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Author for correspondence:
Stephen F. Enloe; Center for Aquatic and Invasive Plants, 7922 NW 71st Street Gainesville, FL 32653.
(Email: sfenloe@ufl.edu)

Output variation of trigger-pump sprayers used for individual plant treatments

Stephen F. Enloe[1], James K. Leary[2], Kenzie Bell[3] and Dwight K. Lauer[4]

[1]Professor, Agronomy Department, University of Florida, Center for Aquatic and Invasive Plants, Gainesville, FL, USA; [2]Assistant Professor, Agronomy Department, University of Florida, Center for Aquatic and Invasive Plants, Gainesville, FL, USA; [3]Former Graduate Research Assistant, Agronomy Department, University of Florida, Gainesville, FL, USA and [4]Analyst, Silvics Analytic, Wingate, NC, USA

Abstract

Individual plant treatment (IPT) techniques (e.g., basal bark, cut stump, hack and squirt) are used for woody invasive plant management and often rely on small trigger-pump spray bottles as an economical and efficient way to deliver a herbicide to the target species. Worldwide, plastic suppliers produce many models and designs with a wide range of uses, including pesticide application. However, spray bottle performance has rarely been examined in relation to IPT techniques for operational invasive plant management. We tested 10 commonly available spray bottles for trigger output and variation over repeated strokes. We also examined sustained trigger sprayer performance over a 6-wk period for spray bottles containing water or basal oil carriers blended with amine and ester formulations of triclopyr, respectively. In the first study, we found significant differences in spray output per stroke between almost every bottle tested. Almost all spray bottle brands yielded outputs greater than 1.0 ml per stroke, which exceeds the maximum application amount specified for hack and squirt. Several bottles produced an output of greater than 2.5 ml per stroke. In the second study, the output per stroke was reduced for basal oil mixes, with significant reductions measured for two brands by 21 d and for all three brands tested by 42 d after mixing. These results indicate that consumer-grade trigger sprayers are likely to depreciate rapidly with routine operational use without proper hygiene maintenance. Even then it is likely that these application devices may need to be replaced several times annually. Trigger-pump spray bottles are an economical and practical solution for remote field operations and volunteer weed control activities. These sprayers are most suitable for spray-to-wet techniques such as basal bark and cut-surface treatments but may potentially be less suited for hack and squirt application, which often requires sub-milliliter precision.

Introduction

Individual plant treatments (IPT) can be administered by multiple herbicide application methods, including foliar, basal bark, cut stump, and hack and squirt application techniques. IPT equipment is not typically calibrated, which contrasts with broadcast herbicide application equipment such as boom sprayers. Calibration ensures delivery of an effective herbicide dose without exceeding the use rate, according to the label. However, individual plant treatments by design are administered as directed applications to low-density target populations. Intuition suggests that this uses less total herbicide and is nominal to the maximum allowable use rate. However, IPT is often administered to difficult-to-control species that require a high lethal dose. In this case, recommendations generally call for mixing high concentrations and thorough spray coverage (e.g., spray-to-wet), which could ultimately lead to localized overapplication exceeding label rates (Holmes and Berry 2009).

Backpack sprayers are globally the industry standard for ground pesticide applications. In the United States, 15-L (4-gal) sprayers are widely used. While effective, backpacks can cause fatigue due to heavy weight loads (Cole 2006; Konthonbut et al. 2020), chronic injury (Avargani et al. 2020), and pesticide exposure (Blanco et al. 2005; Konthunbut et al. 2020; Lunner-Kolstrup and Ssali 2016). These issues have prompted examination of alternative approaches to better protect applicators while maintaining treatment efficacy (Bell 2019). One key alternative is hack and squirt treatment, where small concentrated doses (0.5 to 1 ml) of a herbicide are delivered directly to the phloem and cambium via a series of downward hacks through the outer bark. The small dose size allows the use of trigger-pump spray bottles to apply the herbicide into the hack.

Small trigger-pump spray bottles have a wide range of industrial and consumer uses dispensing chemical formulations, including pesticides, and are often recommended for administering directed herbicide treatments (Tu et al. 2001). Trigger-pump spray bottles function by a spring-loaded piston that draws liquid with a vacuum from a drop tube submerged in a small reservoir (e.g., 0.5 to 1.0 L), and forces the metered aliquot through a spray nozzle that adjusts to

Management Implications

Trigger-pump sprayers are widely used for individual plant treatment techniques including cut stump, basal bark, and hack and squirt. Although there are numerous brands and models available, very few retailers provide application detail that is sufficient for calibration, including stroke output. We tested 10 widely available spray bottle brands for performance metrics, including trigger output and variation per stroke. Additionally, we tested three brands for these metrics when used with water-based and oil-based triclopyr herbicide mixes. We found trigger output varied significantly between almost all brands tested and ranged from 0.85 to 3.88 ml stroke^{-1}. This is very noteworthy, as herbicide labels commonly specify an application volume of 0.5 to 1.0 ml per hack. We also found significant declines in trigger output over time when bottles were stored with oil or water triclopyr mixes for 21 to 42 d. These results indicate the onus is upon the applicator to verify the trigger output of a given spray bottle before commencing treatment. Furthermore, applicators should monitor spray bottle output over time and consider replacing spray bottles on a relatively frequent basis because their performance degrades.

deliver fine particle sizes in a full cone or a coarser solid-stream emission. The volume amounts of the sprayer are typically not specified (Table 1) but can range from <1.0 ml to >3.0 ml according to various manufacturers.

In weed management settings, there are many considerations for selecting a trigger spray bottle. Bottle features that are useful for IPT include an adjustable nozzle that ranges from a fine mist to a straight stream; graduated measurements on the bottle for accurate mixing; a wide neck opening, making it easier to fill; ability to spray at a range of angles, including upside down; fabrication with chemical-resistant materials (e.g., high-density polyethylene); a heavy-duty trigger that can deliver a consistent output, and secure containment with no leaking. Technical specifications on output are often not readily available, even on manufacturer websites. This results in applicator uncertainty over spray bottle selection and potential issues with calibrating herbicide dose accuracy in accordance with herbicide labels.

Given the lack of available information, our objective was to assess the utility of several commonly used trigger spray bottles for operational IPT with two experiments to measure output variations among brands and integrity over time. Answering these questions would greatly assist applicators in proper equipment selection for invasive plant IPT efforts.

Materials and Methods

Studies were conducted in a laboratory at the University of Florida Center for Aquatic and Invasive Plants in Gainesville, FL, USA. Ten spray bottle brands were purchased online and at local hardware, and agricultural supply stores (Table 1). Study 1 was conducted in the summer of 2018. For this study, twelve bottles from each brand were tested. Bottles were filled with 500 ml of tap water. Spray headers were initially primed by fully depressing and releasing the trigger (hereafter referred to as a "stroke") 10 times to remove all air from the drop tube and ensure complete output per stroke. Drop tubes were checked for secure attachment to the spray header, and nozzles were adjusted to a straight stream pattern. This was performed by closing the nozzle completely and then turning the nozzle body in a counterclockwise direction approximately 540° for each bottle. This was to accomplish an approximate standard homogenous straight stream among bottles within brands. Any malfunctioning bottles were replaced before the study was initiated.

Bottles were held upright on a flat surface by a single applicator, always in the same hand. The applicator used the other hand to position a 100-ml beaker close to the nozzle at a 45° angle to capture the spray. The applicator then fully squeezed the trigger in an even motion to completely release the contents. The beaker was then placed on a tared balance, accurate to the nearest milligram. In addition to the output delivered as the trigger was squeezed, a full stroke frequently included a small volume of liquid delivered to the beaker as the trigger was released. This was common among many bottles and was captured as part of the stroke output. The mass of each stroke was immediately recorded, and the balance was reset for the next stroke. This procedure was repeated to collect data on 30 strokes per bottle.

Study 2 was conducted in the summer of 2019. Four bottles each for three different brands from Study 1 were selected for testing. Selection was based upon different brand outputs and known chemical resistance. Four treatment mixes were used to examine spray bottle performance over time. Treatments included water alone (100% v/v), basal bark oil alone (100% v/v) (Impel™ Red, Helena, Collierville, TN, USA), triclopyr amine (Garlon® 3A, Corteva, Indianapolis, IN, USA) mixed at 180 g L^{-1} in water (50% v/v), and triclopyr ester (Garlon® 4 Ultra, Corteva) mixed at 96 g L^{-1} in basal bark oil (20% v/v). The triclopyr amine concentration used is commonly recommended for hack and squirt and cut stump treatments. The triclopyr ester concentration used is commonly recommended for cut stump and basal bark treatments. Bottles were filled with each mix and immediately tested using the protocol described in the first study, the only difference being 20 strokes per spray bottle instead of 30. Output volume was calculated from squirt mass using the specific gravity of each treatment mix. Following each test, bottles were stored in the dark at room temperature (22 C) until the next test. Tests were conducted at 0, 7, 14, 21, and 42 d after mixing. No noticeable storage issues were observed with the treatment mixes over the 42-d period. However, bottles were placed in 3.78-L sealable bags and observed for leakage during storage, which was occasionally found and recorded.

Statistical Analysis

The first study used water mass per stroke as the dependent variable to compare 10 spray bottle brands using 12 bottles per brand (two runs of six) tested in a randomized complete block design. A block consisted of one bottle per brand tested in random order with 30 strokes per bottle. Run and block (one set of different brand bottles) within run were incorporated as random effects and between-bottle variance was estimated for each brand using a heterogeneity of variance model (Littell et al. 2006). The percent standard error (PSE) was also calculated as [100 * (SE/mean)]. A separate ANOVA was conducted for each brand to estimate the within-bottle variation in squirt mass.

The second study utilized a randomized complete block design, and the four sets (blocks) of 12 bottles (four treatment mixes and three brands) were tested together in random order for each storage date. The ANOVA incorporated block, brand and treatment combinations within block, and test date within block, brand, and mix treatment as random effects using a heterogeneity

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Table 1. Spray bottle technical information, as provided from each manufacturer's website.

Spray bottle brand[a]	Output per stroke	Chemical resistance	Manufacturer
	—ml[b]—		
Ace	Not specified	Yes	Ace Hardware, Kensington, IL 60523
Delta	Not specified	Unclear	Delta Industries, King of Prussia, PN 18106
GroundWork®	Not specified	Yes	Tractor Supply Company, Brentwood, TN 37027
Harris® Pro	Not specified	Yes	Harris, Cartersville, GA 30120
HDX™	1.5	Yes	Home Depot, Atlanta, GA 30339
SprayMaster	3.0	Yes	Delta Industries, King of Prussia, PA 18106
Spray-Pro	Not specified	Yes	Continental Commercial Products, St Louis, MO 63146
XR2500	Not specified	Yes	Sprayco, Livonia, MI 48150
Zep Chemical	Not specified	Yes	Zep, Atlanta, GA 30339
Zep Commercial	Not specified	Yes	Zep, Atlanta, GA 30339

[a]All bottles tested had a single adjustable nozzle and a volume of 946 ml (32 oz).
[b]Output per stroke was not specified on the spray bottle or readily available on the manufacturer's website.

Table 2. Mean water outputs (±SE; $n = 12$) of trigger-pump sprayers from Study 1.

		Between bottle				Within bottle
Brand	Output per stroke[a]	SE	PSE[b]	Lower 95%	Upper 95%	SE
	—g—	—g—	—%—	—g—	—g—	—g—
Ace	0.895 gh	0.021	2.4	0.849	0.941	0.002
Delta	1.157 f	0.019	1.7	1.115	1.199	0.002
GroundWork®	0.932 g	0.017	1.8	0.895	0.968	0.003
Harris® Pro	3.884 a	0.022	0.6	3.836	3.933	0.003
HDX™	1.239 e	0.012	1.0	1.212	1.267	0.001
SprayMaster	3.021 c	0.017	0.6	2.984	3.058	0.003
Spray-Pro®	0.848 h	0.011	1.3	0.824	0.872	0.001
XR2500	2.393 d	0.107	4.5	2.157	2.629	0.007
Zep Chemical	2.474 d	0.077	3.1	2.304	2.644	0.013
Zep Commercial	3.371 b	0.017	0.5	3.334	3.408	0.003

[a]Means followed by the same letter are not different ($P = 0.05$).
[b]Percent standard error (PSE) was calculated as [100 * (SE/mean)]. This expresses the standard error as a percent of average stroke mass.

of variance model to allow estimates of variance components by brand. This analysis was performed on both mass and volume outputs. Volume was estimated using output mass and the specific gravity of each treatment mix. Analysis was performed using the PROC GLIMMIX (Littell et al. 2006) package of SAS® v. 9.4 software (SAS Institute, Cary, NC USA). Means comparison tests used the Tukey-Kramer adjustment for multiplicity and a significance level of 5% for main effects. The appropriate Fisher's LSD approach for mean comparisons was used when there was a significant interaction.

Results and Discussion

In the first study, there were three variables of interest with the 10 bottle brands tested with water. A consistent trigger output is important for reliably calibrating application rates to ensure treatments are compliant with label specifications. There were significant differences in stroke output between most bottle brands tested (Table 2). Output per stroke ranged from 0.85 g ± 0.01 g for the Spray-Pro® to 3.88 ± 0.02 g for the Harris® Pro. Most herbicide labels specify up to 1.0-ml volume per hack for the hack and squirt technique. Three of the brands had a mean output of <1.0 ml and only one of these was within 10% of the 1-ml stroke output recommended by herbicide labels. Of the seven brands with a stroke output greater than 1 ml, none were within 10% of 1 ml, and only one was within 20%. Overall, only 4 out of the 10 brands tested were within 20% of 1 ml. These differences may appear minimal, but without this knowledge, an applicator assuming a 1.0-ml output could in fact be underapplying or greatly exceeding the maximum allowable use rate. From a sprayer calibration perspective, sprayer calibration guides generally recommend replacing nozzles when output is greater or less than 10% of the specified target output (Ayers and Bosley 2005).

Additionally, depending on the size of the cut (hack) administered to the trunk, the retention capacity is generally approximately 1 ml (SFE, unpublished data). Higher output volumes can result in herbicide runoff from the hacks. For soil residual herbicides such as imazapyr, this could result in injury to nearby non-target plants.

Given that many spray bottle brands do not provide the technical specifications either directly on the bottle or on most retail or manufacturers' websites, the impetus is on the applicator to determine spray bottle output. This can be easily accomplished via low-cost volumetric measuring devices such as small 10-ml graduated cylinders. Another option is by calculating the weight of spray solution per stroke with a small portable electronic balance. These accurate and low-cost options are available through online retailers.

The second aspect of interest was the variation in stroke output between bottles of a given brand. This provides an indication of how consistent output is between bottles within brands.

Standard errors were quite low for each brand, ranging from 0.011 to 0.107 g stroke^{-1} (Table 2). However, PSE, which expresses the standard error (between bottles within brands) as a percent of average stroke mass, varied from 0.6% to 4.5%. If stroke output approximates the target specified on a given herbicide label, we argue that spray bottle brands with a lower PSE should be preferred, as PSE is a measure of variation across bottles relative to mass (or volume) per stroke. Ideally, this would be useful for hack and squirt, girdle, and cut stump applications to assist applicators in making more consistent IPT herbicide applications.

Finally, variation of "within-bottle" stroke mass is a measure of how consistent a spray mechanism functions for a given bottle

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Table 3. Comparison of spray volume (ml) by main effects (spray bottle brand and spray mix treatment) averaged across storage times.

Brand	Mean[a]	SE	Lower 95%	Upper 95%
HDX™	1.479 b	0.015	1.427	1.530
SprayMaster	2.867 a	0.016	2.831	2.903
Zep Commercial	2.912 a	0.040	2.825	2.999
Mix treatment[b]				
Water alone	2.526 a	0.030	2.463	2.589
Water + triclopyr amine[c]	2.469 a	0.030	2.406	2.532
Basal oil alone	2.334 b	0.030	2.270	2.397
Basal oil + triclopyr ester[d]	2.348 b	0.030	2.285	2.412

[a]Means followed by the same letter are not different (P = 0.05).
[b]The specific gravity for each mix treatment is as follows: water =1.000; triclopyr amine + water = 1.067; basal bark oil = 0.890; and triclopyr ester + basal bark oil = 0.928.
[c]Triclopyr amine was applied at 180 g L^{-1}.
[d]Triclopyr ester was applied at 96 g L^{-1}.

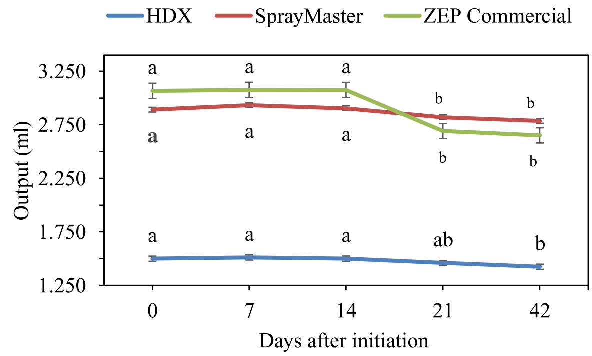

Figure 1. Comparison of spray volume (ml) by storage day within each brand. Means compared within each brand were compared using Fisher's LSD at the 5% level of significance only if the *F*-test of differences among days within brand was significant.

brand. The within-bottle variation was significantly less than the between-bottle variation for each brand (P < 0.001); the within-bottle standard errors were 6.5% to 17.6% of the between-bottle standard errors for all brands (Table 2). These indicate a high degree of consistency in the actuator mechanisms for all spray bottle brands tested. While a high degree of consistency should be expected from manufacturers, this is the first study to evaluate several brands from an IPT perspective.

For Study 2, the primary question of interest was how well spray bottle brands maintain consistent output over time when using different spray mixes. There was no significant interaction between spray bottle brand and treatment mix (P = 0.189), indicating consistency in spray output between brands for the four spray mixes tested. Additionally, there was no interaction between storage date and treatment mix (P = 0.926), indicating all treatment mixes influenced spray output similarly over time across brands. The same was true for the three-way interaction of storage date, spray bottle brand and treatment mix (P = 0.973).

Both spray bottle brand (P < 0.001) and treatment mix (P < 0.001) were significant as main effects. The first is consistent with the findings from Study 1 that brands differ in their designed output volume (Table 3). The significant effect of treatment mix was due to an approximate 6% lower spray output per stroke for both oil treatments compared with the water and water + triclopyr amine treatment mixes (Table 3). The higher viscosity of the oil carrier was the likely mechanism for reduced output per stroke.

There was also a significant interaction of storage date with spray bottle brand on output per stroke (P < 0.001). Additionally, the test of differences with storage date for each spray bottle brand was also significant (Figure 1). For the HDX™ spray bottle, output was consistent after 0, 7, 14, and 21 d of storage. However, output declined at 42 d after storage by approximately 4.7%. For the SprayMaster spray bottle, spray output did not differ at 0, 7, or 14 d after storage. However, spray output significantly declined by 2.4% and 3.6% at 21 and 42 d after storage, respectively (Figure 1). For the ZEP commercial spray bottle, spray output did not differ at 0, 7, or 14 d after storage. However, spray output significantly declined by 12.2% and 13.5% at 21 and 42 d after storage, respectively.

These studies indicate a wide range in variation in spray bottle output for commonly available spray bottles. Very few bottles tested were within 10% of a maximum output goal of 1 ml stroke^{-1}, and several bottles exceeded 3 ml in output, which is well above label recommendations. Given a common lack of information available on spray bottle output, it will require the due diligence of the applicator to ensure appropriate spray bottle selection when doing hack and squirt. This could also impact cut stump treatments, for which applicators are targeting very specific areas of the stump, including the cambium and phloem tissues. A high spray output per stroke could result in excessive application to unnecessary parts of the stump, such as the xylem tissue.

Additionally, all spray bottles tested in Study 2 declined in performance over a 42-d period, with two out of three declining by 21 d. This also indicates a need for applicators to frequently check output and expect to replace spray bottles frequently. Following these recommendations, applicators can better adhere to herbicide label recommendations for IPT techniques, which should lead to more consistent efficacy and reduced herbicide losses into the environment from overapplication.

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