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Basic Calibrations of Basal Bark Applications With Ester-Based Triclopyr in Oil Carrier

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Purpose

The purpose of this publication is to explain how to utilize calibration techniques for delivering reliable herbicidal doses to individual plant stems to ensure that efficient applications are administered within the maximum allowable use rate.

Figure 1. Basal bark applications are applied as "spray to wet."

Introduction

Herbicide use rate (HUR) is defined as the amount of herbicide active ingredient applied per unit area (e.g., lbs acid equivalents $acre^{-1}$). All registered herbicide product labels report the maximum HUR allowable on an annual basis. Federal and state laws prohibit exceeding this application rate.

Other PROHIBITED ACTS according to the Hawaii Pesticides Law, Chapter 149A of the Hawaii Revised Statutes include the following:

- Any pesticide use **INCONSISTENT** with its label;
- Pesticide application **DOSAGE**, **CONCENTRATION**, or **FREQUENCY** that is **GREATER THAN** label specification;
- Pesticide application to a crop, animal, or **SITE** that is **NOT SPECIFIED** on the label; and
- Employing a **METHOD OF APPLICATION** that is specifically **PROHIBITED** on the label.

Basal Bark Application Technique

Basal bark herbicide applications are administered as individual plant stem treatments, typically with a high concentration of active ingredient (e.g., 20–50% v/v) blended in an oil carrier (Jackson 2013, Enloe 2010; see Table 1). The technique uses a low-pressure sprayer or squirt bottle to cover the lower 12–15 inches of the stem applied as "spray-to-wet." To be effective, the entire stem and root collar area must be thoroughly wet. Some sources indicate that spray-to-wet equates to ≥100 gallons per acre (Wolf 2010; see Fig. 1 for stem dose conversion), although it can be much higher depending on the applicator. The oil carrier (e.g., commercially available basal oil, diesel fuel, no. 1 or no. 2 fuel oil, or kerosene) should have adjuvant characteristics for penetrating the bark periderm, allowing for uptake and vascular movement into the cambium layer of the treated plant. It should be noted that stems >4 inches in diameter may start to develop an outer bark layer called the rhytidome and might require a girdle around the circumference to expose the vascular cambium.

Herbicide Active Ingredient

Triclopyr is the most common active ingredient in basal bark applications and is available in water-soluble amine and oil-soluble ester formulations. Basal bark applications are almost exclusively administered with the oil-soluble formulations at concentrations of 20–50% v/v, but may be applied at 100% v/v. Triclopyr formulations have a high HUR of 6-8 lbs acid equivalents per acre, with the listed sites of application including non-crop, forest, wildlife openings, range and pasture, turf, and ornamental. Triclopyr is in the pyridine carboxylic acid family, with a synthetic auxin mode of action leading to abnormal growth, particularly at the apical points, and eventual death. Symptoms of necrosis are often observed within several weeks to several months, depending on species. It is a broadleaf- and woody plant-selective herbicide with some sensitivity to warm-season grasses, including kikuyu grass (*Pennisetum clandestinum*). It is effective on many legume species. Drift injury from foliar applications may be more prevalent with the ester formulations due to the higher potential for volatilization. Registered products include Garlon® 3A (amine at 3 lbs ae/gal, EPA reg. no. 62719-37), Garlon® 4 Ultra (ester at 4 lbs ae/gal, EPA reg. no. 62719-527), Remedy® Ultra (ester at 4 lbs ae/gal, EPA reg. no. 62719-70, Renovate 3 (amine at 3 lbs ai/gal, EPA reg no. 62719-37-67690), and Element 4 (ester at 4 lbs ae/gal, EPA reg. no. 62719-040), among others. See Appendix 1 for a list of species where triclopyr administered as a basal bark application is known to be effective.

Determining Stem Dose

Dose is defined as a quantifiable amount of an active substance administered to achieve effective results. Without proper dose calibration, basal bark treatments can often exceed the allowable HUR according to label, particularly in high stem-density areas (Holmes and Berry 2009). The same principles of calibrating large-scale broadcast applications can also be applied to small-scale individual plant treatments using basic (albeit extreme) reduction conversions, as follows:

$$1 \text{ gal} = 3785.41 \text{ ml}$$
$$1 \text{ acre} = 43{,}560 \text{ ft}^2$$
$$1 \text{ lb} = 453.59 \text{ g}$$
$$1 \text{ gal acre}^{-1} = 0.09 \text{ ml ft}^2$$

This relationship allows the proper dose to be calculated for an individual stem based on estimations of basal surface area and herbicide use rate depending on

Table 1. Aspects of a basal bark application technique

Definition	Herbicide Mix[b]	Calibration	Tools	Pro	Con
Oil-diluted, high-concentration herbicide, low-volume application directed at the base of main stems	Active ingredient 10–50% v/v, penetrant oil adjuvant 50–90% v/v	Flow rate (ml/squirt), stem dia. (in),	Squirt bottle or small hand-pump sprayer (1 gal), full-cone or solid-stream nozzle	Easy application, no water consumption, light payload	Less effective on large trees, dead standing biomass

[a]Adapted from Leary et al. 2013
[b] v/v = volume product/volume total solution

stem density. Figure 1 shows the dose volumes needed to achieve spray-to-wet (100 and 200 gal $acre^{-1}$) where dose is dependent on stem size. For example, Figure 1 indicates that stem dose rates increase 2.8–5.7 ml for every 1-inch diameter to achieve 100 and 200 gallons $acre^{-1}$ (gpa) respectively.

Calibrating Dose

Many methods can be used for calibrating delivery rate, but it is most often accomplished by measuring liquid volumes collected over a measured time period (e.g., ml sec^{-1}). For calibrating more refined basal bark applications, delivery rates should be measured by weight with a "gravimetric" conversion to volume based on the known density of the solution.

Figure 3 shows a graph of water weight accumulated by the number of trigger pulls (10X) from a spray bottle into the tared collection vessel. In four repetitions, this spray bottle was not exact but was consistent. The weight accumulation from the delivery has a linear relationship with trigger pulls, so the delivery rate can be estimated using the slope of the linear relationship between pulls and weight; i.e., rise over run:

$$rate = \frac{wt_f - wt_i}{pulls_f - pulls_i}$$

where wt_f and wt_i are final and initial weights (grams) respectively, and $pulls_f$ and $pulls_i$ are the final and initial trigger pulls respectively from the spray bottle. In Microsoft® Excel®, the SLOPE f_x may also be used for direct calculation, written as

= SLOPE (known y's, known x's)

where the y's are in weights and x's are in trigger pulls. In this sample calibration, the average weight accumulation was ~1.0 gram per trigger pull.

The specific gravity of the fluid must also be known in order to determine dose rate. Water at 4°C has a specific gravity of 1.0 gram cm^{-3}. Many seed oils and also petroleum diesel are less dense, at 0.90–0.95 grams cm^{-3}. The ester formulation of triclopyr is heavier, at 1.11 grams cm^{-3}. Thus, a 25% v/v blend with an oil adjuvant is likely to be between 0.95 and 0.99 grams cm^{-3}, which is almost equivalent to the specific gravity of water for the purpose of calibrating delivery rates of a spray bottle. For hygienic purposes, most calibrations should be conducted with clean water, which may warrant a 1–10% reduction conversion of the oil-based formulations, if necessary. Individual spray bottles may also have inconsistencies confounded by the viscosity of the oil fluid, particularly after much use. Thus, comparing delivery rates between clean water and oil adjuvants has merit, and frequent calibrations are encouraged to ensure consistency and uniform delivery rates. In this example, each trigger pull is ~1.0 ml, which, as can be seen in Fig. 1, indicates that approximately 6–12 trigger pulls are needed to treat a 2-in. stem diameter at "spray-to-wet."

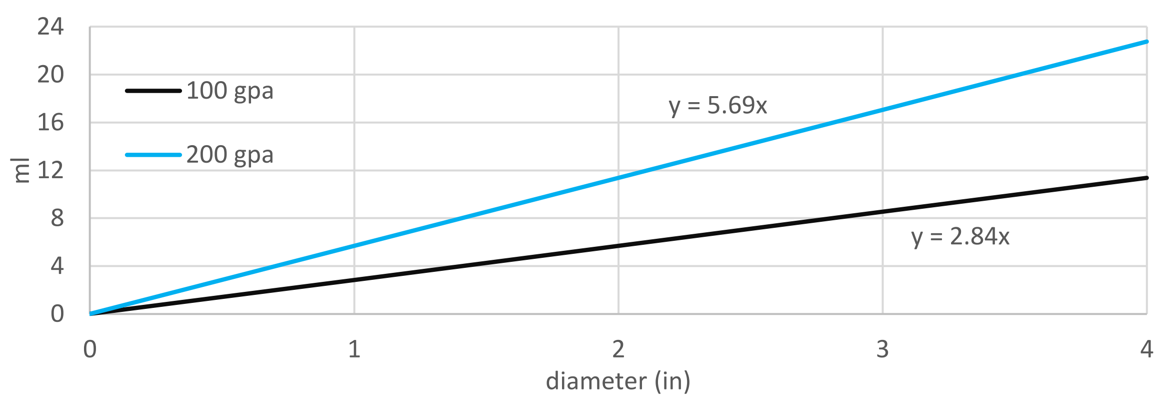

Figure 1. Dose volume rates for 100 gpa and 200 gpa basal bark applications based on stem diameter (i.e., stem surface area for 15 in. from soil line derived from the equation *A = l*πd*, e.g., 1-in. dia. = ~0.33 ft²).

Figure 2. Demonstration of a basic gravimetric approach to sprayer calibration: (A) calibration on a digital gram scale, (B) taring (zeroing) the collection vessel, and (C) recording the weight at determined intervals. The weight of tap water after 10 trigger pulls from spray bottle is measured. Assuming a specific gravity of water as 1.0 g cm^{-3}, the average dose per trigger pull is equal to 1.04 ml. This value is likely to vary among different sprayers, even those of the same model.

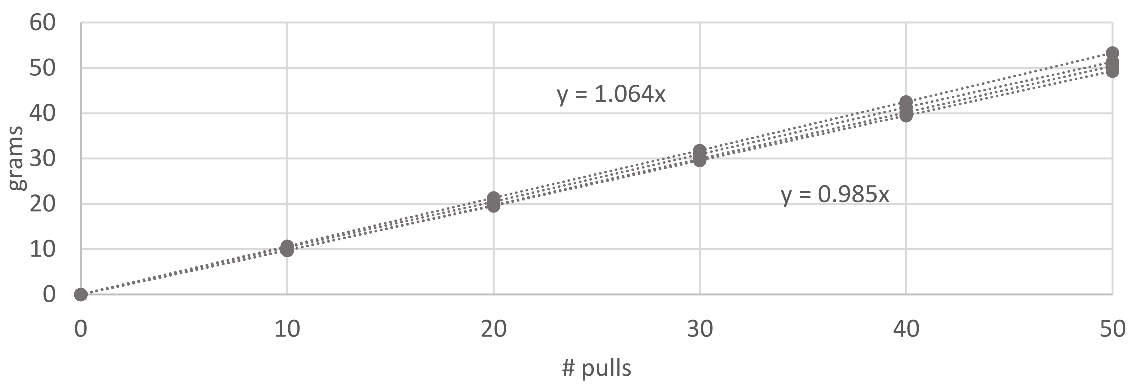

Figure 3. Weight (grams) of delivery volume from trigger pulls from a spray bottle. This calibration was replicated four times. The slope for the highest and lowest rates is given.

Relating HUR With Stem Size and Patch Density

Knowing the (i) correct stem dose (refer to Fig. 1), (ii) the active ingredient concentration of the treatment formulation (e.g., 20–50% v/v), and (iii) the maximum allowable use rate (i.e., 8 lbs ae $acre^{-1}$), allows target density thresholds to be predetermined. Figure 4 shows that larger specimens, higher dose rates, and increasing concentrations have compounding effects that lower treatable target densities.

How to Monitor HUR in the Field

The ability to monitor HUR is contingent on (i) good, preemptive intelligence of the management area, (ii) adequate methods for recording herbicide dose delivery, and (iii) new techniques for calculating treatment area. Accurate HUR historically has been achieved in agricultural settings under highly managed conditions (e.g., broadcast applications with constant flow rates, over planted row plots). Herbicide applications to individual plants in naturalized settings present a multitude of challenges. Land areas to be treated are not perfect squares, and invasive weeds do not typically grow in uniform rows. The challenges for determining HUR in this setting can be addressed by using global positioning system (GPS) loggers. Presented below are two basic field methods that can be used.

Block method: The total work area is divided into 1-acre (or smaller) blocks with corner points (and sides, if possible) loaded on a GPS with a map display. The maximum amount of herbicide allowed for a block is divided

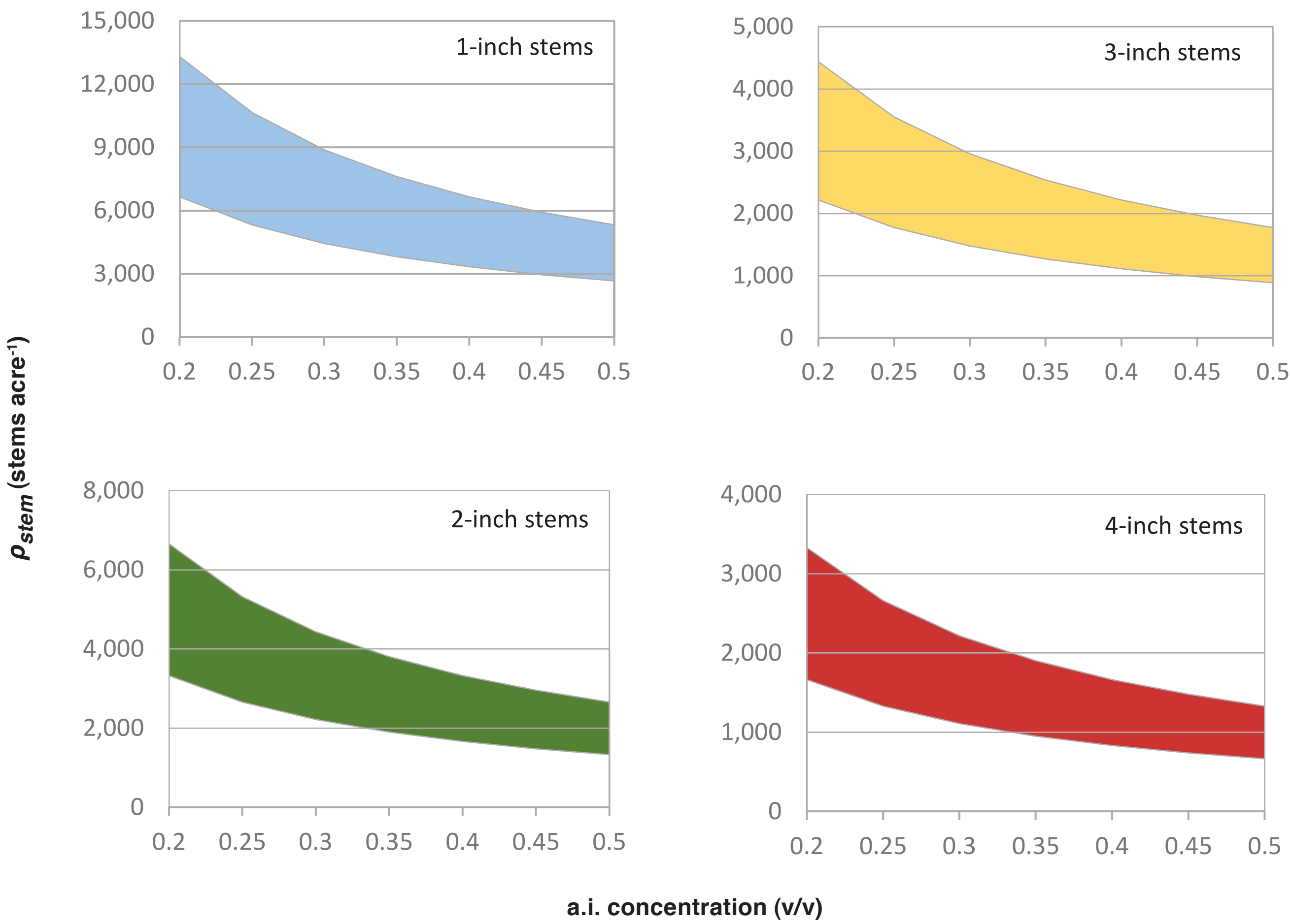

Figure 4. Stem densities (ρ_{stem}) at maximum allowable threshold of 8 lbs ae acre^{-1} for different stem diameters at application rates between 100 and 200 GPA (top and bottom edge, respectively) with the active ingredient triclopyr at concentrations of 20–50%. See Fig. 1 to convert gpa to stem dose in ml. Different scales are used on the y-axes of the respective stem sizes.

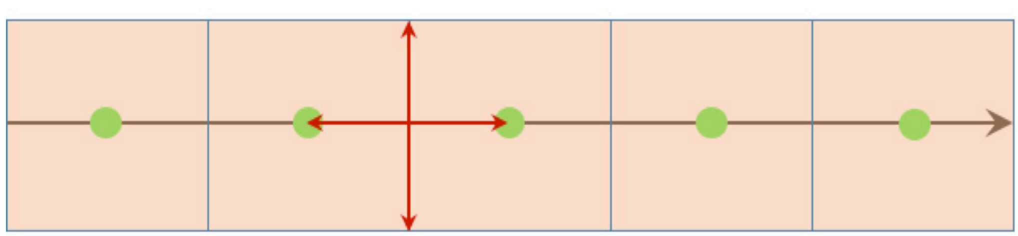

Figure 5. Square areas calculated from stems (green points) recorded on a transect (black arrow) where , with the side (s) of the square is equivalent to the distance between stems (red arrows).

among field personnel. Remaining herbicide is collected and measured at the end of the workday to determine the total application amount. Any blocks left untreated after the herbicide allotment is depleted can be treated later with a different herbicide or revisited the next year.

Transect method: A transect is a straight line followed by surveyors for making observations at intermittent points along the way. In weed management, lines are created between treated stems. Herbicide use rate can be monitored in the field with quick calculations for average stem density and dose. Stem density is the number of stems per unit of area; one simple way to measure this is to record the average distance between stems (s) where the area surrounding that stem is equal to that distance squared (Fig. 5).

The distance travelled can be monitored with most GPS receivers. For instance, if you travelled 1000 ft., treating 250 stems, the average distance between stems is 4 ft. That corresponds to an estimated stem density of 2,722 stems acre^{-1} along the transect, as determined by the following equation:

$$\rho_{transect} = 43{,}560 s^{-2}$$

where *s* is the distance between stems (Fig. 5). Average dose can be monitored a number of different ways, by volumetric (e.g., before-and-after volume) and gravimetric (before-and-after weight) measures, as well as by count if using a calibrated squirt bottle as described above. Depending on the concentration of the solution, an applicator can intermittently check the use rate by estimating their average dose per stem (Fig. 6). For example, with an average 4 ft. distance between stems and with a 25% v/v solution the dose volume can be up to 11.1 ml stem^{-1} (e.g., 10 trigger pulls) to reach the maximum label rate of 8 lbs ae acre^{-1} (see close-up of Fig 6). This maximum rate at 25% v/v solution is equivalent to the total allowable quantity of 30,283 ml per acre. An alternative to calculating dose is with the following equation:

$$dose_{max} = \left(\frac{v_{active\ max}}{[v_{active}]}\right) / \rho_{stem}$$

In this case, where $v_{active\ max}$ is the volume of the undiluted concentrate at the maximum allowable rate

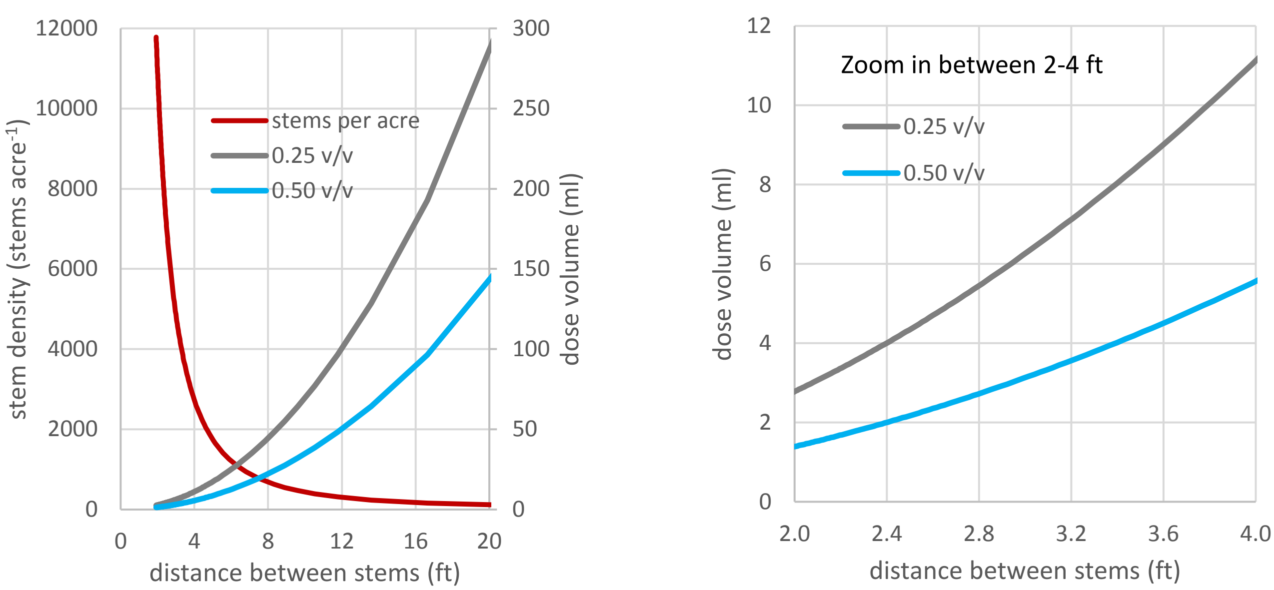

Figure 6. Stem density and stem dose volume with a 25% and 50% active ingredient solution to reach the maximum allowable use rate (i.e., 8 lbs ae acre^{-1}) determined by the distance between stems along a single transect to estimate the square area (). The right graph is a close-up of the dose volume between 2–4 ft. distance between stems in high-density patches (e.g., >2000 stems acre $^{-1}$). These closer stem distances can result in high (excessive) doses exceeding HUR.

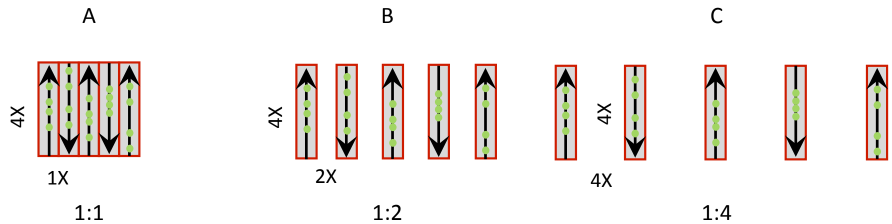

Figure 7. An example of mean stem densities ($\rho_{TRANSECT}$) measured from transects (n=5) where each length is equal to 4X and the spaces between transects are 1X, 2X and 4X for A, B, and C diagrams, respectively. A total of 20 stems treated is equivalent to a mean distance between stems of 1X, which is used to calculate the square area. The density of the block area (ρ_{BLOCK}) is proportional to the ratio stem distance:transect spacing.

(i.e., 8 lbs ae max /4 lbs ae gal^{-1} conc. = 2 gal), [v_{active}] is the active concentration of the dose solution blended with an oil carrier (e.g., 25% v/v) and ρ_{stem} is the stem density.

Multiple transects running parallel to each other create a block area, where the ρ_{block} is proportional to the transect distance between stems but inversely proportional to the spacing between transects. The transect estimation of HUR can be further adjusted for the entire block, where wider transect spacing will proportionally reduce values. For example, where the average stem distance is equal to the transect spacing, ρ_{block} is equal to $\rho_{transect}$ (Fig. 7). Likewise, if the spacing between transects are 2x or 4x, ρ_{block} would be ½ to ¼ of the calculated transect density, assuming there are no other stems between transects.

Many other approaches to monitoring herbicide use rate exist, and practitioners are strongly encouraged to adopt a comparable system to ensure effective legal applications. As stated above, the most basic approach is dividing before-and-after quantities applied by the calculated treatment area, resulting in a composite average. If using a squirt bottle with a calibrated dose delivery, applicators might also consider a clicker or a smart phone application with GPS and tally counter to record when, where, and how much herbicide was delivered in an exact location.

Conclusion

The ability to calibrate an herbicide dose to individual weed targets advances invasive weed management by empowering applicators with new knowledge, allowing them to become more efficient and environmentally responsible with the use of pesticides in natural areas.

Acknowledgements

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Disclaimer

Mention of specific brand names does not constitute endorsement on the part of the authors, CTAHR, or the University of Hawai‘i.

Cited Literature and Useful Links

Anonymous. Hawaii Pesticides Law, Chapter 149A, Hawaii Revised Statutes. http://hawaii.gov/hdoa/pi/pest/reg

Anonymous. Material Safety Data Sheet. Garlon® 4 Ultra. Issue date: 09/15/2011. http://www.cdms.net/LDat/mp7IN011.pdf

Anonymous. North American Invasive Species Mapping Standards. Approved in October 2014 by the North American Invasive Species Management Association. http://www.naisma.org/images/NAISMA_Mapping_Standards2014_1.pdf

Enloe et al. 2010. Basal bark herbicide treatment for invasive plants in pastures, natural areas, and forests. Alabama Cooperative Extension Service. Auburn University, Auburn, AL. http://www.aces.edu/timelyinfo/Ag%20Soil/2010/December/Dec_2010.pdf

Ferrell et al. Calibration of herbicide applicators. 2012. SS-AGR-102. Agronomy Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Gainesville, FL. http://edis.ifas.ufl.edu/wg013

Hellman, E. Herbicide sprayer calibration worksheet. AgriLife Extension Texas A&M System. College

Station, TX. https://winegrapes.tamu.edu/grow/herbicide.pdf

Holmes, K.A. and A.M. Berry. 2009. Evaluation of off-target effects due to basal bark treatment for control of invasive fig trees (*Ficus carica*). *Inv. Plant. Sci. Mgmt*. 2:345-351.

Jackson, D.R. 2013. Using basal bark herbicide applications to control understory tree species. College of Agriculture Sciences. Pennsylvania State University. Happy Valley, PA http://pubs.cas.psu.edu/FreePubs/PDFs/ee0059.pdf

Keyser et al. undated. Chemical application methods for herbaceous weeds. University of California Cooperative Extension. Davis, CA. http://ucanr.org/sites/csnce/files/57613.pdf

Keyser, G. undated. Spray-to-wet spot treatments. University of California Cooperative Extension. Davis, CA. http://ucanr.edu/sites/Grown_in_Marin/files/207446.pdf

Leary, J., et al. 2012. Practitioner's guide for effective non-restricted herbicide techniques to control and suppress invasive woody species in Hawai'i. Extension Bulletin WC-10. University of Hawai'i at Manoa. p. 8. http://www.ctahr.hawaii.edu/ oc/freepubs/pdf/WC-10.pdf

Wolf, R.E. Calibration steps worksheet. 2010. Kansas State University. Manhattan, KS. http://www.bae.ksu.edu/faculty/wolf/PDF/MF2915-Hand%20Sprayer.pdf

Glossary of Terms and Definitions

Dose – The amount of an active ingredient administered to achieve an effective response

Herbicide use rate – The amount of herbicide active ingredient applied per unit area

Acid equivalents (ae) – The amount of actual active chemical compound derived from the molar amount of the ionic salt

Adjuvant – A chemical solvent designed to enhance active ingredient performance

Gravimetric – Measurement based on weight

Volumetric – Measurement based on volume

Cambium – The vascular network (i.e., xylem and phloem) of the plant

Periderm – The corky outer layer of the stem distal to the cambium

Rhytidome – The external-most layer of the stem (i.e., bark)

Appendix 1.
Woody species known* to be effectively controlled by basal bark applications with triclopyr.

Family	Genus	Species	Common Name
Anacardiaceae	*Schinus*	*terebinthifolius*	Christmas berry
Araucariaceae	*Araucaria*	*columnaris*	Cook pine
Asteraceae	*Ageratina*	*adenophora*	Maui pamakani
	Ageratina	*riparia*	Hamakua pamakani
	Chromolaena	*odorata*	Devil weed
	Montanoa	*hibiscifolia*	Tree daisy
	Pluchea	*carolinensis*	Sour bush
Bignoniaceae	*Spathodea*	*campanulata*	African tulip
Buddlejaceae	*Buddleia*	*asiatica*	Asiatic dog tail
Casuarinaceae	*Casaurina*	*glauca*	Ironwood
	Casuarina	*equisetifolia*	Ironwood
Chenopodiaceae	*Atriplex*	*semibaccata*	Salt bush
Dryopteridaceae	*Deparia*	*petersenii*	Deparia
Euphorbiaceae	*Aleurites*	*moluccana*	Kukui nut
Fabaceae	*Acacia*	*confusa*	Formosan koa
	Acacia	*farnesiana*	Klu
	Acacia	*mangium*	Black wattle
	Acacia	*mearnsii*	Black wattle
	Falcataria	*moluccana*	Albizia
Malvaceae	*Triumfetta*	*semitriloba*	Sacramento bur
Melastomataceae	*Clidemia*	*hirta*	Soap bush
	Miconia	*calvescens*	Miconia
Meliaceae	*Toona*	*ciliata*	Australia red cedar
Moraceae	*Ficus*	*microcarpa*	Chinese banyan
Myrsinaceae	*Ardesia*	*elliptica*	Ink berry
Myrtaceae	*Syzygium*	*cumini*	Java plum
	Psidium	*cattleianum*	Strawberry guava
Proteaceae	*Grevillea*	*robusta*	Silk oak
Rosaceae	*Rubus*	*rosifolius*	Thimbleberry
Rubiaceae	*Coffea*	*arabica*	Coffee
Thelypteridaceae	*Cyclosorus*	*dentatus*	Christella
	Cyclosorus	*parisiticus*	Christella
Verbenaceae	*Citharexylum*	*caudatum*	Fiddlewood
	Stachytarpheta	spp.	Blue rat tail

*** Species information contributed by Oahu Army Natural Resource Program, Koolau Mountain Watershed Partnership, The Waimea Valley Botanical Gardens, and the Hawaii Division of Forestry and Wildlife.**