BOXWOOD (*Buxus sempervirens*.'Woodburn Select') (*Buxus* x 'Green Velvet')

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Spray coverage of Boxwood canopies using an air assisted boom sprayer and a cannon sprayer, 2021.

Boxwood is an important commodity plant grown by the Oregon nursery industry. In 2011 Boxwood blight (*Calonectria pseudonaviculata*) was found in Oregon, and is currently managed using cultural and chemical tactics. When using fungicides for Boxwood Blight management, thorough coverage of the foliage and penetration into the canopy is essential for good disease management.

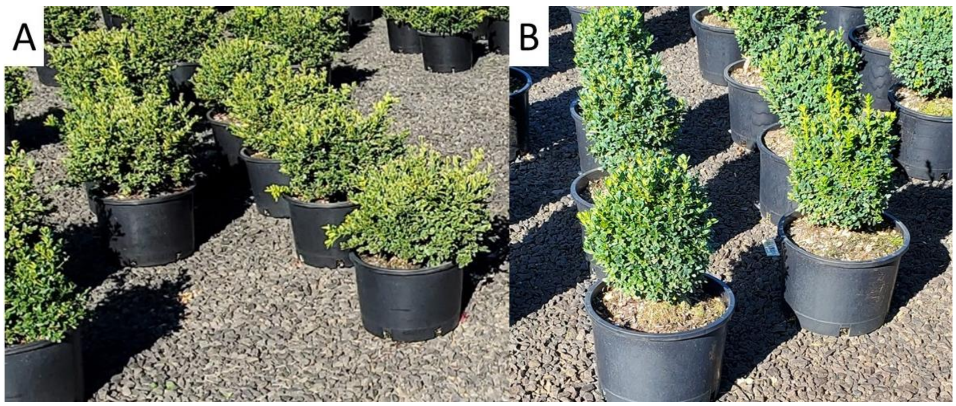

Figure 1. Boxwood plants used in the on-nursery coverage trial, (A) Green Velvet, and (B) Woodburn Select.

A spray coverage trial was conducted on 7 Oct 2021 in two blocks of a commercial nursery located in Marion County, Oregon. The boxwood blocks were 48 ft wide and 220 ft long. Within each block plants were spaced 6 in between plants and 8 in between rows. Bushes were sheared to a height of approximately 12 to 16 inches. Two different cultivars were used in this study, 'Woodburn Select' and 'Green Velvet'. Woodburn Select plants displayed a tight growth habit and a roughly ovoid shape while Green Velvet plants exhibited a looser growth habit with more of a roughly spherical spreading shape (Figure 1). The sprayers used in the study were an air-assisted boom sprayer, a cannon sprayer (5004, AgTec, Plymouth, IN), and a 50 gallon air-blast sprayer retrofitted with the Intelligent Spray System (ISS). The air assisted boom sprayer was fabricated by the nursery for their own use and consisted of two 30 ft wide booms with 3 nozzle selections at each nozzle head and ducting along the length of the boom made of approximately 12 in diameter aluminum piping to channel air and spray downwards at the crop. The boom sprayer was used at 50 and 100 gallons per acre (GPA) and the cannon sprayer was used at 50 GPA. The ISS uses a combination of a LiDAR sensor and ground speed sensor with a computer and individual nozzle control to scan plant canopies and synchronize spray output to match plant canopy volume in real time. The ISS was calibrated to apply 300 GPA when used in standard mode (nozzles fully on), but since the sprayer was used in Intelligent mode using the sensors, a lower volume (100 GPA based on other studies) was applied in this study.

Plots sprayed by the boom and cannon sprayer consisted of approximately 40 ft wide sections of each boxwood block, so that the area encompassing a plot consisted of 40 ft length along the alley and 48 ft across the row. Boxwood plots were sprayed from both sides by both the air assisted boom sprayer and the cannon sprayer as is normal practice for the nursery. In each plot water sensitive cards were placed into boxwood canopies at 5 ft (outer zone) and 15 ft (inner zone) into the block from the alley (Figure 2A). The cards placed 15 ft into the block were meant to represent spray coverage at the outer edge of the boom. In each plot three sets of water sensitive cards (TeeJet Technologies, Wheaton, IL) were placed in three different bushes in the inner zone and three sets of cards were placed in three different bushes in the outer zone. In each bush there were three different locations water sensitive cards were placed and oriented (Figure 2B). Two cards were stapled back to back so that their water sensitive surface was exposed. These cards were placed inside the boxwood canopy approximately 7 inches above the soil line so that their water sensitive sides faced the alleys; these cards were termed double-sided cards. Cards placed into bushes were not perfectly centered so double sided cards that faced the alley were closer to one alley than another (termed "alley-facing") and cards that faced away from the alley were furthest away from the opposite alley (termed "row-center-facing"). In addition, a single card was placed at the same height as the double sided card but faced the block of bushes rather than the alley; these cards were termed “inline cards”. Lastly, a single card was placed in the center of the boxwood bush horizontal to the ground and gently nestled approximately 2 inches into the canopy so that the boxwood branches relaxed back into their natural configuration; these cards were termed “upward-facing cards”.

Plots sprayed by the ISS consisted of a subset of each of the Green Velvet and Woodburn Select boxwood blocks. In each of the cultivar blocks 4 rows of potted boxwood plants were removed on either side of a section of 4 rows of potted boxwood bushes, such that there were 4 rows of boxwood bushes with an alley on either side. Cards were placed into boxwood canopies in the same locations as described above except there were two replicates of each card position per plot instead of three. For example there were two double-sided, inline and upwards facing cards placed in one the inner two rows of boxwood bushes, with the same placed in the outer rows of bushes. Plots were sprayed from both sides with the ISS. For all sprayer types plants were sprayed with water and allowed to dry for approximately 30 min, then cards were collected into plastic zip top bags.

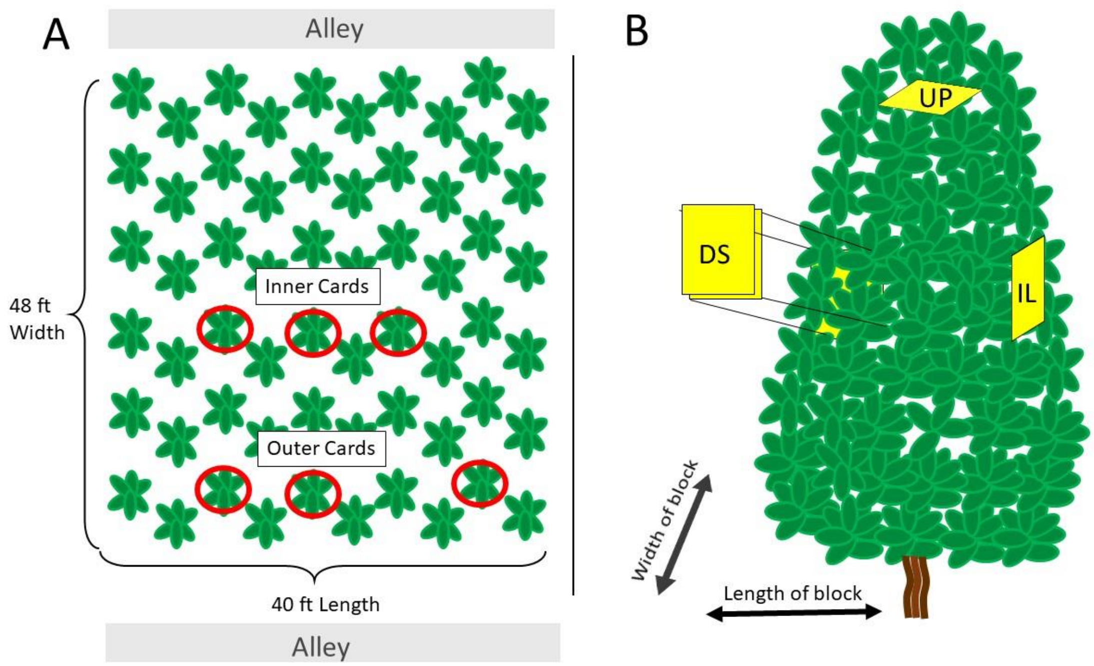

Figure 2. (A) Schematic of a plot with example bushes that had cards placed in them indicated with red circles. (B) Placement of water sensitive cards in boxwood bushes: Double sided (DS), upward-facing (UP), and inline (IL).

Water sensitive cards were then scanned and analyzed for percent coverage and deposit density (deposits/cm^2) using DepositScan software. Percent coverage on double sided cards using the boom sprayer was analyzed using a generalized least squares model to account for unequal variance among replicates and deposit density was analyzed with a linear model. For ISS double-sided cards percent coverage and deposit density were analyzed using a linear model. Treatment comparisons for double-sided cards were conducted within each cultivar using the emmeans package. For the inline and upward-facing cards treated with the boom sprayer and ISS, and all cards treated using the cannon sprayer, insufficient data was available to fit models so Wilcox rank sum tests were used to test for significant differences in coverage and deposit density among card row placement (inner or outer), between cultivars, and for double sided cards only, the direction they were facing. All data was analyzed in R version 4.0.3.

Card placement in the inner or outer zones of the boxwood block did not detect a significant difference in coverage or deposit density observed in boom treated plots, so values were averaged across those groups for this analysis. In addition, there was no significant difference in the direction the double sided cards faced in the boom treated plots, so values were averaged across those groups for this analysis.

Coverage and deposit density was significantly higher on double sided cards in Green Velvet bushes treated at 100 GPA than on cards placed in plots treated at 50 GPA (Table 1). In addition, deposit density was significantly higher on inline cards from bushes treated at 100 GPA than cards from bushes treated at 50 GPA in Woodburn Select plots.

Table 1. Percent coverage and deposit density on boxwood bushes treated with the air-assisted boom sprayer.

Cultivar	Card Placement[x]	Treatment	Coverage (%)[y]	Deposit Density (deposits cm^{-2})[y]
Green Velvet	Doubled Sided	50 GPA	0.6 (0.3 – 1.0)	10.2 (-4.1 – 24.4)
		100 GPA	3.8 (2.4 – 5.3) *(cv*)[z]	62.5 (48.3 – 76.8) *(cv*)[z]
	Inline	50 GPA	4.3 ± 2.9	47.2 ± 20.0
		100 GPA	3.6 ± 1.7	54.4 ± 21.5
	Upward Facing	50 GPA	9.4 ± 3.3	89.8 ± 28.6
		100 GPA	21.6 ± 10.6	152.0 ± 33.4
Woodburn Select	Doubled Sided	50 GPA	0.5 (0.2 – 0.8)	13.7 (-0.6 – 28.0)
		100 GPA	1.1 (-0.3 - 2.4)	24.4 (10.1 – 38.7)
	Inline	50 GPA	0.4 ± 0.3	5.4 ± 3.6
		100 GPA	3.1 ± 1.9	62.9 ± 28.6*
	Upward Facing	50 GPA	1.6 ±0.7	116.0 ± 43.2
		100 GPA	12.7 ± 6.0	27.4 ± 13.7

[x] Double sided cards were two water sensitive cards stapled back to back and placed perpendicular to the plane of spray. Inline cards were a single card placed parallel to the plane of spray in the boxwood canopy. Upward facing cards were single cards placed in the center of the boxwood canopy (from above), nestled approximately 2 inches into the boxwood canopy.
[y] Means followed by 95% confidence intervals in parentheses or by standard error if the (±) symbol follows the mean.
[z] Significantly higher value from the other cultivar for that specific card position and treatment.
* Significant difference from the other treatment within that card placement and cultivar.

Table 2. Percent coverage and deposit density on boxwood bushes treated with the cannon sprayer.

Cultivar	Card placement[v]	Position in block[w]	Facing direction[x]	Mean coverage (%)[y]	Mean Deposit Density (deposits cm^{-2})[y]
Green Velvet	Double-Sided	NA	Row-center	0.3 ± 0.1	12.5 ± 4.2
			Alley	16.8 ± 6.5*(cv*)[z]	309.7 ± 50.1* (cv*)[z]
	Inline	Inner	NA	7.1 ± 5.1	196.0 ± 99.7
		Outer		0.9 ± 0.1	68.3 ± 2.5
	Upward-facing	Inner		7.1 ± 0.5	283.8 ± 26.7
		Outer		4.1 ± 2.5	123.1 ± 63.2
Woodburn Select	Double-Sided	NA	Row-center	0.2 ± 0.1	8.4 ± 2.8
			Alley	3.2 ± 1.9*	96.6 ± 39.9*
	Inline	Inner	NA	6.5 ± 3.8	233.7 ± 96.1
		Outer		1.2 ± 0.5	76.1 ± 33.3
	Upward-facing	Inner		6.1 ± 0.4	196.4 ± 1.6
		Outer		2.0 ± 1.3	106.8 ± 60.8

[v] Double sided cards were two water sensitive cards stapled back to back and placed perpendicular to the plane of spray. Inline cards were a single card placed parallel to the plane of spray in the boxwood canopy. Upward facing cards were single cards placed in the center of the boxwood canopy (from above), nestled approximately 2 inches into the boxwood canopy.
[w] Position in block refers to whether the card was placed 5ft (outer) or 15ft (inner) away from the alley into the block. Position did not have an impact on spray quality on double sided cards so values were averaged over position (NA = not applicable).
[x] Facing direction refers to the feature the card face was closest to. Double sided cards were not placed in the center of the boxwood blocks so one card faced closer to the alley and one card faced the row center. Inline and upward facing cards only faced a single direction as specified by their placement (NA = not applicable)
[y] Means followed by standard error.
[z] Significantly higher value from the other cultivar for that specific card position and treatment.
* Significantly different from the other treatment within that card placement and cultivar.

Percent coverage and deposit density was significantly higher in Green Velvet bushes treated at 100 GPA than in Woodburn Select bushes treated at 100 GPA.

There were no significant differences in percent coverage or deposit density on double-sided, upwards-facing, or inline cards between Woodburn Select and Green Velvet treated blocks treated with the cannon sprayer (Table 2). Within both Woodburn Select and Green Velvet blocks the double-sided cards that were facing the sprayer had significantly higher coverage and deposit densities than those that were facing towards the inside of the block. There were no significant differences in coverage or deposit densities between cards placed in the inner portions of the rows compared to the outer portions of the rows on any of the card placements.

In the area sprayed by the ISS, there were no significant differences in coverage or deposit density between cards placed in the inner portions of rows or the outer portions, so values were averaged over those categories. Among double sided cards there were no significant differences in coverage or deposit density between cards that faced the row center or alley except deposit density was significantly higher on cards that faced the alley in Green Velvet plots (Table 3). However, coverage and deposit density was significantly higher in Green Velvet plots than Woodburn Select plots for both row-center-facing and alley-facing cards. There were no significant differences in coverage or deposit density between cultivars on inline cards, however upward-facing cards had significantly higher coverage and deposit density in Green Velvet plots than Woodburn Select plots.

Table 3. Percent coverage and deposit density on boxwood bushes treated with the intelligent sprayer.

Cultivar	Card placement[w]	Facing towards[x]	Mean coverage (%)[y]	Mean Deposit Density (deposits cm^{-2})[y]
Green Velvet	Double-Sided	Row-center	19.6 (11.5-27.7) (cv*)[z]	156.9 (106.6-207.0) (cv*)[z]
		Alley	27.7 (19.6-35.8) (cv*)[z]	263.80 (213.4-314.0) * (cv*)[z]
	Inline	NA	18.9 ± 10.8	235.0 ± 103.1
	Upward-facing		11.3 ± 8.0 (cv*)[z]	191.1 ± 43.4 (cv*)[z]
Woodburn Select	Double-Sided	Row-center	-2.6 (-10.7-5.5)	55.5 (5.2-106.0)
		Alley	5.5 (-2.6-13.6)	53.0 (2.7-103.0)
	Inline	NA	8.0 ± 5.3	139.5 ± 71.6
	Upward-facing		0.6 ± 0.5	30.6 ± 23.9

[w] Double sided cards were two water sensitive cards stapled back to back and placed perpendicular to the plane of spray. Inline cards were a single card placed parallel to the plane of spray in the boxwood canopy. Upward facing cards were single cards placed in the center of the boxwood canopy (from above), nestled approximately 2 inches into the boxwood canopy.
[x] Facing direction refers to the feature the card face was closest to. Double sided cards were not placed in the center of the boxwood blocks so one card faced closer to the alley and one card faced the row-center. Inline and upward facing cards only faced a single direction as specified by their placement.
[y] Means followed by 95% confidence intervals in parentheses or by standard error if the (±) symbol follows the mean.
[z] Significantly higher value from the other cultivar for that specific card position and treatment.
* Significantly different from the other treatment within that card placement and cultivar.

While the data from the boom, cannon, and ISS sprayers are not directly comparable, these data indicate the coverage distribution that can be expected from an over-the-row sprayer such as from the air-assisted boom sprayer and spray that was received from the side as from the cannon sprayer or ISS. For the boom sprayer it did not matter whether cards were placed in bushes in the middle of the boxwood block or towards the outer edge, coverage and deposit density values were similar between the two. For the cannon sprayer, while coverage and deposit density were not significantly different for cards in the inner and outer portions of the blocks, double sided cards that faced the alley had significantly higher coverage and deposit density than cards that faced across the majority of the boxwood block. This trend continued with the ISS when it came to Green Velvet plots, however coverage and deposit density were not significantly different among alley facing card in Woodburn Select plots. In addition for the cannon sprayer, while not significant, coverage and deposit densities were higher among cards in the inner part of the boxwood block, where the majority of the spray from the cannon sprayer was directed. Those trends were consistent among both boxwood cultivars in the study for the cannon sprayer.

The data from all of the sprayers indicates the influence of boxwood canopy structure in spray penetration and coverage. For double sided cards when all sprayers were used, coverage and deposit density were higher among alley facing cards in Green Velvet block than Woodburn Select blocks. In addition for ISS treated plots, coverage on upward-facing cards was significantly higher in Green Velvet plots than Woodburn Select plots. While coverage or deposit density were not significantly different between cultivars for other card placements, values were consistently higher in the more open canopy Green Velvet cultivar.

The coverage and deposit density values on cards in this study were mostly lower than what is considered acceptable for good disease and pest control by pesticide application professionals. The generally accepted thresholds for percent coverage and deposit density range from 10%-15% and >85 drops per square centimeter, respectively. Those values represent an even spread of fairly small droplets across a surface with not much overlap of droplets. This amount of coverage is typically enough for most common pesticides to be effective on their target organism. Only one of the card positions among boom and cannon treated plots in the study met those values: upward facing cards in Green Velvet plots treated at 100 GPA with the boom sprayer. Card locations in the boxwood canopies were chosen to both favor and disfavor the sprayer types. Upward facing cards were meant to favor the boom sprayer which sprays downward onto plants, while double sided cards favor the cannon sprayer or ISS which both spray from the side. Inline cards did not favor either sprayer type as the plane of spray from both sprayers runs parallel with the water sensitive surface. That the only card placement that met spray application quality metrics was in the cultivar with a more diffuse canopy treated at the highest volume of the boom sprayer illustrates just how difficult it is to get thorough coverage on boxwood canopies. To get the most effective spray coverage and penetration into boxwood canopies, nurseries likely need to use high volume sprays when making applications targeted at managing Boxwood Blight.

When using the ISS, coverage and deposit density met thresholds among all cards placed in Green Velvet canopies but not Woodburn Select canopies. The ISS was used in a modified portion of the nursery's blocks where the row width, or effective swath the sprayer had to spray across, was approximately 7 ft. This smaller swath width compared to those of the boom and cannon sprayer likely played a role in why coverage and deposit density was higher in ISS plots than those sprayed by the boom sprayer or cannon sprayer. The spray swaths of the boom and cannon sprayer were effectively 30 ft and 48ft, respectively, resulting in a much larger area to cover in a single pass than the ISS. When spray and sprayer air (if applicable) is released closer to the target crop, coverage and penetration is typically better than when spray is released further away from the crop. This does not discount the difficulty of penetrating a highly dense canopy such as that present in Woodburn Select. It is not practical for many nurseries to spray boxwoods with as narrow of spray swaths as those used by the ISS due to the sheer volume of boxwood plants they produce. However, releasing spray and air as close to the boxwood canopy as possible could help with spray penetration and distribution. The air assisted boom sprayer attempted to do this on a large scale but spray penetration into the canopy was minimal, indicating that the fan air volume is too low, driving speed is too fast or spray volume is too low, or a combination thereof. Given the difficulty of achieving adequate coverage on boxwood canopies for effective Boxwood Blight Management, it may be that other pesticide application methods (e.g. drenching or chemigation) or cultural tactics (e.g. resistant cultivars, wider plant spacing) would be a more effective use of resources.

Future work could investigate testing of other sprayer types (such as tunnel sprayers) or application methods (such as drip or drench applications) to elucidate methods to get more effective coverage on boxwood canopies. When making applications targeted at Boxwood Blight Management locally systemic fungicides should be used when weather conditions favor *C. pseudonaviculata* growth and reproduction, and when newly emerging susceptible tissue is present, such as in spring.

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