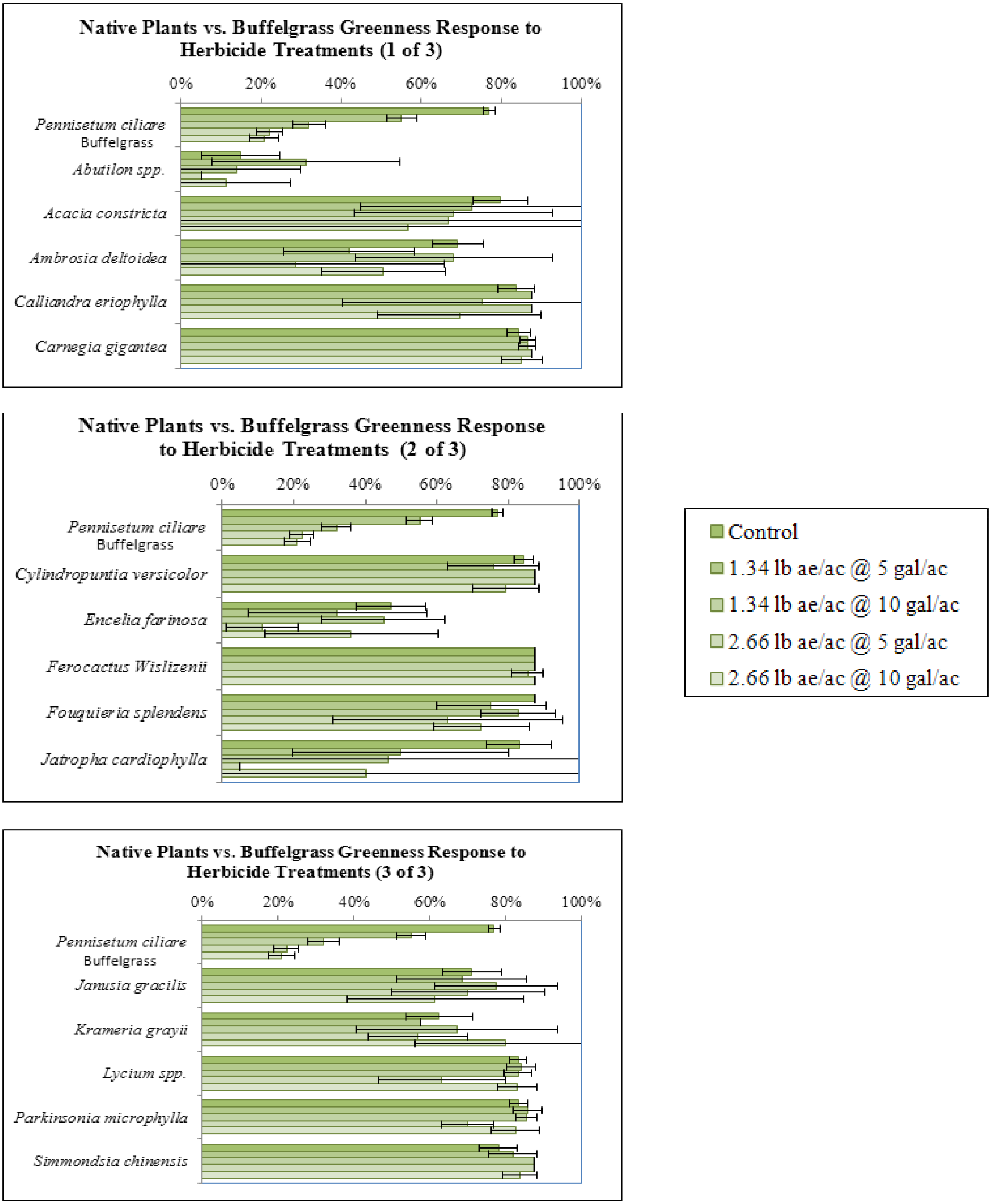


Table 1: Percent green means separations for lifeforms and species for (1) all treatments combined vs. control, (2) glyphosate rates vs. control (all carrier rates combined), and (3) carrier rates vs. control (all glyphosate rates combined). Means followed by the same letter within the same row are not significantly different (P ≤ 0.05).

		Control	Treatment
Lifeform	Other Cacti	83.4A	82.6A
	Saguaro	84.2A	86.3A
	Shrub	76.3A	71.8A
	Subshrub	60.9A	50.1B
	Tree	82.9A	77.6B
	Tree (*Fouquiesian splendens* excluded)	81.9A	78.4B
Species	*Abutilon* spp.	14.9A	17.8A
	Acacia constricta	79.8A	67.0A
	Ambrosia deltoidea	69.0A	47.3B
	Calliandra eriophylla	83.6A	76.6A
	Cylindropuntia versicolor	84.4A	80.9A
	Encelia farinosa	47.1A	31.7B
	Ferocactus Wislizenii	87.5A	86.8A
	Fouquieria splendens	87.5A	75.6B
	Jatropha cardiophylla	83.2A	39.7B
	Janusia gracilis	71.1A	68.7A
	Krameria grayii	62.4A	62.8A
	Lycium spp.	83.2A	79.6B
	Parkinsonia microphylla	83.4A	80.2B
	Pennisetum ciliare	76.9A	32.4B
	Simmondsia chinensis	84.2A	78.0B
Glyphosate rate	1.34 lb ae/ac	76.0A	60.0B
	2.66 lb ae/ac	75.9A	42.9B
Carrier rate	5 gal/A	79.3A	51.3B
	10 gal/A	72.0A	50.8B
All lifeforms, species, glyphosate and carrier rates combined		76.0A	51.0B

Application Recommendations

Aircraft Operation

The Sonoran Desert terrain flown in the demonstration project consisted of extremely complex terrain including steep hillsides, rocky outcrops, and arroyos that presented an extreme scenario for precision aerial application. Ground elevation varied by tens of feet over short distances, and slopes approached vertical in some places. In addition to the steep terrain, helicopter operations were also affected by the presence of saguaro cacti (*Carnegiea gigantea*) which can grow to 30-50 feet in height. *Recommendation:* Because of the variable topography associated with the Sonoran Desert, a licensed aerial applicator with experience in spraying over complex terrain should be used.

Summary of Application

An aerial spray project near the city of Tucson was performed in August, 2010 to test effects of two rates of the herbicide glyphosate at two rates of dilution on invasive buffelgrass (*Cenchrus ciliaris*, syn. *Pennisetum ciliare*). Buffelgrass is currently impacting the Sonoran Desert ecosystem by introducing a fire cycle and by competition with native vegetation. Roundup Pro® was the glyphosate formulation used in the spray project. The spray project was conducted during the morning on 12 test plots (one acre in size) to determine the feasibility of applying glyphosate using rotary wing aircraft with a boom sprayer to control buffelgrass in southern Arizona. Aerial spraying in this desert landscape presents challenges due to uneven, steep, and rocky terrain which can have target infestations of buffelgrass potentially existing on rocky knobs and in deep gullies. Buffelgrass is only susceptible to herbicide treatment during a green-up period that may last only a few weeks from the onset of monsoon precipitation.

In addition to the buffelgrass spray project, an auxiliary study was also conducted in September, 2010 at Ironwood Forest National Monument northwest of Tucson to evaluate the use of a tethered spray nozzle technique to accomplish small spot applications rather than the swath applications made by a helicopter boom sprayer. In the auxiliary study, water with a blue dye was used to test spray results. The tethered spray nozzle approach uses either a weighted "spray ball" with a single nozzle or a set of spray nozzles contained in a small pyramidal housing. Each of these two nozzle configurations can be lowered over relatively small infestations of buffelgrass for precise application. During application, herbicide is discharged onto target plants from the spray ball nozzle (or nozzles in the pyramid housing) which is suspended by a 50-foot hose beneath the helicopter.

The buffelgrass spray project and auxiliary study highlighted the difficult application scenarios that can occur with aerial application of herbicide to control buffelgrass in the Sonoran Desert. Based on previous experience as well as observations and results obtained from the spray project and the auxiliary study, the considerations outlined below should be incorporated into the design of any aerial application program.

Application Precision

Considerable variability of herbicide deposition was measured in the target area. Some of this variability is inherent in aerial application as deposition tends to be higher near the center of the spray swath and tapers toward the edges. If the aircraft is flying across slope, the area underneath the spray swath will be larger than if the aircraft is flying over flat ground, thus lowering the application rate. Furthermore, aircraft fly more slowly when headed up a slope. This will result in more material being applied per area if a flow control system is not used. Another source of variability is the constantly changing altitude of the aircraft with respect to changes in ground elevation beneath the moving helicopter.

Small target areas (approximately an acre in size as in the buffelgrass spray project) present a challenge as the pilot needs to anticipate turning the spray system on and off at the target edges. The initiation and termination of spraying are both a matter of pilot reaction and the mechanical lag in the spray system. Although automated systems using the electronic map information are available to compensate for these errors, such systems are not perfect. Therefore, many pilots prefer to retain control of this function. This can result in application errors at the target edges with both underspray occurring within the spray target and overspray past the edge of the target. On large spray blocks, this error is relatively minor as a percentage of total area; however, it can amount to a relatively large percentage error on small targets such as the one-acre plots used in the aerial study.

Recommendations: The aircraft used for spraying needs to be equipped with differential global position system (DGPS) guidance that allows logging of the position of the aircraft as well as whether the spray boom is 'on' or 'off'. The aircraft should also be equipped with a spatially registered flow controller to compensate for variation in aircraft speed as the plane flies up and down over this terrain. Electronic logging of flow allows the amount applied where and when to be evaluated by the spray manager on a post-application basis. It is desirable to map buffelgrass infestations electronically by creating spatially registered files prior to the initiation of a spray project. These map files should be loaded into the aircraft at the time of spraying and used to guide the pilot.

Meteorology

Relative humidity during the demonstration project in the morning hours varied between 35% and 60%, and application became more problematic later in the morning as the landscape heated up. Even during monsoonal weather in the Southwest, surface heating during the summer causes convection (i.e., 'thermals' or lifting of air from the surface) which interacts with evaporating falling spray droplets thereby decreasing deposition. Because of this effect, many spray programs invoke humidity cut-offs when humidity drops to a certain point to avoid inadequate deposition of chemical.

Terrain can influence local meteorological conditions. In areas with varying topography, local air flows can occur early in the morning, which tend to move cold air downslope. These air flows can transport airborne material in unexpected directions as the flows are very local and are inadequately addressed by regional weather observations and forecasts. The air flows are most likely to occur under windless, clear conditions near dawn (spraying in these conditions may be precluded by low wind speed cut-offs on the herbicide label). These air flows are indicative of temperature inversions. Should such conditions occur, the herbicide label should be referenced and appropriate action taken.

Helicopter with boom sprayer. (US Forest Service)

Pesticide labels often specify high wind speed cut-offs (often around 10 mph). If spray drift is a major concern, conservative wind speed cut-offs such as 7 or 5 mph may be invoked by the spray manager. Lower wind speeds also allow more precise application as the pilot may feel more comfortable operating in lower wind speeds. Many labels also have low wind speed cut-offs (generally < 2 mph when present). The label for the glyphosate product used in this spray demonstration project advised that drift potential is lowest between wind speeds of 2 to 10 mph. The downside of very narrow weather constraints is that it reduces the time frame in which spraying will be allowed.

Recommendations: Based on the conditions encountered during the buffelgrass spray project, the window for spray operations should occur only from the time of operationally safe light after dawn until conditions warrant ceasing the operation. This window has the added advantages of avoiding winds arising during mid-day and a cessation of work during the hottest parts of the day. It may be possible to resume spraying two hours before dusk, but the window in the evening is necessarily smaller to allow the heat of the day to dissipate and convection to subside. A negative aspect of evening spraying is that work may end in conditions of low light which can cause safety problems.

Release Height

Complex terrain makes flying difficult, and pilots tend to fly higher in this type of terrain to avoid slopes and obstacles (e.g., saguaro cacti). Increases in release height will influence accuracy and drift.

Recommendations: Operationally, release height cannot be dictated because it is a major safety concern and must be left to the pilot. However, the effect of release height on application precision and drift should be discussed with the pilot. The release height must be sufficient to avoid collision with saguaro cacti which can grow to a height of 30-50 feet and are generally the tallest vegetation present in the Sonoran Desert. The spray manager should understand the influence that tall vegetation or extremely uneven terrain will have on release height above the target and allow for the greater potential for drift when release height is increased.

Droplet Size

It is critical in desert applications that large droplet sizes be used. This is due to the need to get material down to ground level in the evaporating, convective environment that is common in arid landscapes (as described above in the **Meteorology** section). Since droplet size is the most important variable in controlling spray drift, large droplets are also necessary to minimize drift. The trade-off with increasing droplet size is that larger droplets reduce coverage and efficacy in some cases. In the buffelgrass spray project, droplets with a size distribution of 600-800 micrometer (µm) volume median diameter (VMD) were used. The VMD represents the droplet size where half of the spray volume is contained in droplets larger than the VMD, and half of the volume occurs in droplets smaller than the VMD.

Recommendation: Assuming that acceptable buffelgrass control can be achieved, it is recommended that droplet VMDs of $>$ 600 µm be used in buffelgrass applications using glyphosate products in this landscape.

Drift and Overspray

In general, major variables affecting spray drift are droplet size, wind speed, and release height. In the desert, humidity also becomes a major factor due to its influence on droplet size. Droplets smaller than 150-200 µm in diameter are more likely to move off-target, and generation of these relatively small droplet sizes should be minimized for most spray applications. Although there is always some drift of fine material during spraying, this drift greatly attenuates over distance and may have little if any impact on non-target species in the area affected by drift. In the buffelgrass spray project, there was no substantial drift at 75 feet away from the one-acre spray blocks involved in the trial (the detection limit was around 5% of the application rate). To investigate drift further, the measured conditions and type of equipment used during the project were entered into a computer model. The modeling exercise indicated that drift resulted in 1% of the application rate at 90 feet downwind. This modeled data corresponds to the measured data, i.e., 1% modeled at 90 feet vs. 5% measured at 75 feet. These numbers for drift must be combined with biological information to determine whether this amount of drift is damaging to non-target species.

Overspray as discussed in the **Application Precision** section above is not considered drift since it is part of the spray volume directly sprayed rather than limited to fine droplet sizes associated with drift. However, overspray may be a consideration if there are sensitive areas or species near the spray target. Overspray generally occurs on the order of tens of feet and may be a consideration in sample transects used to determine off-target impacts from drift.

Test spraying with “spray ball” nozzle assembly (US Forest Service)

Recommendations: Buffer zones sufficient to allow for adequate attenuation of drift should be established if sensitive non-target species or areas occur near the spray target. Similarly, no-spray buffers should be established to prevent problems with overspray if non-targets may be impacted.

Adjuvants

Adjuvants are ingredients added to spray mixes to improve herbicide performance and minimize potential failures under adverse conditions. Adjuvants include surfactants (wetting agents), spreaders, emulsifiers, dispersants, and penetrants. There is an ongoing debate in the technical literature discussing the effect of hardwater on glyphosate efficacy. In the buffelgrass spray project, ammonium sulfate (AMS) adjuvant was used as a conditioner to lower the water pH

“Pyramid housing” nozzle assembly (US Forest Service)

and to improve uptake of herbicide by the target species. Roundup Pro® itself actually contains a surfactant in the formulation to provide greater uptake of the herbicide. Surfactants help herbicide uptake by reducing the surface tension of liquids.

Recommendations: Given that depositional rates apparently fell during the buffelgrass spray project as the humidity dropped and convection increased in late morning, an anti-evaporant adjuvant should be considered for use in aerial applications. The anti-evaporant adjuvant would have the effect of slowing the decrease in droplet size due to evaporation thus increasing deposition on-target.

Auxiliary Study with Tethered Spray Nozzle Technique

Results of the auxiliary study indicate that the tethered spray nozzle technique with the spray ball or pyramid housing is a highly accurate delivery system for small areas. With the close proximity of the nozzle assembly to the target, drift can be minimized. The spray ball was capable of being navigated to within 3 to 5 feet above the ground while avoiding obstacles. In comparison to the spray ball, the pyramid housing assembly was less maneuverable but did cover a greater area with spray. The smallest observed target that the pilot was able to spray with the spray ball was 12 feet in diameter.

Helicopter time is very expensive, and treatment of buffelgrass with the tethered spray nozzle technique may prove to be cost prohibitive. The cost of helicopter time is approximately $1,200 per hour of flight time as opposed to a cost of $300-$500 per hour for fixed wing aircraft. The cost for spraying an individual area will depend on (1) the size and number of spots to be treated, (2) the time to ferry between spots, and (3) the ferry time to and from the helibase. In addition, the need for hovering by the helicopter while spraying with tethered spray nozzle equipment compromises some of the aerodynamic efficiency of a

rotary wing aircraft. This practice may be more dangerous than application during forward flight.
Recommendations: A licensed aerial applicator with experience in using the tethered spray nozzle technique should be used when feasible. The use of a GPS system is critical for the pilot to minimize unnecessary flight time while navigating to target areas. Also critical with the tethered spray nozzle technique is a quick release tether that can avoid accidents due to entanglement or other in-flight emergencies.

Interagency Contributors

City of Tucson - Office of Conservation & Sustainable Development
Pima County Natural Resources Parks and Recreation
University of Arizona
USDI Bureau of Land Management - Tucson Office
USDI National Park Service - Saguaro National Park
USDA Forest Service - Forest Health Protection (FHP)
USDA Forest Service - Missoula Technology & Development Center (MTDC)

For additional information contact:

Vegetation response: Dana Backer, National Park Service, Tucson, AZ
Email: dana.backer@nps.gov

Application recommendations: Allen White, USDA, Albuquerque, NM
Email: allenwhite@fs.fed.us

Pesticide Precautionary Statement

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.
CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife--if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

FHTET-12-10