Canopy Development and Spray Deposition in Highbush Blueberry

Gary VanEe,¹

Richard Ledebuhr,²

Eric Hanson,³ Jim Hancock,⁴

and Donald C. Ramsdell⁵

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SUMMARY. Most highbush blueberries (*Vaccinium corymbosum* L.) in Michigan are treated annually with fungicides and insecticides with several types of sprayers. The goal of this study was to determine how sprayer type, pruning severity, and canopy development interact to affect spray deposition patterns. Deposition was measured as the percentage of the surface area of card targets that was covered following applications of black dye. Light measurements indicated that the canopy of blueberry bushes, regardless of pruning treatment, closed by the middle of June, and light levels within the canopy changed little from then until fruit harvest in August. A standard airblast sprayer that pushed spray up and

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¹Professor, Department of Agricultural Engineering, Department of Agricultural Engineering, Michigan State University, East Lansing, MI 48824-1325.

²Specialist, Department of Agricultural Engineering, Department of Agricultural Engineering, Michigan State University, East Lansing, MI 48824-1325.

³Professor, Department of Horticulture, Department of Horticulture, Michigan State University, East Lansing, MI 48824-1325 (to whom reprint requests should be addressed; e-mail address: hanson@msu.edu).

⁴Professor, Department of Horticulture, Department of Horticulture, Michigan State University, East Lansing, MI 48824-1325.

⁵Professor, Department of Botany and Plant Pathology (retired), Department of Botany and Plant Pathology, Michigan State University, East Lansing, MI 48824-1325.

through bushes provided acceptable deposition in all parts of the canopy early in the season, but later in the season, coverage was poor in the top and sides furthest from the sprayer. An above-row sprayer with fan-driven micronozzles also provided acceptable coverage throughout the bushes early in the season, but once the canopy had closed, coverage was poor in the bottom of the bush. Both sprayers were operated in bushes receiving light, moderate, and heavy pruning. The more severe pruning regimes increased the amount of spray deposited from the above-row sprayer, but not from the airblast sprayer.

Most commercial plantings of highbush blueberry (*Vaccinium corymbosum*) in the United States are treated each year with fungicides (88% of acreage) and insecticides (83% of acreage) (U.S. Department of Agriculture, National Agricultural Statistics Service, 1998). Pesticides are applied to commercial blueberries in Michigan with fixed-wing aircraft and ground sprayers. Airplanes treat acreage rapidly (high field capacity) and are considered particularly useful prior to harvest when ground equipment can bruise fruit or knock berries off peripheral branches. A limitation of aerial spraying is that calm conditions are needed to minimize off-target drift and provide acceptable deposition uniformity. In addition, aircraft are too expensive for individual producers and commercial application services are not available in some areas. Cannon sprayers that project spray across the top of several blueberry rows are also popular because they have a high field capacity, and since fewer passes through the field are required, the potential for mechanical damage to fruit is minimized. However, cannon sprayers may result in irregular deposition and/or off-target drift during windy conditions. Conventional airblast sprayers that propel spray up and through bushes are also common in Michigan. Airblast sprayers may provide thorough coverage but require longer treatment times (lower field capacity). Field capacity may be increased by driving airblast sprayers down every second or third row middle, but uniformity of coverage may be sacrificed. An above-row sprayer that utilizes multiple fans and nozzles was developed recently by

agricultural engineers at Michigan State University, and this concept is now available commercially. In choosing application technology, growers also must consider the equipment costs relative to the size of their plantings, and the availability of contract application services in their area.

The importance of deposition uniformity and field capacity may depend on the insect pest or pathogen being targeted and each grower's situation. Uniform deposition may be most important for nonsystemic pesticides, such as captan, which is a protectant chemical requiring thorough coverage within the canopy for control of fruit-rotting fungi. Even when recommended fungicide programs are followed, fruit rots caused by *Colletotrichum acutatum* J.H. Simmonds) *Alternaria* Nees, and *Botrytis cinerea* Pers.:Fr. can be prevalent in Michigan blueberries (Hanson et al., 1999). Deposition uniformity may be less critical for control of mobile insect pests such as the blueberry maggot fly (*Rhagoletis mendax* Curran), which may contact insecticide deposits even if deposition is not uniform. High field capacity provides greater flexibility in application timing. Growers treating large areas with low field capacity application technology may need to begin treating early or treat when weather conditions are not optimal to be sure to cover all acreage.

Although spray deposition patterns have been studied in tree fruit and some field crops (Hall, 1991; Hoffman and Salyani, 1996; Kirk et al., 1992), reports of similar studies on blueberries could not be found. The highbush blueberry is a multi-stemmed, deciduous shrub that grows 1.2 to 3.0 m (4 to 10 ft) in height. Pesticides are applied to Michigan blueberries before leaves emerge through the harvest period when the leaf canopy is fully developed. Deposition patterns likely change as the blueberry canopy develops, similar to the way apple tree canopies affect spray deposition patterns (Ferree and Hall, 1980). Some blueberry growers have intuitively tried to compensate for canopy development by driving airblast sprayers down every third or fourth row middle early in the season, and every second row middle later in the season. Although regular, moderate pruning appears to optimize yields and berry size (Siefker and Hancock, 1987), growers vary in their severity and frequency of prun-

ing, so canopy densities in commercial fields vary widely. Growers may need to consider their application equipment and operation, pruning practices, and canopy development in order to optimize spray coverage.

The objectives of this work were to 1) describe the deposition patterns of two types of ground sprayers and 2) determine how deposition patterns and light penetration are affected by canopy development under different pruning regimes.

Materials and methods

The study site was a 40 year-old commercial planting of the 'Jersey' in Muskegon, Mich. Bushes were spaced 1.2 m (4 ft) apart in north to south rows 3 m (10 ft) apart. Three pruning treatments (light, moderate, heavy) were imposed as follows. In March 1995, 20% of the largest canes were removed from bushes in the heavy pruning plots only. In March 1996, 20% of the largest canes were removed from the moderate pruning plots, and an additional 20% were removed from the heavy pruning plots. Light pruning plots were not pruned. Pruning plots were five rows wide and 15 bushes long, and replicated three times in a randomized complete-block design. The number of canes in different diameters at a height of 10 to 20 cm (4 to 8 inches) above the crown was recorded on two bushes per plot in May, 1996 in describe relative differences in canopy densities.

Light measurements were taken on 28 May (first open flowers), 6 June (early bloom), 12 June (full bloom), 27 June (petal fall), 19 July [0.5-cm (0.2-inch) green fruit], and 22 Aug. (first harvest), 1996 with 1 m (3.3 ft) long Line Quantum sensor (LI-COR, Lincoln, Neb.) inserted horizontally into each bush at 1/3, 1/2, and 2/3 the distance from the top of the canopy. Measurements were taken in two bushes in adjacent rows in the middle of each plot. Full sun readings were taken beside each bush, and light intensity was calculated as a percentage of the full sun reading.

Spray deposition patterns were studied by spraying a 4 g·L⁻¹ (0.4%) solution Black Shade "R" dye (Warner-Jenkinson Co., St. Louis, Mo.) and measuring coverage on card targets. Each target consisted of a 5 cm (2 inch) diameter plastic disc holding four alligator clips radiating out from the edge. Four 2.5 × 10.2 cm (1 × 4 inch)

white kromcoat cards were clipped to each target. Targets were placed in four positions within bushes: 1) bottom [0.6 to 1.0 m (2 to 3 ft) height in center of canopy], 2) top of canopy, 3) west side at height of 1.0 to 1.5 m (3 to 5 ft), and 4) east side at the same height. Targets were clipped to branches in a random orientation in the same two bushes used for the light measurements. After the dye solution was sprayed and the cards had dried, the cards were placed in plastic bags, and later read with computer imaging software (Optimas Imaging Corp., Edmonds, Wash.) that measured the percentage of the surface area that was covered with dye. Sixteen measurements were made per target (two per surface on four cards). The mean of 16 measurements was calculated for each target. Coverage usually varied greatly depending on the orientation of surfaces relative to the sprayer. A coefficient of variation was calculated for the 16 measurements per target to illustrate the uniformity of coverage.

This system was used to study the spray deposition patterns of two sprayers on 13 May, 29 May, 3 July, and 11 July 1996. An Agtec (Ag-Chem, Minnetonka, Minn.) three-point hitch airblast sprayer (Fig. 1) was tested at a spray volume of $187 \text{ L}\cdot\text{ha}^{-1}$ (20 gal/acre). The airblast sprayer was driven every other row middle at $1.5 \text{ m}\cdot\text{s}^{-1}$ (3.4 miles/h) and had an estimated field capacity of $3.2 \text{ ha}\cdot\text{h}^{-1}$ (7.9 acre/h). The target bushes were in rows three and four of the five row-wide pruning plots, and the airblast sprayer was driven between rows two and three, and back between rows four and five. Average coverage was calculated between the two target bushes for the top and bottom of the bushes, and for the sides nearest to and farthest from the sprayer pass.

Deposition patterns of an above-row sprayer (Fig. 2) were also studied on the same days. The above-row sprayer was constructed by agricultural engineers at Michigan State University, and was similar to the Proptec machine marketed by Ledebuhr Industries (Bath, Mich.). The sprayer boom covered four rows (two nozzle/fan units per row), and delivered a spray volume of $94 \text{ L}\cdot\text{ha}^{-1}$ (10 gal/acre). The above-row sprayer was driven every fourth row middle at $1.5 \text{ m}\cdot\text{s}^{-1}$ giving a field capacity of $6.7 \text{ ha}\cdot\text{h}^{-1}$ (16.5 acres/h). The nozzle/fan assemblies were positioned

about 1 m apart along the boom, and were oriented facing downward at roughly 10 o'clock and 2 o'clock positions about 1 m (3.3 ft) above the plants. The front fan was angled about 20 degrees forward toward the center of the row, while the back fan was angled 20 degrees rearward towards the center of the row. During the deposition tests, the above-row sprayer was driven between rows three and four of the pruning plots, and the target bushes were the same as those used for the airblast sprayer (rows three and four).

A third study was conducted to compare deposition patterns when the airblast sprayer was driven down each row middle or every other middle. Targets were placed in the same positions in the same bushes for each run. Flow rates were changed when every row middle was sprayed so that the spray volume was the same [$187 \text{ L}\cdot\text{ha}^{-1}$ (20 gal/acre)]. Comparisons were made on 13 May (budbreak) and 14 June (full bloom).

Data were analyzed by SAS computer software (SAS Institute, Cary,

Fig. 1. Conventional airblast sprayer used in spray deposition studies.

Fig. 2. Above-row sprayer used in spray deposition studies.

Table 1. Effect of pruning on the number of canes in different diameter size categories in 'Jersey' bushes in May, 1996.

Pruning treatment	Total canes/ bush	Canes in diameter (cm ²) categories (%)				
		<0.6	0.6–1.3	1.3–1.9	1.9–2.5	>2.5
Light	41.9 a ^y	36 a	41	14 a	7	1
Moderate	37.4 ab	46 b	40	11 ab	3	0
Heavy	34.9 b	42 ab	43	9 b	5	1

^y2.5 cm = 1 inch.^yMeans in columns within each year separated by LSD ($P = 0.05$). F test was not significant if means are not followed by letters.**Table 2. Effect of pruning on light levels in different positions in 'Jersey' blueberry canopies. Data are means of measurements on six dates between 28 May and 22 Aug. 1996.**

Pruning treatment	Light (% of full sun)		
	Bottom third	Middle	Top third
Light	7 a ^z	9 a	27 a
Moderate	12 b	20 b	41 b
Heavy	13 b	18 b	48 c

^zMeans in columns separated by LSD ($P = 0.05$).

N.C.). Light measurements and percent deposition data collected over time were analyzed by ANOVA as a split-split plot, with time, pruning, and position in the bush constituting the main plot, sub plot, and sub-sub plot, respectively. Data from the comparison of alternate row to every row middle spraying with the airblast sprayer were analyzed as the same design, with time, spray application (alternate or every row), and position as the main plots, split plots and split-split plots, respectively.

Results and discussion

Pruning decreased the total number of canes and the percentages in the intermediate size category, and increased the percentage of canes in the smaller size categories, (Table 1). Although the optimum number and age of canes in 'Jersey' bushes has not been clearly defined, based on commercial standards, the light pruning plots were in need of pruning in 1996, whereas the canopy densities in the moderate and heavy pruning plots were considered acceptable.

The ANOVA for light levels indicated that the interactions of position in the canopy (PO) and time (T), and pruning treatment (PR) and PO, were significant at the $P < 0.01$ level, whereas the three-way interaction of $PO \times PR \times T$ was not significant. Both moderate and heavy pruning increased light levels in all three positions in the canopy, relative to the light pruning treatment

(Table 2). Pruning increased light levels in different positions in the canopy, with the most consistent differences in the upper third of the bush (Table 2). Light levels in the top, middle, and bottom of the canopy decreased as the leaf canopy developed between the time of first open flowers and petal fall, but changed little between petal fall and harvest (Fig. 3). Highbush blueberries usually exhibit more than one flush of shoot growth, but the elongation of shoots from the first flush ceases

4 to 5 weeks after bloom (Gough et al., 1978). Light readings indicated that the canopy of these bushes had restricted light penetration by more than 90% in the lower 2/3 of the bush by petal fall, about 1 to 2 weeks after full bloom. Although additional shoot growth clearly occurred after this time, light penetration was not further reduced. As fruit increased in size after petal fall, their weight often pulls canes down. This may have counteracted further shading from continued growth of leaves and shoots.

Analysis of the spray deposition from the airblast and the above-row sprayers over time indicated significant ($P < 0.001$) interactions of PO and T, and PR and PO, but the three-way interaction of T, PR, and PO was not significant. The above-row sprayer resulted in thorough coverage throughout the bush on 13 May (pink bud stage) and 29 May (first bloom) (Fig. 4). By 3 July (late petal fall) and

Fig. 3. Changes in light levels (percent of full sun) in the top third, middle, and bottom third of 'Jersey' blueberry canopies between the time of first open flowers and first fruit harvest. Data are means across three pruning treatments.

Fig. 4. Spray coverage (percent of surface area of card targets) in different positions in 'Jersey' blueberry canopies following treatment with an above-row sprayer on four dates between 13 May (pink bud) and 11 July (green fruit). Data are means across three pruning treatments. LSD value refers to comparisons between dates and positions.

Fig. 5. Spray coverage (percent of surface area of card targets) in different positions in 'Jersey' blueberry canopies following treatment with an airblast sprayer (SP) on four dates between 13 May (pink bud) and 11 July (green fruit). Data are means across three pruning treatments. LSD value refers to comparisons between dates and positions.

11 July, coverage was poor on the sides and in the bottom of the bush, while that in the top of the bush remained high (Fig. 4). Driving the airblast sprayer down alternate row middles resulted in thorough coverage throughout the bush on 13 May and 29 May (Fig. 5). On 3 July and 11 July, coverage was poor on the top and the side farthest from the sprayer, while coverage on the side facing the sprayer remained high (Fig. 5).

The airblast sprayer operated in every row middle resulted in thorough coverage in all parts of the bush, whether sprayed on 13 May or 14 June (Fig. 6). In contrast, alternate row middle spraying with the same sprayer resulted in thorough coverage on 13 May, but poor coverage on the far side of the bush when sprayed at full bloom (14 June) (Fig. 6). Whereas driving airblast sprayers between every row provides excellent coverage, acreage can only be treated at half the speed of alternate row middle spraying. Also, every row middle spraying may not be practical for large bushes close to harvest because berries on overhanging canes may be knocked to the ground or bruised.

The impact of pruning severity on spray coverage with the two sprayers is illustrated in Fig. 7. In general, more severe pruning increased coverage in the areas of the canopy receiving lower overall coverage (e.g., bottom and sides with the above-row sprayer, and the top and far side with the airblast sprayer). Pruning tended to have less effect in positions where overall coverage was high (e.g., top of bush with the above-row sprayer, and bottom and near side with the airblast sprayer).

Spray coverage varied considerably between the 16 measurements on each target. Typically, readings varied from 10% to 90% coverage within a target, presumably due to the orientation of the surfaces relative to the spray source. The uniformity of coverage was assessed by comparing the coefficients of variation (cv) of the 16 measurements within each 4-card target (Table 3). The cvs were lowest with both sprayers early in the season. Targets closest to the spray source (top for the above-row sprayer, near side for the airblast sprayer) had lower cvs than targets in other canopy positions. Pruning reduced the cvs for the above-row sprayer, but not for the airblast sprayer.

The relationships between the

Fig. 6. Spray coverage (percent of surface area of card targets) in different positions in 'Jersey' blueberry canopies following treatment with an airblast sprayer driven down each row middle or alternate row middles on two dates. Data are means across three pruning treatments. LSD value refers to comparisons across spray treatment, date, and position.

percentage and uniformity of coverage, and pesticide efficacy are not understood, and likely vary with the pesticide and target organism. The blueberry maggot fly is a very mobile pest, so high uniformity of coverage (low cv) may not be necessary for control since adults may contact spray droplets even if only some surfaces are treated. This pest may even be controlled if overall coverage is low in some positions in the bush. In contrast, control of less mobile pests, such as the blueberry aphid (*Illinoia pepperi* MacGillivray), may require high percent coverage in all positions in the bush, but thorough coverage on all sides of leaves and fruit (low cv) may not be necessary. The control of some fungal pathogens with nonsystemic fungicides may require the highest overall coverage and uniformity.

Nonsystemic fungicides, such as captan, function by protecting surfaces from fungal infection. Captan is applied to control fungal fruit rots such as those caused by *Colletotrichum acutatum* (anthracnose ripe rot), *Alternaria* sp., and *Botrytis cinerea* (Ramsdell, 1989). These fungi can infect individual flowers or developing berries (Bristow and Windom, 1998; Hartung et al., 1981; Ramsdell, 1992), so effective control with captan likely requires high overall coverage in all positions in the bush, as well as uniform coverage of all surfaces in each position (low cv). Systemic pesticides may compensate for irregular deposition by being redistributed within the plant.

These studies illustrated that spray deposition is greatly affected by canopy development. Uniform coverage may be easily obtained with most application equipment early in the season before the canopy develops fully. Once the blueberry canopy has filled (mid-June in southern Michigan), uniform deposition becomes more difficult to obtain. The two sprayers tested here had different strengths and weaknesses.

Fig. 7. Effect of pruning severity on spray coverage (percent of surface area of card targets) in different positions in 'Jersey' blueberry canopies following treatment with above-row and airblast sprayers. Data are means of four treatment dates between 13 May (pink bud) and 11 July (green fruit). LSD values refers to comparisons across pruning treatment and position.

Table 3. Effect of time of application, position in the canopy, and pruning severity on the coefficients of variation among the 16 measurements of percent coverage on card targets.

Parameter	Coefficient of variation	
	Airblast sprayer	Above-row sprayer
Time		
13 May	70 a ^z	77 a
29 May	70 a	76 a
3 July	101 b	94 b
11 July	104 b	94
Significance	***	***
Position		
Top	89 b	63 a
Bottom	96 c	99 c
Near/east	76 a	88 b
Far/west	82 a	92 b
Significance	**	***
Pruning		
Light	87	96 c
Moderate	84	77 a
Heavy	86	84 b
Significance	ns	**

^zMeans in columns separated by LSD ($P = 0.05$).

ns, **, ***Nonsignificant or significant F test at $P \leq 0.001$ or 0.01, respectively.

The above-row sprayer provided excellent coverage in the top of the bush, but coverage in the bottom and on the sides was poor late in the season. The airblast sprayer resulted in high coverage in the bottom of the bush and on the side facing the sprayer, but coverage was poor later in the season on the side opposite the sprayer and in the top of the bush. Operating the airblast sprayer between each row rather than alternate row middles, increased coverage and uniformity, but also increased treatment time and may result in more fruit damage.

Literature cited

- Bristow, P.R. and G.E. Windom. 1998. Epidemiology of alternaria fruit rot in the Pacific Northwest. Proc. 8th N. Amer. Blueberry Res. Ext. Work. Conf. Wilmington, N.C., 27-29 May.
- Ferree, D.C. and F.R. Hall. 1980. Canopy development, light and spray penetration in Golden Delicious trees in four management systems. Acta Hort. 114:91-99.
- Gough, R.E., V.G. Shutak, and R.L. Hauke. 1978. Growth and development of highbush blueberry. I. Vegetative growth. J. Amer. Soc. Hort. Sci. 103:94-97.
- Hall, F.R. 1991. Influence of canopy geometry in spray deposition and IPM. Hort Science 26:1012-1017.
- Hanson, E., J. Hancock, D. Ramsdell, A. Schilder, G. VanEe, and R. Ledebuhr. 1999. Sprayer type and pruning affect the incidence of blueberry fruit rots. Hort Science (in press).
- Hartung, J.S., C.L. Burton, and D.C. Ramsdell. 1981. Epidemiological studies of blueberry anthracnose disease caused by *Colletotrichum gloeosporioides*. Phytopathology 71:449-453.
- Hoffman, W.C. and M. Salyani. 1996. Spray deposition on citrus canopies under different meteorological conditions. Trans. Amer. Soc. Agr. Eng. 39:17-22.
- Kirk, I.W., L.F. Bouse, J.B. Carlton, E. Franz, and R.A. Stermer. 1992. Aerial spray deposition in cotton. Trans. Amer. Soc. Agr. Eng. 35:1393-1399.
- Ramsdell, D.C. 1989. Blueberry diseases in Michigan. Mich. State Univ. Ext. Bul. E-1731.
- Ramsdell, D.C. 1992. Nematode and disease management, p. 76-94. In: M.P. Pritts and J.F. Hancock (eds.). Highbush blueberry production guide. Northeast Reg. Agr. Eng. Serv., Cornell Univ., Ithaca, N.Y.
- Siefker, J.A. and J.F. Hancock. 1987. Pruning effects on productivity and vegetative growth in the highbush blueberry. Hort Science 22:210-211.
- U.S. Department of Agriculture, National Agricultural Statistics Service. 1998. Agricultural chemical usage 1997 fruits summary. Bul. Agr. Chem. 1(98).