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Contributions in Education and Outreach

No. 2

"Waving Wand" Broadcast Hand Application of Herbicides: Technical Basis and Usage

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and Jack W. Barry

Forest Research Laboratory
College of Forestry
Oregon State University
Corvallis, Oregon

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Abstract

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The waving-wand system of broadcast chemical application implemented in swath widths to 40 ft (>12 m) is capable of simulating broadcast deposition patterns for herbicides similar to those delivered by helicopter. Drop sizes vary from center to edge of swaths, which can range from >1,000 to 5,000 microns (μ). Any backpack sprayer is suitable for such treatments if it has a brass adjustable-cone nozzle and is operated by a trained operator. Effective 3-yr vegetation control was achieved on two forest ecosystem management research areas with a total of 42 plots, ranging from 1.2–1.8 ac (0.5–0.73 ha) in size, on variously steep terrain. Experimental applications of glyphosate (1.5 lb a.e./ac, 1.7 kg/ha) plus imazapyr (2.0 or 2.8 oz a.i./ac, 0.14 or 0.2 kg/ha) plus sulfometuron (2.3 oz a.i./ac, 0.16 kg/ha) in water at 3 gal/ac total volume (28 L/ha) or glyphosate plus imazapyr in a total spray volume of 5 gal/ac (47 L/ha) provided excellent control of numerous deciduous shrubs and two species of ferns following July applications. Equipment consisted of a 6-gal (23 L) backpack sprayer with a single adjustable cone nozzle. Operational considerations focus on consistency of walking speed, swing, and nozzle setting. Rates of 1.0-2.5 ac (0.4 to 1.0 ha)/operator hour are achievable, depending on obstacles. The method appears suitable and practicable for highly translocated, low-toxicity products applied to target vegetation <10 ft (<3 m) tall and to understories where individual targets may be up to 16 ft (5 m) tall. Low volume is a major logistical benefit. This system is suited for most broadcast site preparation and release areas unsuitable for aerial application, and understory target areas beneath overstories dense enough to intercept significant herbicide if aerially applied.

Keywords: spray technology, backpack sprayers, nozzles, coverage, understory treatment, low volume

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A great many areas in need of brush or weed control do not lend themselves to either mechanical application or aerial spraying equipment. Unit size, steep terrain, presence of slash/stumps, and proximity to sensitive areas such as water may limit the use of aerial applications (Figures 1-2). However, manual operations that use backpack sprayers to spot-treat brush or weeds are arduous and time consuming. They also miss many target weeds, necessitating repetitive treatments. Backpack operations for spot treatment tend to use much more volume of diluent than is needed to provide adequate coverage; they also typically have poor control of dosage.

We offer a means of overcoming the limitations imposed by site characteristics, as well as a means of reducing the volume of liquid applied. In Part 1, we describe the "waving-wand" method of hand application, which approximates aerial application in coverage and minimizes both the initial labor and the need for returning to the site in the future to treat skips in patterns. We identify equipment needs, provide data pertaining to function and output of spray nozzles adapted to broadcast spraying, and outline calibration procedures.

Part 2 describes the technology behind this system and experiments providing verification of methods and determination of spray deposition.

Part 3 follows with examples of such treatment in sites where neither aerial nor spot ground applications would work, i.e., steep forest land that had been, or would be thinned to encourage regeneration, and where the operator faced heavy slash and occasional brush 16 ft (5 m) tall.

Part 4 provides a broader discussion of related experiments and their findings, advantages and limitation of the method, and training needs.

Conventions in technical literature in this area use both metric and English units. We use both in this document. Table 1 provides conversions.

Figure 1. This example is for an area where helicopter service is unavailable, Alaska. Photo credit: Liz Cole.

Figure 2. Shrub communities of this height and density are readily treated. Applicators can weave paths among them by allowing for extra width on the side they swerve away from. Rule: Keep as close to planned swath centerline as possible, and aim well above target cover! Photo credit: Mike Newton.

Table 1. Conversion factors from metric to English units. Both are used in this document to conform with domestic use, yet conform to international documents.

Unit	Metric	English
Land area	1 hectare (ha)	2.47 acres (ac)
Distance	1 meter (m)	3.28 feet (ft); 39.37 inches (in.)
	1 kilometer (km)	3,281 ft; 0.62 miles (mi)
Drop diameter (micron)	0.001 mm	0.00004 inch (in.)
Pressure	1 megapascal (MPa)	150 pounds per square inch (psi)
Volume	1 liter (L)	1.06 quarts (qt); 0.264 gallons (gal) U.S.

1 The Waving Wand Method

Figure 3. Cover >10 ft (3 m) tall is readily treated unless the canopy is closed overhead. For tall cover >8 ft (2.4 m) tall use wand elevated 45° or more and spray through gaps in cover where possible. Photo credit: Milo Mihajlovich.

The waving-wand method, first described by Newton and Knight (1981), adapts low-volume aerial application technology to readily available backpack equipment. It is a broadcast application system suitable for a wide variety of forest vegetation problems (Figures 1-4) in which the operator moves forward with a single-nozzle (adjustable solid-cone-type) backpack sprayer, while swinging the elevated nozzle from side to side, either ahead of or behind the direction of travel (Figure 5). The nozzle swings continuously and rhythmically while spraying, until the operator stops moving forward. The depth of coverage within swipes and the distance between swipes (relation between forward speed and frequency of swipes) determine the overlap between swipes and the consistency of coverage within a swath. The width of the pattern is determined by the distance the nozzle projects its stream, combined with the angle at which the operator swings the nozzle from side to side, and it may vary up to about 40 ft (12 m). Smoothness of the edge of the pattern is also determined by the angle of swing (Figure 5) and the frequency of swipes per unit of travel.

A good pattern requires an understanding of patterns of drops of mixed sizes and of uniformity within swaths, and proper frequency of swings across the path of travel. The technology involved with the waving-wand method includes some elements not normally encountered with high-pressure power-sprayers specifically, because nozzles are directed *above* the target. *Patterns consist of fall-out* (rather than direct impact) from a single nozzle when *projecting well above the target vegetation* (slightly above horizontal for low herbaceous vegetation) at moderate pressure (<30 psi; 0.2 MPa).

The secret of uniform application is that the swing of the spray wand from side to side is frequent enough so that the coverage of each swing overlaps with at least the one before and the one after, total coverage being the total of the three swings. Uniformity of coverage takes rhythm tied to strides, uniformity of swing width and height, and steady forward progress as long as the nozzle is spraying.

Practicing with the equipment (clean water only, please!) and adjusting it as it will be used in the field

Figure 4. Uniform application is desirable. Spraying on steep ground leads to high deposit rates above the worker because of the narrower swath. Applicator must compensate by dwelling longer in the downslope part of the nozzle swing. Photo credit: Liz Cole.

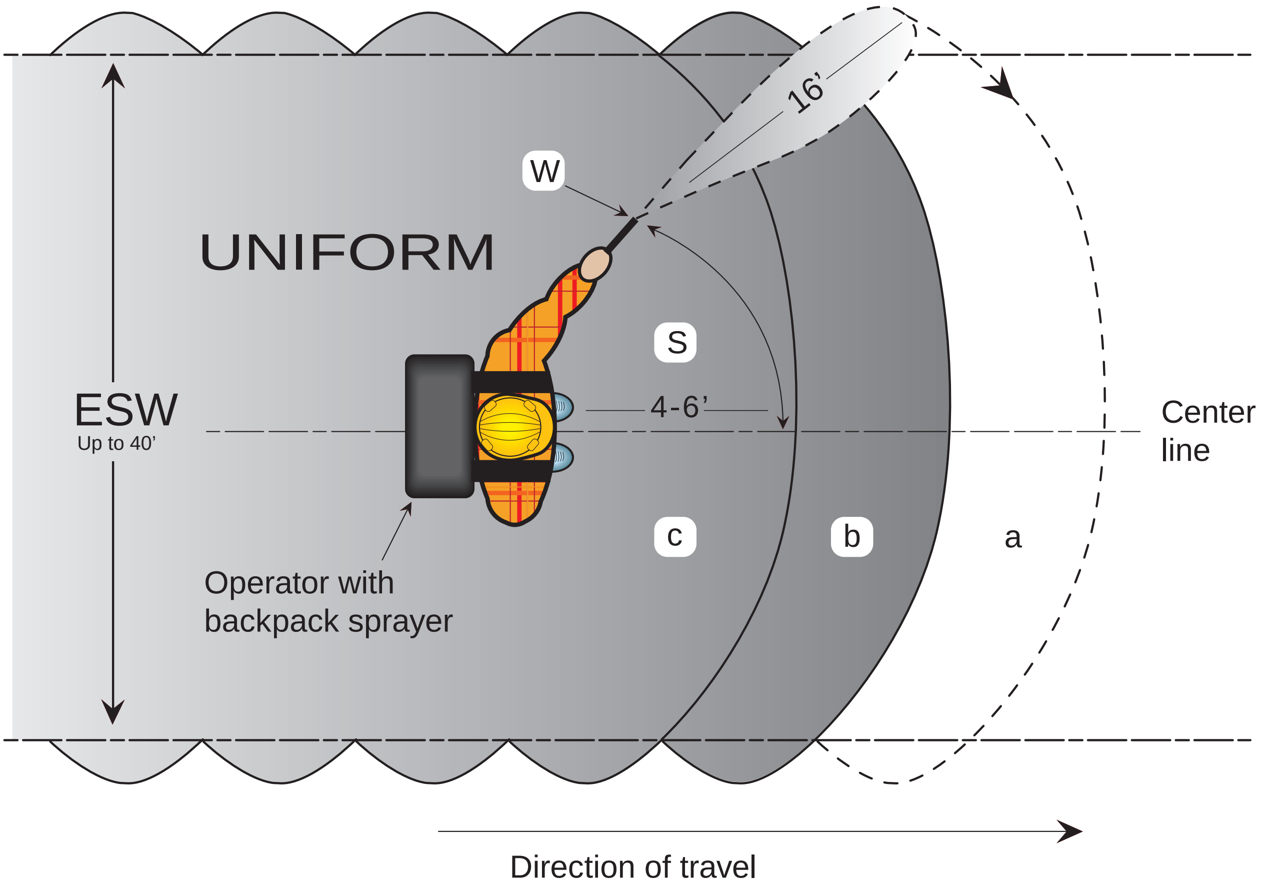

Figure 5. Pattern of swath deposit. Schematic of spray operator moving along a swath centerline while swinging the sprayer wand from side to side with each stride. Areas a, b, and c represent cumulative deposits for successive swings as the operator moves ahead. The effective swath width (ESW) is the width of the swath in which deposition is 50% or more of the average, so that adjacent swaths will not show either an excessive deposit or a gap. S and W refer to still or wobbling, Table 2.

Figure 6. Nozzle should be adjusted (see inset) so that the cone of dispersion from the nozzle is about 10°. Test of the proper setting is the deposit of an oval pattern reaching 8 ft to 20 ft from the applicator (4-6 ft from nozzle) where nozzle is held horizontal 6 ft above ground at about 30 psi pressure. Photo credit: Jim Miller.

is essential. Do this practice on a dry uniform surface like a parking lot. Several steps are involved.

Step 1. Setting the nozzle

Set the nozzle by twisting the thimble-shaped tip (Figure 6). Back the nozzle off until it delivers a solid stream. Then tighten it until it delivers a narrowly conical spray. When held horizontal at chest level, it should have a fall-out pattern at least three times the length of the applicator's stride, i.e., something like 9 to 18 ft (2.7–5.5 m) of deposition with the nozzle held horizontal and still 5 ft off the ground. The adjustable cone nozzle can be adjusted either way until the pattern looks like an oval 2 to 3 ft wide and 8 to 10 ft long, with the nearest end 6 to 8 ft from the operator. The oval should have almost as dense a deposit at the near end as the far end. This provides *depth* to coverage when holding the nozzle horizontal and still. The individual swipe covers a sweep 8 ft or more in depth of coverage with a single swipe, in a pattern much like a windshield wiper. If one takes a swipe with each stride, each square foot is covered lightly several times and from different angles.

The physics of drop trajectory with mixed-drop sizes determines the deposition pattern. Although the drops emerge with more or less constant velocity, they decelerate as a result of air drag in proportion to mass divided by wind resistance. Small drops slow quickly and land near the nozzle when there is no wind. Large drops land progressively farther away with increasing size; average drop size therefore increases with distance from the nozzle, counterbalanced by decreased numbers that even out deposit. When moving while spraying with a swinging wand adjusted like this, drop sizes at swath edges will be consistently large, and centers of swaths would have many fine drops along with a few large ones; some large drops land when the swinging wand passes over the center of the swath, but all the fine drops land toward the center of the swath. Because differences in average drop sizes could influence efficacy across a swath with certain types of products (Richardson 1988) this method is most applicable for products that are highly systemic (e.g., glyphosate, triclopyr, imazapyr, picloram, atrazine, hexazinone, and any others that do not require dense drop patterns for coverage).[1]

Step 2. Calibration

The waving-wand system is calibrated much like any other broadcast application system. Rate of application per unit of ground area is a function of volume of spray delivered, and amount of active ingredient per unit of volume. First, the operator must gain practice in delivering uniform coverage within swaths.

A recommended beginning for this process is to lay out a rectangular "plot" on a bare bit of dry pavement with known length and with the width equal to a proposed swath width. Calculate its percentage of an acre. For example, suppose the plot is 36 ft wide and 121 ft long. The area of an acre is 43,560 sq ft. The area of the plot is 4356 sq ft, or a tenth of an acre.

The volume delivered by a nozzle per minute of spraying will determine the volume per acre while spraying an area. To determine the volume per minute, measure how much the nozzle delivers, as follows. With the nozzle directed into a larger container marked in milliliters or fluid ounces, spray for exactly one minute at working pressure while capturing all of the liquid. Many such nozzles will deliver about 1 qt/min, but each worker will need to confirm this.

Spraying the measured "plot" comes next. Calibration begins with the determination of the volume per unit area delivered. Because the delivery per minute of the nozzle is now known, the next step is to spray the plot several times, with drying between, to allow observation of the drop pattern. After successfully creating a spray pattern that fills the plot with a uniform coverage and a small blurred overlap extending beyond the edges, spray the plot several more times, keeping track of the time. If the plot is 121 ft long, and the applicator is moving at one mile per hour, the time required for spraying will be about 82 sec.

Thus: one mile per hour = 1.47 ft/sec.

Time to travel 121 ft = 121 divided by 1.47, or 82 sec.

If the nozzle delivers 1 qt/min, that is 1/60 qt/sec.

Spray volume applied to the 0.1-ac plot is then 1/60 x 82 = 1.37 qt/0.1-ac plot, or 13.7 qt/ac, just under 3.4 gal of liquid per acre.[2]

New operators will need to practice this until the plot is properly covered and timing is consistent. This procedure should be repeated in the environment in which the chemical will be applied to ensure that with a change in footing the calibration will match the site. And the operator must always bear in mind control of swath width with angle of swing, volume per unit of time delivered by the nozzle according to nozzle setting, and constant walking speed. Walking speed just takes practice. In order to be consistent, speed of travel depends on the comfortable walking speed of the operator *where the spray is to be applied*.

Maintaining a constant walking speed in rough terrain, slash, and obstacles (Figure 7) will be different from calibration in a parking lot. A speed of no more than one mile per hour is recommended even for workers who normally walk much faster than that. One must maintain calibrated speed while stumbling through slash, brush, and so on. Consistency of walking speed, swing width, smoothness and frequency of swing, and angle of wand elevation are all important in maintaining even coverage and accurate calibration of dosage. Training and practice are critical. Rewards in the form of consistent weed control and saved time and money are substantial. This system also places a very high percentage of chemicals on target, leading to high efficiency of use and negligible off-site drift.

Most ground applications of herbicides are registered for use in dilutions leading to volumes adequate to ensure coverage of foliage. However,

1 Herbicide products have labels that identify concentrations of products in ground spray mixtures, and rates of acid equivalent (a.e.) or active ingredient (a.i.) per acre when applied broadcast. Neither is perfectly adapted to the low volumes used with the waving wand method. Always follow the label.

2 Note that if the label states volume per acre must be at least 5 gal/ac (47 L/ha), walking speed must be slowed to 3.4 ÷ 5 × 1 mph = 0.7 mph.

applying large volumes with backpack equipment is impractical. Virtually all operational aerial applications of herbicides in the Pacific Northwest (USA) today are delivered in a volume of 5–10 gal/ac (47–94 L/ha), usually with D-8 jet nozzles oriented to create drops having a volume median diameter (VMD) of 1000 µ (1 mm) and very little drift potential (Yates et al. 1984). The lowest legal volumes per acre listed on herbicide labels are in the upper range of effective volumes when used with the waving wand method. Be sure to comply with volumes per acre listed on labels for broadcast application. Verify whether minimum volumes for aerial applications are acceptable for waving wand use.

2 Background Testing

Proof of an application approach demands that we demonstrate whether efficacy can be achieved with volumes far lower than commonly used by aircraft, and with drops far larger. This is necessary to the logistics of a method where human energy expense is measured in terms of load carried and distance over which re-supply must occur. The steps in this process are, first, demonstrating that a wide swath can be uniformly applied with a handheld nozzle, and second, that the results therefrom are consistent with those expected with conventional broadcast methods. A third step is field training for consistency.

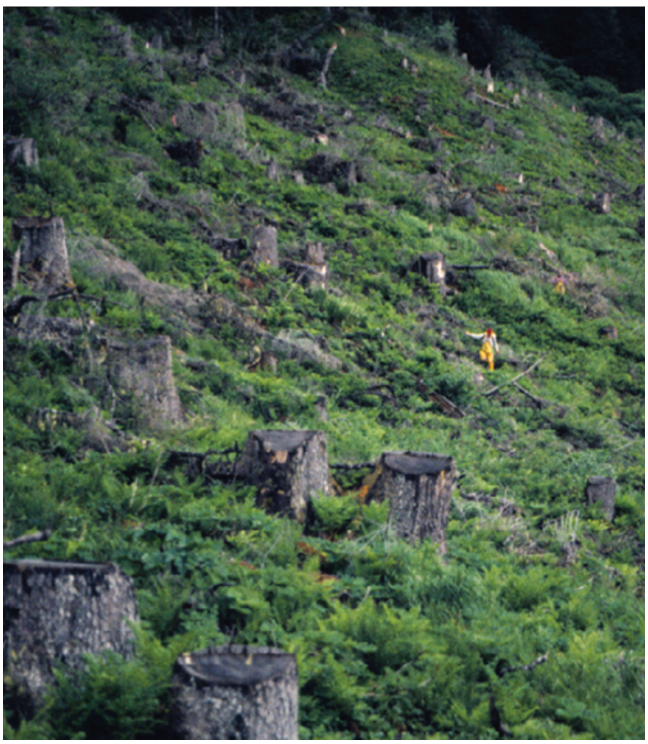

Figure 7. Rough terrain and slash necessitate slow travel and low volumes; also, large units without identifiable features suggest periodic flagging to identify swaths. Photo credit: Liz Cole.

The first step in validating this method is the measurement of deposits from a nozzle held still. The second step is determination of how that static test translates into an effective swath of a given width and uniform deposition. Effective swath width (ESW) is the distance between edges of swath defined as having at least 50% of the average deposition rate. It is usually about 5 ft (1.5 m) less than the extreme width of drop fallout. In our tests, ESW and distribution of drop sizes across each swath were determined with a variety of commercially available solid-cone adjustable nozzles. Operational confirmation of deposition distribution and swath width can be done on a dry paved surface, where distribution of pinpoints of water deposits can be evaluated by eye when observed immediately after application. Here we describe the more technical methods used for method validation, as described in Barry et al. (1978). Note here that any good backpack sprayer will work (Figure 8).

Nozzle Projection Tests

The way a nozzle and its orientation lead to patterns of deposition will dictate whether the applicator's moves lead to consistent deposition patterns. Ten tests (Figures 9–10; tests 1-10, Table 2) relate drop size distribution and distance to different nozzle types and angles of elevation. Their purpose was to

Table 2. Parameters of tests evaluating nozzle projection, drop size distribution, zones of deposition, atmospheric conditions, and nozzle configuration. Dye was Rhodamine B; surfactant was non-ionic R-11; oil was diesel fuel.

Nozzle type/Test #	S or W[a]	Spray mixture	Elevation (°)	Temp. °F(°C)	Relative humidity (%)	Wind velocity	
						mph (m/s)	AZ (°)[b]
Nozzle projection tests[a]							
Chapin adjustable solid cone							
1	W	Water+dye	0	76.5 (24.7)	66	None	None
Spraying Systems 5500-x5							
2	W	Water+dye	0	76.5 (24.7)	66	2.0 (0.9)	302
Cooper-Pegler adjustable solid cone							
3	S	Water+dye	0	76.5 (24.7)	66	4.9 (2.2)	45
4	S	Water+dye	0	76.5 (24.7)	66	2.7 (1.2)	302
Spraying Systems Gunjet 18, AL D-3							
5	S	Water+dye	0	76.5 (24.7)	66	2.7 (1.2)	302
6	S	Water+dye	0	76.5 (24.7)	64	1.1 (0.5)	173
Smith Model 147							
7	S	Water+dye	0	77.2 (25.1)	62	3.0 (1.3)	180
Chapin adjustable cone							
8	W	Water+dye	0	77.5 (25.3)	61	3.8 (1.7)	143
9	W	Water+dye	15	74.5 (23.6)	66	2.7 (1.2)	302
10	S	Water+dye	45	77.7 (25.4)	61	2.2 (1.0)	231
Swath tests[c]							
11	–	Water+dye	45	78.4 (25.8)	59	3.2 (1.4)	155
12[d]	–	–	–	–	–	–	–
13	–	Water+dye+0.5% surf.	45	80.4 (26.9)	56	3.8 (1.7)	145
14	–	Water+dye+0.5% surf+5% oil adj.	45	80.6 (27.0)	55	6.6 (3.0)	246
15	–	Water+dye+0.5% surf+5% oil adj.	45	80.6 (27.0)	54	8.7 (3.9)	291
16	–	Water+dye	45	64.9 (18.3)	81	2.7 (1.2)	270
17	–	Water+dye	15	66.9 (19.4)	79	2.7 (1.2)	302
18	–	Water+dye+5% oil adj.	45	66.6 (19.2)	77	0.6 (0.3)	74
19	–	Water+dye+5% oil adj.	15	67.6 (19.8)	75	1.6 (0.7)	70

[a] Distance tests were those describing spray projection from nozzle held horizontal or at specified angle of elevation from height of 5 feet (1.5 m), still (S) or wobbling 5° side to side (W).

[b] AZ = azimuth of wind relative to direction of nozzle in distance tests, or swath direction in swath tests.

[c] Swath tests were done with waving 80° right and left of centerline, evaluated by two lines of deposit cards. Nozzles in tests 9 and 10 were oriented 15° and 45° upward, respectively. Nozzles 1-8 were level.

[d] Wind gusts led to abandonment of test 12.

Training

Determination of swath width bears close examination as part of training. Trainees should understand the consequences of staying within the preferred parameters of angles of swing and of elevation. The extended reach from elevation of the wand accounted for swath widths being more than twice the projection distance for which nozzles were calibrated in horizontal test series after adding the 6 feet (2 m) of the radius of the arc of the swinging nozzle. In the event preliminary testing reveals a tendency to place higher deposits at swath margins than in the center, the angle of the side-to-side motion can probably be reduced slightly to prevent over-deposition at swath edges. Recalibration of the nozzle to create fewer large drops will reduce the distance to maximum deposit, hence swath width. It will also change calibration. Trials to achieve a balance between drop size and uniformity of deposit can be time well spent.

Whereas we stress training to reduce variability of deposition, the patterns we observed look irregular in Figure 9. One cannot eliminate variability with waving wand or aerial application. Moreover, such variability is normal when observed on a fraction of a spray card simply because one large drop can influence the estimate of deposit. Yates et al. (1984) did numerous spray tests with aircraft, as did Newton et al. (1990); all of these tests show very high coefficients of variation in deposition; this is a feature of data from small sampling cards. Whereas high variability in card deposits might not bode well for controlling such fine-textured vegetation as annual grasses, control of large plants is apparently not jeopardized if one uses systemic products. Narrower swaths and smaller drops with denser patterns may be appropriate for herbaceous vegetation, although we saw no direct evidence of such. Training must focus on uniform speed and swath coverage; mini-scale variation cannot be avoided.

Figure 8. Any good sprayer will work. Brass wands and valves (plastic shown here) are least likely to break. Brass plumbing can be adapted to the hose with a clamp, with uniform threads for fittings beyond (see Figure 6). Wands longer than 3 feet are not recommended. Photo credit: Liz Cole.

Whenever using biologically active chemicals, care must be taken to minimize personal exposure among applicators. The materials likely to be applied with this system in forests are low in mammalian toxicity because they react with plant metabolic systems. Pay close attention to the training needs provided in the paragraphs listing “advantages and limitations”, and pay especially close attention to herbicide labels, listed personal protection equipment, and workers protection standards. We do not recommend this method for insect control or any pesticide other than the low-toxicity materials registered for forest vegetation control that also are readily systemic in their herbicidal activity.

determine the distributions of drop sizes and their flight distances when a spray is released from a nozzle in a fixed position.

In each test, a specific combination of nozzle type and nozzle orientation was used to direct a stream of dyed spray across a series of 4 x 6 in. (10 x 15-cm) Kromecote spray cards (cash register rolls will work) placed 3 ft (90 cm) apart on an airport apron. Common to all tests was a backpack sprayer (6-gal Cooper Pegler C-P3®, but any other industrial grade sprayer will work as well) set to deliver a pressure of about 30 psi (0.2 MPa). The nozzle for these tests was always mounted on a straight wand 2 ft (60 cm) long. Each of these tests was from a fixed height [5 ft; (150 cm)] and horizontal nozzle orientation or specified angle of elevation. For each test, a spray containing a bright pink dye was directed in nearly still air above a series of spray cards at 3.3 ft (1 m) spacing along and beneath the length of the spray pattern. The distribution of drop sizes landing at each sample card was used to calculate deposit at various distances from the nozzle and the proportion of volume contributed by each size class of drop. This was done with several adjustable cone nozzle types. We used three different angles of nozzle elevation to illustrate how that influences spray projection (Table 2, Figures 9 and 10).

Nozzle delivery in each test was adjusted to 1.06 qt (34 fl oz; 1.0 L)/min or less, as determined by spraying for 60 sec into a measured container. Actual deposit was calculated with the spray card method because it provides information on drop size and potential drift. The spray cards were interpreted visually, using a 7X magnification lens-mounted scale. Size classes of drops to 300 μ (= 0.012 in. or 0.3 mm) included six classes at intervals of 50 μ; size classes 300–1400 μ were in 100-μ intervals; size classes 1400–2200 were at 200-μ intervals, and sizes greater than 2200 μ were arrayed at intervals of 1000 μ. Drop count for each size per unit of card area was converted to volume per square centimeter by the procedures of Barry et al. (1978).

Five nozzle types were tested in test series 1-10. Fall-out distance and deposition were evaluated for each. For some nozzles, two tests were conducted, with the spray wand either held steady (S) or with slight movement side to side (W) to widen the deposit pattern so as to separate drops. Table 2 lists the specific parameters of each test along with environmental conditions during the test.

All nozzles selected for study could potentially be adjusted to project a near-continuous stream with a horizontal distance of 23 ft (7 m) or more. Adjustment of each nozzle to break the stream into finer drops decreased the maximum range. The nozzles were all adjusted to a maximum horizontal range of 20 ft (6 m) to ensure uniform setting and to ensure enough break-up to provide reasonable coverage [i.e., at least 30 drops/in^2 (5 drops/cm^2)] over half or more of the projection distance (10-ft or 3-m depth of adequate coverage). All subsequent tests were run at the same pressure and comparable nozzle setting. In general, this setting meant that the cone of dispersion from each nozzle was about the same, with a maximum width of spray cone about 10° to 12°.

After projection tests with horizontal nozzles (tests 1–8, Table 2), we tested the Chapin® nozzle held at 15° and 45° above the horizontal (tests 9 and 10). This permitted us to evaluate the effect of elevation angle on maximum distance of projection (hence potential swath width) and on the width of the zone of good coverage and drop density within that zone. This nozzle also performed most consistently in meeting test objectives.

Nozzle Projection Test Results

Adjustment of each nozzle to project a 20-ft (6 m) swath horizontally from a 5-ft (1.5-m) elevation caused break-up of all streams so that each nozzle projected a conical deposit pattern in drops of less than 4,000 μ diameter of median volume (VMD). Figure 9 depicts the patterns of drop size projected from each nozzle test from either a horizontal or elevated nozzle. When two tests were made with the same nozzle configuration, they display differences in wind conditions. Deposition varied with distance from each nozzle in the same series of tests (Figure 10). In each of the above tests, the end of each deposition line in the figure indicates that no drops were found at that distance or that the drops were too large and too few to measure accurately. In most examples, only the largest drops went the maximum distance, and accuracy of deposition data at maximum range is unknown.

The patterns indicate that when a nozzle is held horizontal and set so that the largest drops project 20 ft (6 m), very few small drops project the maximum distance unless there is a discernible tail wind, and very few large drops fall out at intermediate distances (Figure 9). Thus, with increasing distance from the tip, there is a consistent increase in drop size and an oval zone of 6 to 10 ft (2 to 3 m) in length in which deposit is more than 50% of the maximum observed at any projected distance (Figure 10); the distance from the operator to this band depends on velocity and direction of wind more than variation in nozzle type. While this general pattern varies little among nozzle types, the different arrays of drop size provided by various nozzles will provide differences in projection patterns, as well as minor variations in proportions of drop sizes.

Elevation of nozzles 15° and 45° above the horizontal extended the range slightly without changing the nozzle setting. Potential effect on ESW was increased as defined by the zone with >50% of maximum deposit rate. The difference between 15° and 45° appeared to be greater than the difference between horizontal and 15° in the one comparison done, as seen in Table 3. The higher elevation also makes the spray more susceptible to drift when wind is moving (not shown).

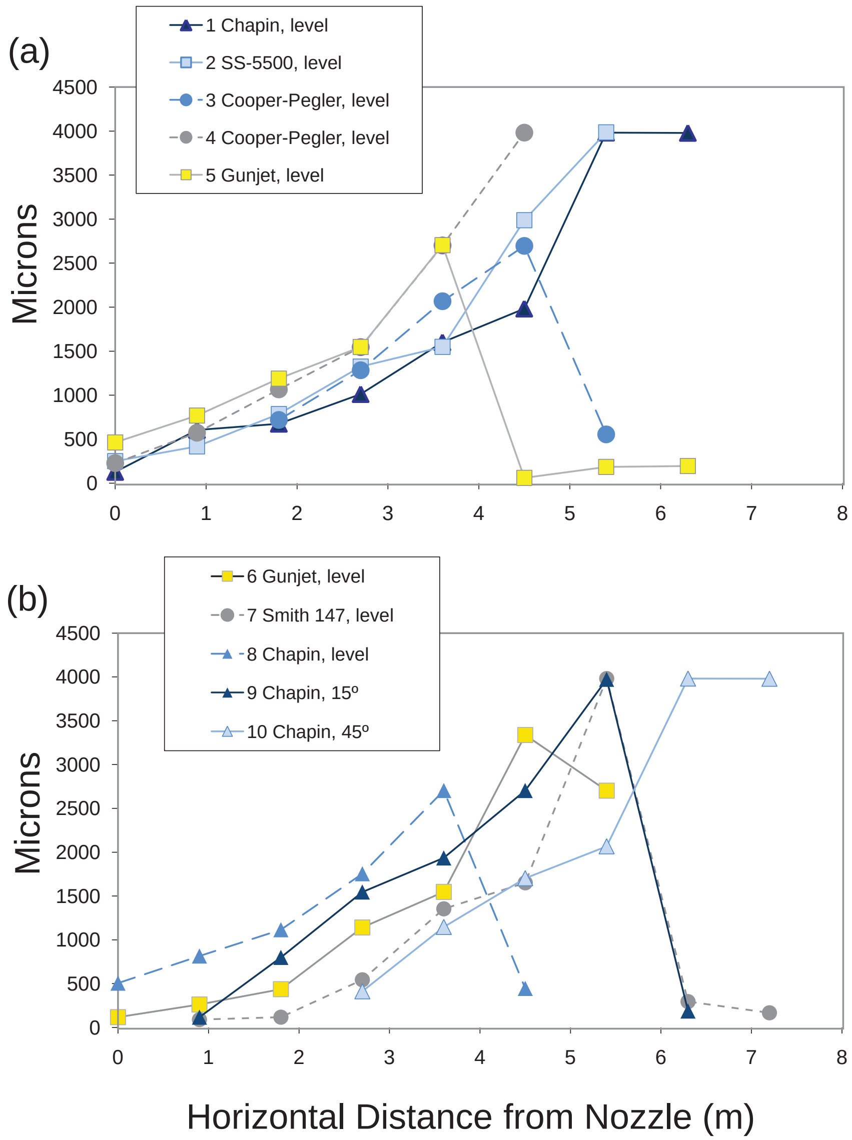

Figure 9. Median drop sizes, at various distances from the nozzle, in tests 1–5 (a) and 6-10 (b).

Swath Deposition Test Methods

Tests 11 and 13-19 were run to evaluate broadcast swath patterns after selecting the Chapin nozzle (Figure 11, Table 3). For swath measurements, the operator walked at 1 mile/hr (1.6 km/hr) and kept the nozzle swinging back and forth at 80° to the right and 80° left while holding the wand 15° or 45° above horizontal. Nozzle delivery in each test was 1 qt (32 fl oz; 0.95 L)/min or less, as determined by spraying for 60 sec into a measured container. Actual deposit was calculated with the same spray card method as nozzle tests. For general use, a simple calculation of volume delivered on a given area will suffice for on-the-job calibrations, and in our use proved quite satisfactory. Experiments reported in these tests were conducted with solutions of water and dye, and sometimes with surfactants to determine whether surface tension influenced drop formation.

We also demonstrated sensitivity of these patterns to degrees of swath displacement under measured crosswind velocities. For each test, we used an anemometer to record wind velocity and direction at nozzle height within 66 ft (20 m) of test runs; for most tests this will not be necessary.

Centerlines of swaths were laid out on the concrete surface, perpendicular to a light wind gauged by the anemometer. Two sets of cards were placed at the centerline and at 3-ft (0.9 m) intervals to the right and left to a distance of 26.5 ft (8.1 m). Eight swath tests (tests 11 and 13-19; test 12 failed because of a wind gust) were run to determine the effective swath width (ESW) allowing for overlap for tapered edges. Recorded in these tests were: variation in deposition across the swath, variation in drop size across the swath, variation in drop numbers, and swath displacement from wind when moving more than one mph across the swath path. For all swath tests, the Chapin adjustable cone nozzle was set to project 20 ft (6.0 m) from a horizontal nozzle at 5 ft (1.5 cm) height.

Besides distance of spray projection, the arm swing and length of the wand determined the ESW described by the nozzle when swinging side to side, and when held at various angles above horizontal. Absolute maximum width was observed in the upper range of angle of wand elevation. The highest degree of elevation did risk displacement when wind came up, as suggested by the nozzle tests.

In all swath-deposition tests, we used the procedure shown in Figure 5 to ensure uniformity.

Swath Deposition Test Results

At the 20-ft (6.0-m) horizontal projection setting, elevation of 45°, and a 160° total swing, the ESW for the Chapin nozzle (i.e., the swath width within which deposition was equal to 50% or more of the average) was about 40 ft (12 m) in still air (Figure 11). This swath width proved consistently achievable in plots described in Section 3 of this report.

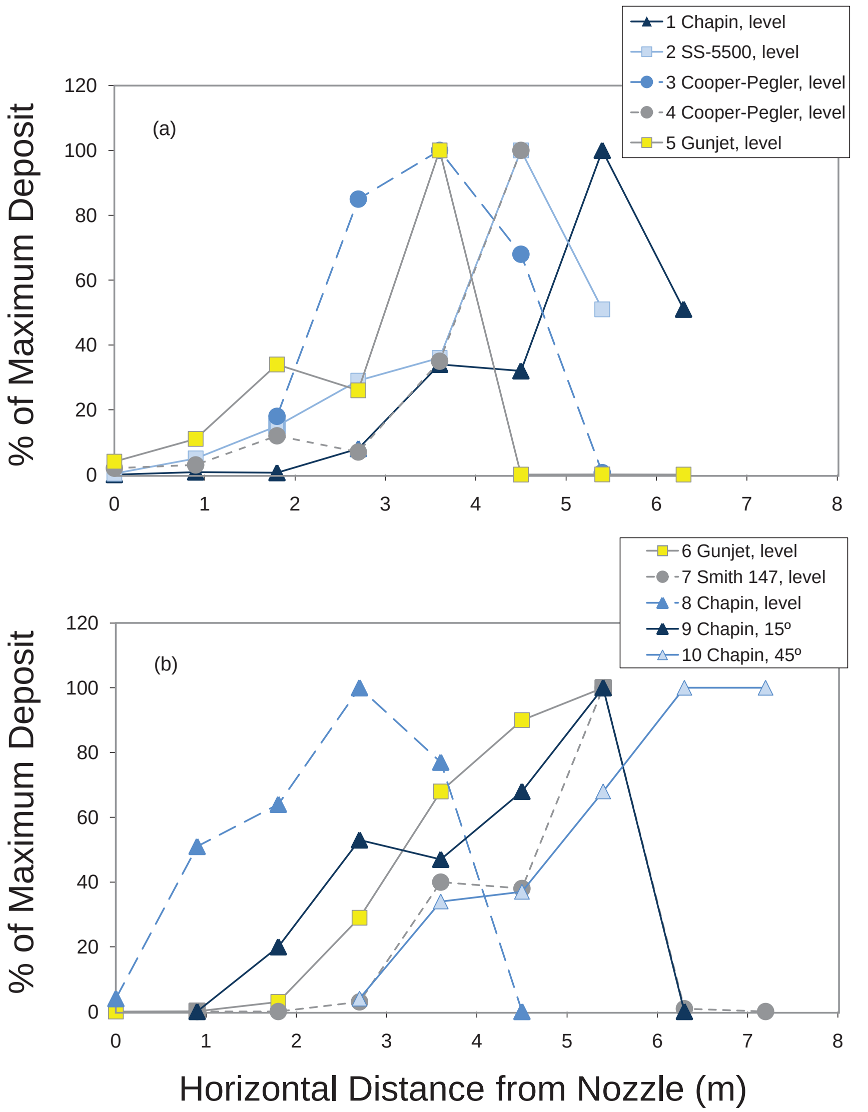

Figure 10. Deposition patterns for spray tests 1-5 (a) and 6–10 (b), reflecting five nozzle types and other application factors. The Chapin nozzle was held level in tests 1 and 8, at 15° in test 9, and at 45° in test 10.

Figure 11 illustrates distribution of deposits across complete swaths with the two test combinations (nozzle and angle) with the best consistency across swaths. Small drops concentrated near the center line (i.e., closest to the nozzle), and large drops were slightly more abundant at the outer edges than at the center, as predicted. Density of drops was highest near the center line, reflecting the concentration of smaller drops close to the nozzle at any point in the arc of the swing. Total deposition across the swath showed no distinct pattern and varied among sample lines across a swath; the occurrence of large drops caused too much variance for precise determination of local deposits on the extreme edges of swaths. Lateral displacement of swaths by over 3 ft (90 cm) was observed when crosswind velocity exceeded 2 mph (0.9 m/s). The centerline referred to in Table 3 lies midway between the margins of uniform deposit, which was not the same as the centerline traveled by the applicator when crosswinds were significant. When crosswind speed was 2–5 mph (0.9–2.2 m/s), the center of deposition was displaced by 5–10 ft (1.5–3 m) (not shown). These numbers are approximate, reflecting the variance from card to card and the differential displacement of the fine and coarse drops, wherein small drops traveled furthest. Actual deposit displacement was small enough to scarcely influence application pattern because the largest drops, falling at the margin of the swath, were little affected by light winds.

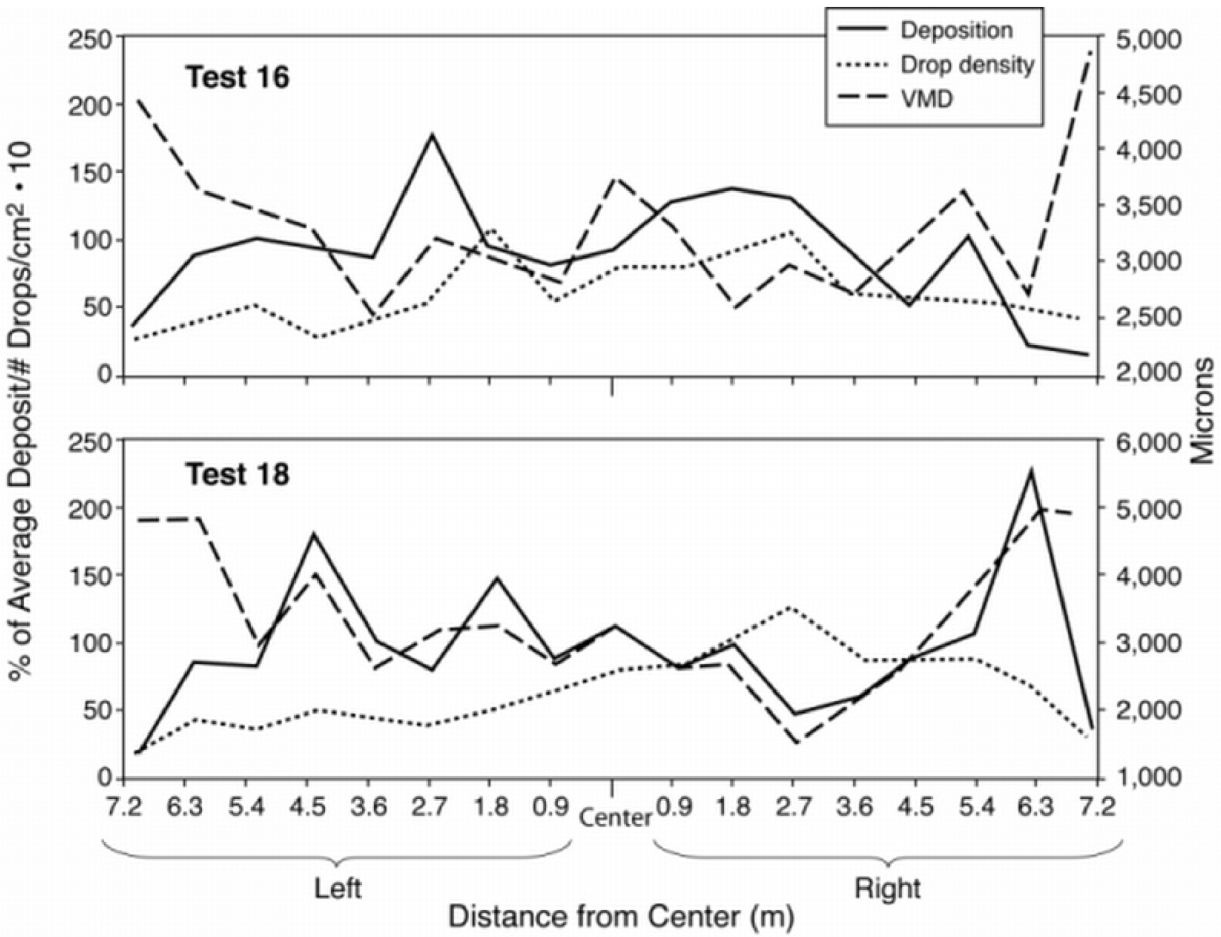

Figure 11. Deposition (% of average deposit), drop density (number drops/cm^2 x 10), and volume median diameter across 13-m swaths with Chapin nozzle held at 45°, with examples from Tests 16 and 18. Both tests were applied at 5 gal/ac (47 L/ha).

Substantial numbers of drops (containing only a minor portion of the deposit) were carried beyond the card arrays at higher crosswind velocities. Tests 3 and 8 (Table 2) allow us to observe that direction of wind influences distance of projection only at the highest wind speeds (not shown). Whereas a "six o'clock" (tail) wind simply projects the pattern a bit farther from the applicator, a headwind more than 4.5 mph (2 m/sec) carried fine drops toward the worker sufficiently to be felt. Lateral displacement is also of concern with wind greater than 4.5 mph (2 m/sec) if a sensitive area such as a stream is downwind, or if gusty wind compromises precision of the walking route when compensating for wind to center a swath. In any case, such lateral displacements result in very small but detectable deposits out of swath.

Several tests of swath distribution varied the nature of the spray mixture to determine whether water solutions or emulsions containing oil and surfactants influenced spray distribution. Swath width and drop distribution (Table 3) did not reveal obvious differences attributable to spray mixture although the operator had the impression that drop size increased if viscosity increased, as with inverted emulsions (data not shown).

Table 3.* Relative deposition expressed as percent of average deposit within the effective swath width (dep), drops/in^2 (cm^2) >50 μ diameter (drops)**, and median drop size expressed as volume median diameter (VMD) across waving-wand swaths.

Test number	11			13			14			15		
Distance from center ft (m), L or R	Dep	Drops	VMD	Dep	Drops	VMD	Dep	Drops	VMD	Dep	Drops	VMD
24 (7.3), L	0	0.0	–	0	0.0	–	0.0	0.0	–	0	0.0	–
21 (6.4), L	75	14 (2.2)	3260	0	0.0	–	204	81 (12.6)	4069	0	0.0	–
18 (5.5), L	35	17 (2.6)	2940	0	0.0	–	117	65 (10.1)	4070	32	17 (2.6)	2515
15 (4.6), L	65	30 (4.7)	2610	167	42 (6.5)	4852	123	53 (8.2)	3219	85	37 (5.7)	3620
12 (3.7), L	153	25 (3.9)	3351	80	61 (9.5)	2789	92	41 (6.4)	3636	89	68 (10.5)	2108
9 (2.7), L	68	40 (6.2)	2049	144	48 (7.4)	2565	127	48 (7.4)	3994	151	52 (8.1)	2741
6 (1.8), L	78	90 (14.0)	1121	108	31 (4.8)	1732	79	56 (8.7)	3186	224	94 (14.6)	2263
3 (0.9), L	22	57 (8.8)	1333	109	78 (12.1)	1215	58	85 (13.2)	2431	14	82 (12.7)	979
Center	129	53 (8.2)	2934	146	86 (13.3)	3541	58	71 (11.0)	2445	37	84 (13.0)	1386
3 (0.9), R	63	114 (17.7)	1996	33	74 (11.5)	2581	89	83 (12.9)	2003	87	87 (13.5)	2098
6 (1.8), R	65	105 (16.3)	1729	139	38 (5.9)	2800	93	81 (12.6)	2839	96	103 (16.0)	2050
9 (2.7), R	234	90 (14.0)	2914	132	43 (6.7)	2401	76	55 (8.5)	2624	138	84 (13.0)	2053
12 (3.7), R	165	79 (12.2)	2607	198	79 (12.2)	2711	133	109 (16.9)	3093	113	81 (12.6)	2381
15 (4.6), R	245	101 (15.7)	3197	12	30 (4.7)	1222	113	88 (13.6)	4058	84	67 (10.4)	3293
18 (5.5), R	100	49 (7.6)	2187	47	12 (1.9)	4451	32	52 (8.1)	2830	0	0.0	–
21 (6.4), R	33	39 (6.0)	2949	0	0.0	–	29	116 (18.0)	2500	0	0.0	–
24 (7.3), R	68	33 (5.1)	3571	0	0.0	–	0.0	0.0	–	0	0.0	–

* Table continues on page 20.

** Basis: two lines of deposit cards per test. Spread factor, 1.6.

Note: L = left; R = right

Table 3, Continued

Test number	16			17			18			19		
Distance from center ft (m), L or R	Dep	Drops	VMD	Dep	Drops	VMD	Dep	Drops	VMD	Dep	Drops	VMD
24 (7.3), L	38	17 (2.6)	4460	34	8 (1.2)	4844	16	10 (1.6)	4851	41	10 (1.6)	4853
21 (6.4), L	91	26 (4.0)	3678	67	20 (3.1)	3678	86	26 (4.0)	4851	129	17 (2.6)	3674
18 (5.5), L	101	34 (5.3)	3475	64	22 (3.4)	3245	82	23 (3.6)	2869	88	26 (4.0)	2655
15 (4.6), L	94	18 (2.8)	3325	152	14 (2.2)	3623	177	33 (5.1)	3956	100	22 (3.4)	3525
12 (3.7), L	88	26 (4.0)	2570	178	24 (3.7)	3830	101	30 (4.7)	2591	83	72 (11.2)	1940
9 (2.7), L	180	35 (5.4)	3229	75	34 (5.3)	3521	78	24 (3.7)	3116	80	86 (13.3)	2315
6 (1.8), L	95	72 (11.2)	3166	129	63 (9.8)	3204	144	32 (5.0)	3220	73	59 (9.1)	2760
3 (0.9), L	82	37 (5.7)	2694	113	57 (8.8)	3968	86	40 (6.2)	1680	79	72 (11.2)	2325
Center	95	50 (7.8)	3808	65	74 (11.5)	1934	111	49 (7.6)	3130	46	65 (10.1)	1995
3 (0.9), R	129	52 (8.1)	3363	52	68 (10.5)	1879	80	53 (8.2)	2705	153	55 (8.5)	3516
6 (1.8), R	138	60 (9.3)	2625	188	50 (7.8)	4001	96	67 (10.4)	2620	109	57 (8.8)	2868
9 (2.7), R	131	70 (10.9)	2988	113	23 (3.6)	3534	46	79 (12.2)	1554	109	81 (12.6)	2518
12 (3.7), R	92	40 (6.2)	2741	118	27 (4.2)	3164	57	55 (8.5)	2055	94	39 (6.0)	2619
15 (4.6), R	52	38 (5.9)	3255	109	11 (1.7)	2399	85	54 (8.4)	2696	230	55 (8.5)	4341
18 (5.5), R	102	37 (5.7)	3628	56	21 (3.3)	3193	104	55 (8.5)	3678	106	50 (7.8)	4853
21 (6.4), R	23	34 (5.3)	2689	73	13 (2.0)	4456	220	40 (6.2)	4853	80	26 (4.0)	4728
24 (7.3), R	17	26 (4.0)	4853	61	15 (2.5)	4845	31	13 (2.0)	4848	0	0.0	–

** Basis: two lines of deposit cards per test. Spread factor, 1.6.

Note: L = left; R = right

3 Waving Wand Efficacy Field Tests

Methods

Field evaluation of the waving-wand method was part of a large ecosystem management study involving understory conifer regeneration and vegetation management. In this study, control of understory vegetation was an approach for determining how, in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stands about to be thinned, subsequent residual overstory density and distribution interact with understory competition to affect planted understory seedlings. We use this example because it involved large plots broadcast sprayed, and it involved different types of shrub/herb cover on many types of terrain. The study was initially conducted in 50-year-old Douglas-fir stands in the McDonald Forest, near Corvallis, Oregon (44°38' N, 123°15' W). The field tests were part of an experiment in which twenty-four 6.15-ac (2.5-ha) plots were about to be thinned to various residual densities, with the specific objective of developing understories of conifers and other vegetation that would approximate late-successional conditions some decades hence. Our approach for this part of the study was to determine how much vegetation of various species groups survived the first few years after thinning with or without pre-harvest application of herbicide, and how much plant development occurred in the subsequent three growing seasons as an index of whether spraying killed root systems of perennial species. This also provided a validation of effective swath width calculated in earlier tests (Part 2).

Within each plot, paired 1.2-ac (0.5-ha) subplots 327 x 160 ft (100 x 48.8 m) were broadcast-sprayed several months prior to felling vs. left unsprayed. The waving-wand method was used to apply a mixture of 1.5 lb a.e./ac (1.7 kg/ha) glyphosate and 2 oz a.i./ac (0.14 kg a.i./ha) imazapyr in 5 gal/ac (47 L/ha) total volume. Plots were sprayed in four 40-ft (12-m) swaths. The spray mixture was applied with a 6-gal (23-L) backpack sprayer equipped with a Chapin® adjustable solid-cone nozzle, with pressure as nearly 30 psi (0.2 MPa) as possible considering the irregular footing and slope of terrain. Operator speed was a slow walk [about 1 mph (1.6 kph)], to permit deliberate consistency of motion and time to shut off when obstacles were encountered. Slopes ranged from nearly flat to 50%, with most swaths traversing the slope, occasionally with gradients of up to 40% within swaths. Footing was generally poor; slash from previous thinnings and blackberry (*Rubus* (Tourn.) L. spp.) shrubs created major obstacles. Furthermore, the ground surface and slash were generally obscured by ferns and shrubs. When the operator fell or stopped to climb over downed logs and obstacles, spraying stopped until forward motion began again. Two assistants helped flag the centerline and hauled batches of chemical to the operator. In most field tests, we were within plus or minus 10% of intended delivery rates (in gal/ac; L/ha) when adapting to operational terrain and slash conditions.

Understory was recorded before, one year after, and 3 years after treatment. Prevalent species were western swordfern (*Polystichum munitum* (Kaulf.) Presl.), as well as numerous blackberry species, scattered hazel (*Corylus cornuta* Marsh. var. *californica* (A. DC.) Sharp), and poison oak (*Toxicodendron diversilobum* (Torr. & A. Gray) Greene). There were also occasional patches of introduced shade-tolerant perennial grass (*Brachipodium* sp. Beauv.) and numerous small forbs. Target height ranged up to 13 ft (4 m).

Vegetation cover by species groups was observed before logging and in the first and third summers after logging, for 10 sample points per subplot (total 240 sprayed and 240 unsprayed over all plots). Observations recorded cover of ferns and shrubs by species in 16.4-ft (5-m) radius areas and herbs in 3.28-ft (1-m) radius nested plots with common centers. These data provided information on species composition and cover and the changes attributable to both herbicide application and logging.

A second series of experimental tests was conducted in the Blodgett Tract near Clatskanie, Oregon (46°05' N, 123°20' W) under stands of similar density, but steeper terrain. For these tests, plot size was larger [1.8 ac (0.73 ha)], the range of steepness was larger (20%–70%), and there was a greater range in understory shrub size (some were above the 16 ft (5-m) comfortable height range for backpack spraying) and density, even though understory cover was generally less. The swath width attempted was 40 ft (12 m). We used a different variable solid cone nozzle with smaller orifice, the Cooper-Pegler®, which with a small increase in walking speed calibrated to deliver 3 gal/ac (28 L/ha). Each plot was sprayed with a 5.6-gal (21 L) load in a 6-gal (23-L sprayer), allowing for complete coverage plus or minus 3% allowance for calibration error. For each of these test plots, the sprayer was "batched" for an entire plot with a 3% overload to ensure completion. For each batch, a gallon or more of water was placed in the sprayer, the chemical added, and the mix thoroughly shaken. The remainder of water was then added and shaken again. As in McDonald Forest, the operator had two assistants who served as flaggers to direct the operator and as carriers for resupply. Time of treatment per treated plot ranged from half an hour to an hour, depending on obstacles and steepness.

Because species composition was dominated by swordfern, blackberry, vine maple (*Acer circinatum* Pursh), salal (*Gaultheria shallon* Pursh), and dwarf Oregon-grape (*Berberis nervosa* Pursh.), we included glyphosate (1.5 lb a.e./ac, 1.7 kg/ha), imazapyr (3 oz a.i./ac, 0.2 kg/ha), and sulfometuron at 2.3 oz a.i./ac (161 g/ha) in the mix. Plots with abundant salal, a glyphosate-tolerant shrub, also received triclopyr ester at the high rate of 3.0 lb a.e./ac (3.3 kg/ha), which required that the spray mixture be 25% triclopyr emulsifiable ester [Garlon 4®, and 16.7% glyphosate

Figure 12. Coast range 4-year-old clearcut with salmonberry threatening plantation of Douglas-fir; salmonberry is easily controlled selectively with glyphosate by waving wand. Many plantations struggle with salmonberry, either in patches or general distribution. The waving wand system is ideal for both situations, and may be the primary practice for areas of 20 ac (8 ha) or less, or places where shrubs occupy only part of a plantation site. Photo credit: Mike Newton.

product (Accord®, plus small amounts of imazapyr (Arsenal Applicators Concentrate®) and sulfometuron (Oust®)]. This concentration of chemical products had a physical influence on the spray behavior; whenever the emulsifiable ester product was present in this concentration, the spray went out as a partly inverted emulsion with extremely large drops and few small drops. Volume delivery per minute was nearly the same as with normal emulsions or water solutions/suspensions, but drop density on the foliage was much lower.

At the Blodgett installation, a second application occurred a year after the first because of a delay in reforestation. This application consisted solely of sulfometuron plus 1 lb a.e./ac (1.1 kg/ha) of 2,4-dichlorophenoxyacetic acid (2,4-D) or a mixture of 2,4-D and diclorprop at 1 lb a.e./ac (1.1 kg/ha) and 2 lb a.e./ac (2.2 kg/ha) triclopyr where this product had been used previously, applied with the same technology as the first application. Vegetation data will include effects of combined treatments.

Data were recorded at Blodgett as in McDonald Forest, but on 15 permanent sample points per treatment subplot instead of 10/subplot. Means and standard errors (based on three blocks at each site) are provided to demonstrate efficacy and reliability of estimates (Tables 4-6).

Results

The understory sprays in both forests had visually remarkable results, in both their efficacy and consistency of coverage. Despite the range of deposition observed on Kromecote cards in swath tests, there was no obvious necrotic spotting of the vegetation that would indicate impact of large drops or of concentrated deposits of active herbicide. Uncontrolled vegetation consistently occurred only in the "shadow" of large objects, such as large-diameter trees, logs, and very large stumps. Occasional strips of untreated understory vegetation gave evidence of swath misalignment or errors in handling of the waving wand. These cases were rare, and too small to influence net efficacy. Effective swath widths of 36 and 40 ft (11 and 12 m) were readily achieved with few skips in narrow stripes.

All combinations of herbicides consistently removed most perennial plants other than conifers and hardwoods with crowns out of reach. Susceptible groups of species, e.g., ferns and deciduous shrubs, showed the greatest differences between sprayed and unsprayed (Tables 4-5). Decreases in vegetative cover in year 1 reflect the mechanical effects of felling and ground skidding while removing 10%–50% of overstory trees when evaluating vegetation in both sprayed and unsprayed plots. However, differences between sprayed and unsprayed plots for susceptible perennial species groups were clearly seen after year 3, by which time mechanically damaged perennials had recovered if not sprayed. Table 6 illustrates recovery of low cover when thinning reduced overstory severely.

In plots where triclopyr was used at the Blodgett Tract and the spray emulsion was inverted, the distribution of drops on foliage was very low; we estimated coverage at less than 6 drops/in^2 (1 drop/cm^2). The diameters of many of the drops were in the range of 3,000–5,000 μ with occasional "bombs", as indicated by drops seen on foliage and the spread factor of 1.6. These mega-drops obviously contained a significant portion of the spray volume while having a density of roughly 1 drop/4 in^2 (26 cm^2). Moreover, the distribution of drops with these mixtures appeared quite different from those for the mixtures without triclopyr, as a result of the viscous material leaving the nozzle as a continuous creamy stream. Skips did not appear to be a problem with this mixture despite the low volume of application and near-absence of small drops. The evergreen shrub species at which the triclopyr was targeted, salal and dwarf Oregon-grape, were covered consistently enough to provide better temporary relief from competition than would have been expected given their tolerance of herbicides, but there has been enough resprouting of salal to suggest limited translocation. Although means and standard errors do not indicate differences in evergreen shrub cover between sprayed and unsprayed plots after three years, there were visual differences on the site presumably related to shorter stature of treated plants. The large standard errors result from salal and Oregon-grape being the dominant pretreatment vegetation on one of the blocks, but being in relatively low abundance on the other two blocks.

Table 4. Percent cover of shrubs and two fern species (and standard errors) before thinning to 74-135 ft^2/ac (17-31 m^2), and 1 and 3 years after thinning at McDonald Forest. Half of the plots had been sprayed before thinning with glyphosate/imazapyr mixtures at 5 gal/ac (47 L/ha) by the waving-wand method.

Cover type	Before thinning	1 year after	3 years after
		Sprayed	
Shrubs	13.1 (2.5)	2.2 (1.3)	4.8 (1.1)
Bracken fern	1.4 (0.4)	0.1 (0.07)	0.4 (0.1)
Sword fern	11.6 (1.9)	2.0 (0.7)	1.5 (0.5)
		Unsprayed	
Shrubs	12.3 (1.7)	7.5 (1.5)	17.1 (4.3)
Bracken fern	1.4 (0.4)	1.5 (0.4)	3.3 (0.2)
Sword fern	8.3 (2.8)	4.3 (0.1)	17.9 (2.4)

Table 5. Percent cover of deciduous and evergreen shrubs and two fern species (and standard errors) before thinning to 78-135 ft^2/ac (18-31 m^2/ha), and 1 and 3 years after thinning at Blodgett. Before thinning, half of the plots had been sprayed by the waving-wand method with glyphosate/imazapyr/sulfometuron mixtures in 3 gal/ac (28 L/ha); sulfometuron was applied again 12 months later.

Cover type	Before thinning	1 year after	3 years after
		Sprayed	
Deciduous shrubs	8.2 (2.5)	0.7 (0.2)	1.7 (0.4)
Evergreen shrubs	10.0 (6.6)	1.7 (0.7)	3.5 (1.8)
Bracken fern	1.3 (0.3)	0.04 (0.02)	0.2 (0.05)
Sword fern	11.2 (2.0)	4.5 (1.2)	1.6 (0.4)
		Unsprayed	
Deciduous shrubs	8.2 (1.8)	3.7 (0.8)	7.0 (1.6)
Evergreen shrubs	7.3 (5.7)	3.2 (2.1)	5.3 (3.8)
Bracken fern	0.4 (0.1)	0.5 (0.2)	2.8 (0.3)
Sword fern	12.1 (2.6)	10.0 (2.6)	15.3 (4.1)

Table 6. Percent cover of species other than conifers <3.3 ft (1 m) tall (and standard errors) before thinning to <100 ft^2/ac (23 m^2/ha), and 1 and 3 years after thinning. Before thinning, half of the plots had been sprayed by the waving-wand method with glyphosate/imazapyr mixtures in 5 gal/ha (47 L/ha). Observations represent means for twelve 1.2 ac (0.5-ha) plots, each in turn derived from the mean of 10 sample plots with 3.3 ft (1-m) radius. Plots are in McDonald Forest.

Cover type	Before thinning	1 year after	3 years after
		Sprayed	
Shrubs	9.4 (2.6)	0.6 (0.2)	4.2 (1.3)
Sword fern	13.5 (3.0)	1.2 (0.3)	0.3 (0.2)
Bracken fern	2.3 (1.4)	0.02 (0.01)	0.2 (0.1)
Forbs	13.6 (2.5)	16.4 (2.6)	22.2 (3.3)
Grasses	1.1 (0.3)	0.9 (0.3)	3.3 (1.1)
Trailing blackberry	5.2 (1.1)	0.5 (0.1)	8.3 (1.6)
Total cover	45.2 (3.3)	19.7 (2.7)	38.6 (4.1)
		Unsprayed	
Shrubs	10.1 (2.9)	15.3 (1.3)	12.0 (2.9)
Sword fern	10.7 (2.4)	5.7 (1.9)	15.3 (2.7)
Bracken fern	2.6 (1.0)	1.4 (0.4)	4.5 (1.3)
Forbs	9.3 (1.4)	14.3 (2.6)	7.1 (1.4)
Grasses	0.7 (0.2)	2.3 (0.6)	1.8 (0.6)
Trailing blackberry	5.9 (1.3)	5.8 (0.9)	17.2 (2.4)
Total cover	39.2 (3.9)	34.7 (2.6)	57.9 (3.8)

4 Discussion

Efficacy and Efficiency

Broadcast foliar application of herbicides with backpack equipment has generally been characterized by spray-to-wet volumes often exceeding 100 gal/ac (935 L/ha), as in the case of vehicle-mounted power sprayers for power lines and rights of way. Much of the efficacy data for ground equipment is based on such high-volume treatments, and chemical product labels for ground application in the USA do not offer use instructions for volumes less than 5 gal/ac (47 L/ha), hence very low-volume mixing or calibration instructions are not given on labels, and their legal use awaits label modification. Extensive data for controlling individual forest species have been summarized for western shrubs by Gratkowski (1975) and Stewart (1978), and for various woody species across North America (Bovey 1977; Newton and Knight 1981). These summaries have dealt with dosage in terms of concentrations of various products (expressed as acid equivalent per unit volume) applied to individual shrubs. In operational use, however, the usual logistics of broadcast ground application with high volumes do not adapt well to steep forest lands nor to locations without ready access to resupply. The waving wand method avoids this problem and is labor-efficient for broadcast treatments because of reduced handling of low volumes of inerts without decreasing active ingredient.

Our experiments indicate that drop size with the waving-wand method varies across a swath while deposition of active ingredient approximates that of aerial sprays as reported elsewhere (Chamberlain et al. 1955; Yates et al. 1984). If drop size influences efficacy independently of total deposition, one would look for streaky control. Our field experiments indicate that consistent control of shrubs can be expected, and regrowth of treated ferns and deciduous shrubs was greatly reduced. Many deciduous shrubs, e.g., vine maple and hazel, were killed without the upper crowns having been reached, despite high variability in deposition on leaf-sized targets, as reported earlier by Newton et al. (1990), indicating the translocation efficiency of slow-acting products. We do not extend these results to products that desiccate foliage quickly.

Success of the waving-wand method depends on herbicides being effective at low volumes of total spray delivered. Herbicides must not kill translocating tissue quickly when deposited in large drops with high concentrations of active herbicides (McKinlay et al. 1972). The consistency of applications suggests that aerial spray labels for these herbicides are equally applicable to waving-wand applications when in lower-volume mixtures, and perhaps that the labels be modified to include volumes per acre ranging down to 3 gal (28 L/ha).

We have found few other reports of low-volume broadcast backpack application. Fredrickson and Newton (1998) demonstrated that the method's efficacy was equal on many species of shrubs when several herbicides were applied as either 5 or 10 gal/ac (47 or 94 L/ha) in the Sierra Nevada of California, eastern Oregon, and coastal Oregon. They also showed that higher volumes were slightly more likely to injure conifers than the low volumes, but that shrub control did not depend on volume, whether with triclopyr or glyphosate. Richardson (1988) demonstrated that glyphosate was equally effective on bracken fern [western brackenfern (*Pteridium aquilinum* (L.) Kuhn] in mixes of slightly over 5.3 and 11 gal/ac (50 and 100 L/ha); fluroxypyr was equally effective on greenleaf manzanita (*Arctostaphylos patula* Greene), an evergreen shrub, with those same volumes. Richardson pointed out, however, that decreasing the drop size for a given volume tended to increase efficacy. We did not observe this effect in any experiment reported here. Moreover, Liu et al. (1996) indicated that *concentration* of glyphosate was more influential in efficacy on quaking aspen (*Populus tremuloides* Michx.) than drop size or number, a principle that tends to support the use of low volumes and high concentrations. Bohannon and Jordan (1985) observed that glyphosate

Advantages and Limitations — Focus on Supervision for Optimization

Every application system has advantages and disadvantages. The principal disadvantages of the waving-wand method are: (1) it requires careful supervision and training to prevent careless handling and spotty application. (2) Use in certain situations can lead to measurable operator exposure. Observing Worker Protection Standards and using appropriate personal protection equipment (PPE) will minimize exposure when applying. (3) For large projects, this method is physically and technically demanding. Use of the lowest-effective-volume applications reduces the effort of hauling inert ingredients.

Disadvantages can be minimized. Training to maintain constant walking speed on uneven and brushy ground while nozzle is “on”, and instantaneous turning off when stopping will minimize spotty deposition. Practice with water patterns on dry pavement will illustrate flaws in smooth swinging and walking speed under ideal conditions; practice on rough ground is desirable. Periodic marking of swath centerlines with bright plastic tape will help maintain spacing of swaths and minimize skips without tying up personnel as flaggers. Avoid spraying into a headwind when possible. Products registered for forest use have low toxicological risks for mammals. Spray that falls directly on the applicator’s skin will result in some operator intake, probably very low (Newton and Norris, 1981).

Applicators should wear required PPE, such as rubber boots (caulks), non-absorbant pants and gloves, long sleeves, and hat (preferably with a broad brim). Good field practice and personal hygiene should be maintained to minimize dermal contact with any concentrated chemicals. Use and re-application of such products as waterproof sunblocks may minimize exposure through skin contact. Terrain hazards vary widely; slash and debris cause tripping leading to puncture wounds on hands if uncovered.

Advantages of the waving-wand method include (1) efficient use of chemical products, with negligible losses to air or offsite movement; (2) efficient targeting of sprays is achieved because one may shut off sprays where treatment is not needed, (3) when properly applied, precise targeting near water is possible without measurable drift; (4) operations are inconspicuous, and (5) typically costs are competitive with aerial application. Although labor requirements were not rigorously monitored in these field tests, production rates varied approximately between 1.0 to 2.5 ac (0.4 to 1.0 ha) per sprayer-hour, rates the first author has experienced operationally under a wide range of conditions. This latter work rate is achieved when the applicator marks swath centers periodically with bright flagging, and where re-supply is available within 500 ft (150 m).

Figure 13. The wand can be held only slightly above horizontal, when treating low cover in swaths < 10 m wide. This also minimizes the effect of wind and the movement of spray drops toward the applicator. This photo shows application on an easy site. Photo credit: Liz Cole.

was effective when applied in volumes of 1 gal/ac (9 L/ha) that included oil.

Aerial applications evaluating similar parameters elsewhere have used volumes of 3 gal/ac (<28 L/ha) with success. Fisher et al. (1974) observed that 2,4,5-T applications to honey mesquite (*Prosopis juliflora* (Swartz) DC. var *glandulosa* (Torr.) Cockerell) in Texas were equally effective when aerially applied in volumes of 0.5–4.0 gal/ac (4.7–37.0 L/ha) of emulsions containing 25% diesel fuel in drop sizes averaging 200–240 μ. Fisher et al. (1974) also demonstrated that net deposits of active herbicide were the same for 0.5, 1.0, and 4.0 gal/ac (4.7, 9.4, and 37 L/ha) in winds of 1.1–17.6 mph (0.5–8 m/sec). At 10 gal/ac (94 L/ha) and 900 μ VMD, the drop density used was greater than is typical for aerial spray to forests in the Pacific Northwest and far greater than we observed with the waving-wand method. Newton et al. (1992) described highly satisfactory conifer release with several water-soluble and emulsifiable products applied by helicopter in 4 gal/ac (37 L/ha) of water in central Maine spruce-fir forests, again with nozzles delivering relatively small drops uniformly across swaths.

Our observations with forest understories and low volumes of the water carrier are generally consistent with studies of glyphosate in agronomic situations. Jordan (1981) reported an inverse relation between volume in which glyphosate is delivered and efficacy on bermudagrass (*Cynodon dactylon* (L.) Pers). He reported substantially more efficacy with 5 gal/ac (47 L/ha) than with 40 gal/ac (374 L/ha). Bohannon and Jordan (1995) observed highly effective use of glyphosate applied in a soybean oil carrier at 1 gal/ac (9.4 L/ha), but also showed a trend of slightly decreased efficacy at low volumes when glyphosate was applied in water at 1 gal/ac (9.4 L/ha relative to that at 10 gal/ac (94 L/ha). Thus, there may

Figure 14. Riparian areas are very productive sites. They usually require brush control with something like glyphosate, late summer, right before planting; forest practice rules allow ground application to 10 ft (3 m) from the stream. Photo credit: Liz Cole.

be a volume × carrier interaction that we did not evaluate, and also a drop off in efficacy when volume is less than 3 gal/ac (28 L/ha).

Efficacy on plants of different form may differ with the angle of impingement of spray drops. The angle of nozzle elevation appears to be more important for conifer release than for site preparation because the vertically oriented conifer tops would presumably intercept a disproportionate amount of spray from a near-horizontally directed stream, compared to a spray directed 15–45° upward and allowed to fall as if from an aircraft. Therefore the nozzle should be held at least 15° above horizontal to maximize reach and swath width; the optimum for conifer release treatments may well be above 30° to ensure free-falling drops with minimum risk of damage to crop species.

Special Vegetation Management Needs

The availability of tools such as the waving-wand application system makes it possible to favor desirable plant communities in understory settings by targeting local areas of undesirable plants. Jerra and Vogt (1998) and Tappeiner (1997) indicated that natural regeneration under overstory conifers is likely to be inhibited without controlling understory shrubs. In our two-aged stands, and also in loblolly pine in the central USA (Guldin and Baker 1997), reduction of dominant overstory conifers releases shrubs and other understory competitors that may outcompete desired regeneration. The efficacy of the waving-wand method in this situation suggests a role in initiating uneven-aged stands. Brandeis et al. (2001) describes gappy or patchy distributions of trees in forests managed for habitat diversity. Gaps too large for spot treatment are well suited to waving-wand treatment. Areas with vines, e.g., poison oak, may be treatable by spraying lower portions of lianas with high concentrations sufficient to kill roots without injuring host trees, a condition that existed in our experiments in McDonald Forest.

Efficacy of the understory treatments was likely enhanced by the application occurring before the target species were disturbed. At both of our study sites, allowing a month between spraying and logging permitted these products to have a systemic effect that markedly reduced sprouting. Cole and Newton (2009) observed that underplanted conifers of several species in these plots showed better survival and growth 10 years later.

The use of ground equipment clearly reduces interception by overstory trees, and improves on-target placement of chemicals in understories or riparian zones where aerial application cannot reach effectively. Our results demonstrate a very clear pattern of control in treated areas, with precise edges. Results reported by Newton et al. (1982, 1984) suggest that any time herbicide liquids are applied by aircraft to an understory protected by a dominant conifer cover, even with relatively open crowns, the amount of interception by overstory canopy will reduce deposits on shrubs to ineffective levels. Thus, the waving wand system contributes a measurable increase in efficiency of chemical use, and helps aid reforestation beneath residual stands and riparian buffers, as well as normal reforestation areas.

References

Barry, JW, RB Ekblad, GP Markin, and GC Trostle. 1978. *Methods for sampling and assessing deposits of insecticidal sprays released over forests.* Technical Bulletin 1596, USDA Forest Service, Davis, CA.

Bohannon, DR, and TN Jordan. 1995. Effects of ultra-low volume application on herbicide efficacy using oil diluents as carriers. *Weed Technology* 9(4): 682–688.

Bovey, RW. 1977. *Response of selected woody plants in the United States to herbicides.* Agricultural Handbook 493, USDA ARS, Washington, D.C.

Brandeis, TJ, M Newton, and EC Cole. 2001. Underplanted conifer seedling survival and growth in thinned Douglas-fir stands. *Canadian Journal of Forest Research* 31(2): 302-312.

Chamberlain, JC, CW Getzendaner, HH Hessig, and VD Young. 1955. *Studies of airplane spray-deposit patterns.* Technical Bulletin 1101, USDA Forest Service, Washington, D.C.

Cole, EC, and M Newton. 2009. Tenth-year survival and size of underplanted seedlings in the Oregon Coast Range. *Canadian Journal of Forest Research* 39(3): 580–595.

Fisher, CE, CH Meadors, JP Walter, JH Brock, and HT Wedemann. 1974. *Influence of volume of herbicide carriers on control of honey mesquite.* Texas Agricultural Experiment Station Report PR-3282.

Fredrickson, E, and M Newton. 1998. *Maximizing efficiency of forest herbicides in the Sierra Nevada and Oregon: research background and user guide.* Research Contribution 19, Forest Research Laboratory, Oregon State University, Corvallis.

Gratkowski, H. 1975. *Silvicultural use of herbicides in the Pacific Northwest.* General Technical Report PNW-37, USDA Forest Service, Pacific Northwest Research Station, Portland, OR.

Guldin, JM, and JB Baker. 1997. Conversions of stands from even-aged stands to uneven-aged structure in the interior highlands of Arkansas, U.S.A.—Silvicultural considerations, pp. 225-226 in *Proceedings of the IUFRO Interdisciplinary Uneven-aged Management Symposium. [Originally – Proc. Symposium 1.14.00 Interdisciplinary Uneven-aged Silviculture*.] Corvallis, OR.

Jerra, B, and K. Vogt. 1998. Possibilities of applications for uneven-aged management or the so-called "selection system" to Pacific Northwest conditions in the U.S.A. Diploma thesis, Federal Institute of Technology, Zurich, Switzerland.

Jordan, TN. 1981. Effects of diluent volumes and surfactant on the phytotoxicity of glyphosate to bermudagrass (*Cynodon dactylon*). *Weed Science* 29(1): 79–82.

Liu, SH, RA Campbell, JA Studens, and RG Wagner. 1996. Absorption and translocation of glyphosate in aspen (*Populus tremuloides* Michx.) as influenced by droplet size, droplet number, and herbicide concentration. *Weed Science* 44(3): 482–488.

McKinlay, KS, SA Brandt, P Morse, and R Ashford. 1972. Drop size and phytotoxicity of herbicides. *Weed Sci*ence 20(5): 450–452.

Newton, M, and FB Knight. 1981. *Handbook of weed and insect control chemicals for forest resource managers*. Timber Press, Beaverton, OR.

Newton, M, and LA Norris. 1981. Potential exposure of humans to 2, 4, 5-T and TCDD in the Oregon Coast Range. *Fundamental and Applied Toxicology* 1(4): 339-346.

Newton, M, DE White, KM Howard, and G Cline. 1982. *Can we control brush by helicopter spraying before harvest?* Research Note 76, Forest Research Laboratory, Oregon State University, Corvallis, OR.

Newton, M, KM Howard, BR Kelpsas, R Danhaus, S Dubelman, and M Lottman. 1984. Fate of glyphosate in an Oregon forest ecosystem. *Journal of Agricultural and Food Chemistry* 32: 1144–1151.

Newton, M, F Roberts, A Allen, BR Kelpsas, DE White, and P Boyd. 1990. Deposition and dissipation of three herbicides in foliage, litter and soil of brushfields of southwestern Oregon. *Journal of Agricultural and Food Chemistry* 38: 574–583.

Newton, M, EC Cole, DE White, and ML McCormack, Jr. 1992. Response of spruce-fir forests to release by herbicides. I. Response of hardwoods and shrubs. *Northern Journal of Applied Forestry* 9: 130–135.

Richardson, B. 1988. The role of droplet size, concentration, spray volume and canopy architecture in herbicide application. PhD dissertation, College of Forestry, Oregon State University, Corvallis, OR.

Stewart, R. 1978. Site preparation, pp. 99-133 in *Regenerating Oregon's forests.* eds. B.D. Cleary, R.D. Greaves, and R.K. Hermann. Extension Service, Oregon State University, Corvallis, OR.

Tappeiner, J.C. 1997. Regeneration characteristics of selected understory shrubs and hardwoods in western Oregon forests: response to uneven-aged forests, pp. 346-352 in *Proceedings of the IUFRO Interdisciplinary Uneven-aged Management Symposium. [Originally – Proc. Symposium 1.14.00 Interdisciplinary Uneven-aged Silviculture*.] Corvallis, OR.

Yates, WE, NB Akesson, and RE Cowden. 1984. *Measurement of drop size frequency from nozzles used for the aerial application of pesticides to forests.* USDA Forest Service, Equipment Development Center, Missoula, MT.

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