Honey Bee Activity in Northern Highbush Blueberry Differs across Growing Regions in Washington State

Lisa W. DeVetter1,5
Department of Horticulture, Washington State University, Northwestern Washington Research and Extension Center, 16650 State Route 536, Mount Vernon, WA 98273

Sean Watkinson2
Washington State University, Northwestern Washington Research and Extension Center, 16650 State Route 536, Mount Vernon, WA 98273

Ramesh Sagili3
Department of Horticulture, Oregon State University, 4017 Ag and Life Sciences Building, Corvallis, OR 97331

Timothy Lawrence4
Washington State University Extension Agriculture and Natural Resources, P.O. Box 5000, Coupeville, WA 98239

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Abstract. Commercial production of northern highbush blueberry (Vaccinium corymbosum) is dependent upon rented colonies of honey bees (Apis mellifera) for meeting pollination requirements. Despite the prevalent use of honey bees, growers in Washington State and the greater Pacific Northwest (PNW), particularly those located in the western regions, claim pollination is limited and yield potential is subsequently reduced due to pollination deficits. However, there have been no studies or surveys that document this occurrence for this economically important region of blueberry production. The objective of this study was to survey honey bee activity in commercial plantings of ‘Duke’ highbush blueberry in western and eastern Washington and to assess the relationship between honey bee activity, growing region, and select yield components. Honey bee colony strength was also assessed to evaluate this variable’s relationship to honey bee activity and measured yield components. Sixteen and 18 commercial ‘Duke’ blueberry fields across Washington State were surveyed in 2014 and 2015, respectively. Average number of honey bee visitations per plant and honey bee colony strength were determined to evaluate overall honey bee activity. Estimated yield, berry number per plant, berry size (mass), and seed number per berry were also determined and analyzed to determine their relationship to honey bee activity through regression analysis. Honey bee visitation rates differed between western and eastern Washington, with western Washington sites consistently below recommended honey bee densities. Colony strength was also below recommended levels, but was lower for western Washington relative to eastern Washington. Estimated yield and berry number differed across sites and years, but were not related to honey bee visitation rates. Regression analysis revealed few significant relationships, although honey bee visitation rates were positively related to seed number per berry and seed number was positively related to berry size ($R^2 = 0.25$ and 0.16, respectively). Berry size was also positively related to colony strength ($R^2 = 0.63$). This study demonstrates that honey bee activity is limited in Washington blueberry production, particularly in western Washington, when compared with recommendations for optimal honey bee activity in blueberry. However, yields were unaffected between the compared regions. The lack of a relationship between honey bee visitation rates and yields suggests that pollination is sufficient for ‘Duke’ blueberry in Washington State and pollination deficits do not limit yield for this cultivar under the conditions of the study.

Commercial production of northern highbush blueberry (Vaccinium corymbosum) is concentrated in the PNW, which includes Washington State, Oregon, and British Columbia. Washington State is the leading national producer, representing ~18.6% (4452 ha) of total national cultivated blueberry production in the United States of America in 2015 (NASS, 2016). Despite the significance of the industry, production is reportedly limited by pollination deficits, particularly in western Washington (Washington Highbush Blueberry Commission, personal communication). Effective pollination is essential for optimal fruit set and large berry size in most commercial cultivars of northern highbush blueberry and is insect mediated (MacKenzie, 1997). Several tactics have been employed in the past to enhance bee pollination in crops including blueberry, where environmental conditions are often suboptimal during bloom or the crop is not attractive to bees (Sagili et al., 2015). Most of the blueberry plantings in Washington and elsewhere employ honey bees (Apis mellifera ligustica) for pollination, which are rented from commercial beekeepers and placed and fields at ~5% bloom. These rented colonies are particularly valuable for large plantings given native bee populations and their pollination contributions are relatively low (Isaacs and Kirk, 2010).

Blueberry flowers primarily exhibit protandry, whereby flowers release pollen before stigmas are receptive (Vander Kloet, 1988). Receptivity of flowers to pollination is related to flower age, with receptivity typically limited to 5 d after anthesis (Merrill, 1936; Moore, 1964). These features limit the effective pollination period of blueberry. Pollination and fruit set may be further constrained in Washington due to unfavorable weather conditions that limit pollinator activity. Tuell and Isaacs (2010) demonstrated that foraging activity of honey bees was reduced in Michigan-grown blueberry during poor weather. Honey bee flight and foraging activity begins between 12 and 14 °C, which is frequently not achieved during the typical cool, wet springs in western Washington and the greater PNW (Winston, 1987). Additionally, high wind velocities can further reduce honey bee activity. Pollination declines over time due to poor health of both domestic and wild pollinators is also suspected to contribute to pollination deficits in blueberry. As reviewed by Potts et al. (2010), pollinator health and subsequent crop pollination declines are likely due to an array of integrated and interacting factors, including pests and pathogens [e.g., ectoparasitic varroa mites (Varroa destructor)], malnutrition, loss of habitat, decreasing genetic diversity, improper pesticide use in both hives and fields, and climate change.

Research on promoting pollination within highbush blueberry and the variable environmental conditions in which they are produced is limited. Pritts and Hançöök (1992) recommended stocking densities of 0.2 to 0.8 healthy honey bee colonies per hectare in northeastern United States. Recommendations from research performed in Oregon range from 0.2 to 1.2 healthy colonies per hectare (Sagili and Burgett, 2011; Strik et al., 2006). In Washington, we have observed stocking densities ranging from 0.4 to 3.2 hives per hectare within a given cultivar. This wide range across farms reflects uncertainty in pollinator management and appears to be the result of a lack of adequate research-based information in formulating recommendations for optimizing pollination. Recommended stocking densities should vary based on cultivar, which differ in their degree of self-incompatibility, attractiveness to pollinators, and flower morphology (Courcelles et al., 2013; MacKenzie, 1997; Strik et al., 2006). Very little is known about cultivar-based honey bee stocking densities.
Investigating and developing a comprehensive understanding of the factors limiting pollination and fruit development would be beneficial to the blueberry industry in Washington and the PNW region in general, as it seeks to overcome these limitations and improve yields. The objective of this study was to survey honey bee activity in commercial plantings of ‘Duke’ highbush blueberry in western and eastern Washington and to assess the relationship between honey bee activity, growing region, and select yield components. Additionally, we also surveyed honey bee colony strength to monitor this variable’s relationship to honey bee activity and measured yield components. Documentation and knowledge of honey bee activity, colony strength, and potential pollination limitations would enable blueberry growers to work with researchers and other entities to refine their approaches to enhance pollination, as well as overall crop yields.

Materials and Methods

Data collection occurred within 16 and 18 commercial grower sites in 2014 and 2015, respectively. All sites included in this study had established ‘Duke’ plants (about 6 years old or older), although the size of the plants themselves varied across sites. Sites were distributed across Washington State and were classified as western or eastern sites depending on whether they resided west or east of the Cascade Range. The reason for this distinction is because of the climatological differences created by the mountain range, which results in different climate, soils, and production practices (DeVetter et al., 2015). Sites were assigned an identification number and this identification was maintained throughout the project. All sites included in the study were a minimum of 3.2 km apart from one another, which helped maintain independence in data collection by ensuring the majority of honey bees being observed were from the hives placed on the specific grower plots. Colony strength was evaluated concurrent to measures of honey bee activity at each site. These data were collected by enumerating the number of honey bees entering their colony within 1-min intervals, repeated twice per day for 2 d in 2014 and five times per day for 3 d in 2015. These data were video-recorded so that accuracy could be later verified.

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Assistant Professor.
Scientific Assistant.
County Director of Island County and Apiculturist.
Corresponding author. E-mail: lisa.devetter@wsu.edu.
Table 1. Regional effects on honey bee visitation rates, hive strength, estimated yield, berry size, and seed number in Washington blueberry fields, 2014–15. Site location was determined by their relative location east or west of the Cascade Range.

| Location | Avg no. honey bee visits/min | Avg no. honey bees entering a hive/min | Yield (kg/plant) | Berry size (g) | Avg seed no/berry |
|----------|-----------------------------|---------------------------------------|------------------|---------------|------------------|
| Location | 2014–15 | 2014 | 2015 | 2014 | 2015 | 2014–15 | 2014 | 2015 | 2014–15 |
| East     | 5.7 ± 0.7 a' | 65 ± 5.3 a | 27 ± 2.7 a | 5.2 ± 1.2 | 4.5 ± 1.1 | 2.02 ± 0.1 a | 1.04 ± 0.1 | 31.1 ± 1.5 a |
| West     | 1.2 ± 0.2 b | 46 ± 3.6 b | 6 ± 1.1 b | 6.2 ± 1.4 | 3.9 ± 0.6 | 1.84 ± 0.1 b | 1.00 ± 0.1 | 21.3 ± 1.0 b |

Significance: NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, $0.01$, or $0.001$, respectively.

Values are means and standard errors (SE); means with the same letter within a column are not different at $P \leq 0.05$ using Duncan’s multiple range test; means were combined across both years when analyses revealed no significant interaction due to year.

NS * ** *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Results and Discussion

Honey bee visitation rates differed among sites and regions (i.e., eastern vs. western Washington), but there was no year effect (Fig. 1; Table 1). Honey bee visitation rates were consistently greater in eastern Washington relative to western Washington (Table 1). Western Washington honey bee visitation rates were consistently below the recommendation of 4 to 8 honey bees per bush during the warmest part of the day, whereas sites in eastern Washington on average fell within this recommended range (Isaacs et al., 2014). Honey bee colony strength, which was measured as the average number of honey bees entering a hive per minute, was greater in 2014 compared with 2015 and greater in eastern Washington relative to western Washington (Table 1). Despite regional differences, none of the sites met the recommendation of having 100 or more bees enter a hive per minute, indicating colony strength was not optimal according to current guidelines (Fig. 2; Sagili and Burgett, 2011).

Estimated yield was greater in 2014 relative to 2015, with the greater yield being attributed to greater average berry size, despite berry number being higher in 2015 (Table 1; Figs. 3–5). We observed very high yields at Site 10 in 2014, which was attributed to the large size of the plants (Fig. 4). Minimal pruning also likely impacted yield of these plants between years, as unpruned or minimally pruned plants can be induced

Previous reports have indicated that good pollinating colonies have uniform flight and ≈100 or more bees return to their colonies per minute when temperatures are 18 °C or above (Sagili and Burgett, 2011).

Select yield components, including berry number, berry size, and estimated yield per bush were measured to evaluate the effects of honey bee activity on blueberry productivity across the sites and years. Average seed number per berry was also determined from a sample of 30 berries per transect (90 berries per site), as number of healthy, fertile berries per site), as number of healthy, fertile berries per plant (cane number per plant). Evaluation of potential pollination efficiency was accomplished by using the equation: Berry number per plant = (cane number per plant) × (number of flower clusters per cane) × (average berry number per cluster). Note that the number of fruiting clusters per cane was determined from one randomly selected cane per bush and average berry number per cluster was determined by taking the average of two randomly selected clusters for one cane. Yield per bush was subsequently estimated by using the following formula: Estimated yield = (berry number per bush) × (average berry weight). Average berry weight was determined from a sample of 30 berries randomly collected from the study sites immediately before the first harvest. Sampling berries before the first picking has the potential to overestimate average berry weight, as berries from the first harvest tend to be larger than berries from subsequent harvests, but was a constraint of the experiment due to geography and grower harvest schedules.

Data were first evaluated for normality and homogeneity of variance before being analyzed using analysis of variance. Instances of unequal variance were corrected by taking a log transformation of the response variable. All data presented are reported in their original units. Means were combined when analyses revealed no significant interaction due to year. Modeling and analysis of the data were performed using R Studio (R Studio Team, 2015). Tests of significance were done at $P \leq 0.05$ using a least significant differences option with a Duncan’s test for multiple comparisons. Tests of individual variables’ relationship to yield components were assessed by examination of the coefficient of determination ($R^2$). Individual variables were considered significant at $P \leq 0.05$. 

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![Fig. 2. Average number of honey bees entering a colony per minute in eastern and western Washington blueberry fields, 2014 to 2015. Sites 1 to 6 were located in eastern Washington, whereas sites 7 to 18 were located in western Washington. No data were collected from sites 17 and 18 in 2014 or site 12 in 2015. Bars represent standard error.](image-url)
to bear biennially (Siefker and Hancock, 1987). Despite this, our results for the study were consistent whether Site 10 was included or excluded in the analyses. No regional effects were detected for berry number nor estimated yield (Table 1) and overall estimated yield was not related to honey bee visitation rates ($R^2 = 0.03$). As previously indicated, berries sampled for this project were on average larger in 2014 relative to 2015. Berry size was also greater in eastern Washington compared with western Washington, which may be attributed to differences in climate between the two regions. Additionally, these data demonstrate the plasticity of 'Duke', even under conditions less conducive to honey bee activity relative to western Washington, as honey bees tend to be more active at higher temperatures combined with low rainfall and, as a consequence, have established systems of irrigation and evaporative cooling. Solar radiation from 1 Apr. to 31 May was greater in 2015 in western Washington, 14.7 and 18.3 °C, respectively, whereas in 2015 they were 14.6 and 18.2 °C, respectively. Precipitation during the pollination period in western and eastern Washington in 2014 were 14.6 and 18.2 °C, respectively, whereas in 2015 they were 14.7 and 18.3 °C, respectively. Precipitation differed across regions and the two seasons, with a drought experienced in western Washington in the 2015 season. Total precipitation during the pollination periods in western Washington was 172 and 42 mm in 2014 and 2015, respectively. Precipitation was 30 and 45 mm in 2014 and 2015, respectively, in eastern Washington. Eastern Washington growers are more accustomed to high temperatures combined with low precipitation and, as a consequence, have established systems of irrigation and evaporative cooling. Solar radiation from 1 Apr. to 31 May was greater in 2015 in western Washington, 14.7 and 18.3 °C, respectively, whereas in 2015 they were 14.6 and 18.2 °C, respectively. Precipitation during the pollination period in western and eastern Washington in 2014 were 14.6 and 18.2 °C, respectively, whereas in 2015 they were 14.7 and 18.3 °C, respectively. Precipitation differed across regions and the two seasons, with a drought experienced in western Washington in the 2015 season. Total precipitation during the pollination periods in western Washington was 172 and 42 mm in 2014 and 2015, respectively. Precipitation was 30 and 45 mm in 2014 and 2015, respectively, in eastern Washington. Eastern Washington growers are more accustomed to high temperatures combined with low rainfall and, as a consequence, have established systems of irrigation and evaporative cooling. Solar radiation from 1 Apr. to 31 May was greater in 2015 in western Washington, averaging 218 W/m$^2$ compared with 192 W/m$^2$ in 2014. Average solar radiation in eastern Washington did not differ across the 2 years and averaged 260 W/m$^2$. These environmental variables demonstrate the differences in climate between the two regions. Additionally, these data demonstrate that eastern Washington is environmentally more conducive to honey bee activity relative to western Washington, as honey bees tend to be more active at higher temperatures and only begin foraging between 12 and 14 °C (Winston, 1987). Although precipitation was greatly reduced in 2015 for western Washington, honey bee visitation rates were not influenced by the year and this is likely due to temperatures still being too low for optimal honey bee activity in this region.

Regression analyses indicated that seed number per berry was positively related to colony strength (Table 1).

Regression analyses showed few other statistically significant relationships. No relationships were found between hive stocking strength (data not presented). Berry size was positively related to colony strength ($R^2 = 0.63$), indicating that a stronger and more active hive can increase berry size through enhanced pollination. Berry size also demonstrated a weak, but positive relationship with seed number ($R^2 = 0.16$). This relationship varies by cultivar, as some cultivars of highbush blueberry are more parthenocarpic than other cultivars (Ehlenfeldt and Vorsa, 2007). 'Duke', for example, can produce large berries even if fertilization and seed development is low (Ehlenfeldt and Martin, 2010). The high berry sizing capacity and plasticity of 'Duke', even under conditions of low pollination and fertilization, may partially explain why few differences in yield components were observed in our study. Despite our findings, provision of pollinators is still important for fruit set and berry development in blueberry, particularly for cultivars that have a greater seed set requirement for berry development.

Weather data indicated that the two regions and pollination periods differed with respect to temperature, precipitation, and solar radiation. Temperature varied less across the years, but differed by region. The average temperatures during the pollination period in western and eastern Washington in 2014 were 14.6 and 18.2 °C, respectively, whereas in 2015 they were 14.7 and 18.3 °C, respectively. Precipitation differed across regions and the two seasons, with a drought experienced in western Washington in the 2015 season. Total precipitation during the pollination periods in western Washington was 172 and 42 mm in 2014 and 2015, respectively. Precipitation was 30 and 45 mm in 2014 and 2015, respectively, in eastern Washington. Eastern Washington growers are more accustomed to high temperatures combined with low rainfall and, as a consequence, have established systems of irrigation and evaporative cooling. Solar radiation from 1 Apr. to 31 May was greater in 2015 in western Washington, averaging 218 W/m$^2$ compared with 192 W/m$^2$ in 2014. Average solar radiation in eastern Washington did not differ across the 2 years and averaged 260 W/m$^2$. These environmental variables demonstrate the differences in climate between the two regions. Additionally, these data demonstrate that eastern Washington is environmentally more conducive to honey bee activity relative to western Washington, as honey bees tend to be more active at higher temperatures and only begin foraging between 12 and 14 °C (Winston, 1987). Although precipitation was greatly reduced in 2015 for western Washington, honey bee visitation rates were not influenced by the year and this is likely due to temperatures still being too low for optimal honey bee activity in this region.

Fig. 3. Estimated average number of berries per bush in eastern and western Washington blueberry fields, 2014 to 2015. Sites 1 to 6 were located in eastern Washington, whereas sites 7 to 18 were located in western Washington. No data were collected from sites 17 and 18 in 2014 or site 12 in 2015. Bars represent standard error.

Fig. 4. Estimated yield in eastern and western Washington blueberry fields, 2014 to 2015. Sites 1 to 6 were located in eastern Washington, whereas sites 7 to 18 were located in western Washington. No data were collected from sites 17 and 18 in 2014 or site 12 in 2015. Bars represent standard error.
Washington exhibited the greatest number of deficits with regard to honey bee visitation rates and colony strength, which may contribute to reduced seed number per berry and berry size (Table 1). Differences in honey bee visitation rates may also influence yield, which is characteristically lower in western vs. eastern Washington (DeVetter et al., 2015). However, estimated yield of ‘Duke’ did not differ between the regions during the years in which the study was conducted and the relationship between honey bee visitation rates and yield was found to be insignificant. These findings indicate that pollination may, in fact, not be a yield limiting factor for ‘Duke’ grown in western Washington. Other source-sink, climactic, and management factors may be responsible for the regional yield differences observed in other studies (Brady et al., 2015; DeVetter et al., 2015). Pollination deficits may still be an issue for other cultivars of blueberry that have a higher pollination requirement for berry development or are less appealing to pollinators. To better understand and overcome potential pollination deficits in blueberry, future research investigating stocking densities of honey bees and augmentation with alternative pollinators, including native bumble bee (Bombus spp.) species, should be explored with honey bee pheromones to stimulate honey bee foraging and enhance pollination (Sagili et al., 2015). These practices and their potential utility should be further explored through research.

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