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In-field sensing for crop protection: Efficacy of air-blast sprayer generated crosswind in rainwater removal from cherry canopies

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ABSTRACT

Rainwater-induced fruit cracking leads to serious economic loss to fresh market sweet cherry growers. To prevent fruit cracking, the key is timely and effective removal of rainwater from canopies during and after rain events. Current rainwater removal methods include use of orchard air-blast crosswind and manned helicopter downwash based on empirical judgement of growers. The goal of this study was to develop an in-field sensing system to monitor canopy wetness and micro-climate, which will help growers to decide upon when and how much rainwater needs to be removed from canopies. The developed sensing system was tested to evaluate the efficacy of an air-blast orchard sprayer in rainwater removal from cherry trees with Y-trellised (Skeena) and vertical (Selah) architectures. Results show that the sensing system could capture the wetness threshold rainfall level that may cause fruit cracking (2.5 mm). Crosswind generated by the orchard sprayer was unevenly distributed on tree canopies, especially in vertical architecture, where crosswind velocity in bottom-section of canopies (1.1 m above ground) was significantly higher than that in middle- (1.9 m) and top-sections (2.7 m). Overall, orchard sprayer crosswind had the highest rainwater removal than natural drying (control) in both architectures. Rainwater removal was significantly affected by rainfall levels studied, with significantly higher in lower rain level (2.5 mm) than those of medium (5.0 mm) and high level (10 mm) from vertical tree canopies. Also, in vertical architecture, the interaction effect of travel speed and location was significant on rainwater removal, and the rainwater removal due to crosswind at any travel seed was significantly higher than that of control at middle section of vertical tree canopies.

1. Introduction

Sweet cherry (*Prunus avium* L.) is a high value tree fruit crop. In Washington State of U.S., there are 14,164 ha of sweet cherry trees with a production volume of 252,000 tons, accounting for approximately 66% of the total U.S. production as of 2014 (USDA-NASS, 2015). However, the marketability of fresh market sweet cherry due to fruit cracking (or splitting) during production and post-harvest has been a major concern to the growers. Crop losses induced by fruit cracking could be 63% of total harvest in some varieties (Cline et al., 1995).

The key hypothesis on the causes of cherry fruit cracking during last few weeks prior to harvest is the excessive water uptake by the maturing fruit through either tree roots or fruit cuticle (Simon, 2006). Rainwater induced mechanical stress on fruit cuticle and resulting fruit core-cuticle interface changes are related to fruit cracking (Considine and Brown, 1981). Existing fruit cracking prevention solutions from rainfall include use of canopy covers, chemical applications, and mechanical methods of rainwater removal. Børve et al. (2003) studied the effectiveness of canopy covers and reported that covers improved marketability of the fruit from 54% on uncovered to 89% on covered trees in a two-years research. Thomidis and Exadaktylou (2013) studied effect of a plastic rain shield on fruit cracking. Such rain shield effectively

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reduced up to 38% of cracking in the cracking-susceptible sweet cherry varieties of Lapin, Germesdorfi, and Van. However, covered cherry trees had a higher incidence of 'Shot Hole', one of the most important foliar diseases of cherry trees. Additionally, canopy cover installation, operation, and recycling of used materials was labor-intensive and costly, limiting large-scale applicability (Meland et al., 2014). Besides canopy covers, methods of spraying cherry fruits with minerals or chemicals have been widely used in the U.S. Spraying fruit with $CaCl_2$ or similar mineral compounds can effectively delay or reduce the amount of water uptake into the fruit, and increase the transpiration of rainwater from the fruit surface (Simon, 2006). However, multiple spray applications needed to keep the fruit protected (Kafle et al., 2016) and an unsightly fruit appearance caused by the spray residue (Jedlow and Schrader, 2005) are some of the challenges associated with mineral spray applications.

Another promising method to prevent fruit cracking is to remove rainwater as soon as possible after a rain event using crosswind air-blast of orchard sprayers and/or helicopter downwash (Jedlow and Schrader, 2005). Manned helicopters flying 3.0–6.0 m (10–20 feet) above tree canopies at the speed of 8.0–16.1 km h^{-1} (5–10 mph) can generate sufficient downwash and blow rainwater off fruits and leaves (Pihl, 2012). Similarly, the air-blast orchard sprayers driven in orchard alleys to shake the canopies after rainfall can also remove or disperse rainwater. Rainwater removal from canopies using mechanical approach can reduce the effects of physical exclusion or spraying of fruits. However, low flying altitude and resulting downwash of helicopter can cause damage to fruits. The low-altitude manned helicopter flights may also cause serious injury, even death, to pilots. For example, four helicopters were crashed and four pilots died during 2010–2014 only in central area of Washington State (Wheat, 2014).

Therefore, there is a need to critically evaluate the efficacy of mechanical rainwater removal techniques so that growers can make informed decision on appropriateness of the technique to suit pertinent situation (e.g. varied canopy wetness due to varied rainfall levels). No research exists on this aspect, mainly due to lack of appropriate sensing tools to evaluate the efficacy of the rainwater removal techniques. The overall focus of this study was to develop an in-field sensing system that could provide real-time micro-climate information to growers/farm managers, leading towards better decision making in terms of canopy rainwater removal and crop loss management. The specific objectives of presented research were 1) to quantify the velocity of the crosswind generated by an air-blast orchard sprayer within tree canopies using an in-field sensing system, and 2) to evaluate the efficacy of the crosswind in rainwater removal from cherry tree canopies with different architectures.

2. Materials and methods

2.1. Experimental orchard and in-field sensing system

Field experiments were conducted at Washington State University's Roza experimental orchard near Prosser, WA, USA. Two varieties of sweet cherry (*Prunus avium* L.) with two canopy architectures were used in this study, specifically 'Skeena' variety with Y-trellised fruiting wall canopy (termed as Y-trellised architecture henceforth, Fig. 1a) and 'Selah' variety with vertical fruiting wall canopy (termed as vertical architecture henceforth, Fig. 1b). Y-trellised cherry trees were planted on Gisela® 6 root stock at around 7 years ago with the inter- and intra-row spacing of 4.6 and 0.9 m, respectively. Approximate eight branches of each tree were trained to grow at both sides of the row with an angle of 55° to ground level. The average height of the trees is approximate 4.0 m above ground level. Vertical architecture trees also grow on the Gisela® 6 root stock planted approximately 10 years ago. The inter- and intra-spacing was 3.0 and 2.4 m, respectively. All branches grow vertically to the ground with the maximum canopy height of 4.2 m. The experiments were conducted at the cherry growth stage (BBCH stage) of 85–87 (Fadón et al., 2015), which was prior to the commercial harvesting window on 18–19 June 2015.

The micro-climate information within tree canopies, including wetness level, wind velocity, temperature and humidity, was measured using a custom designed in-field sensing system developed by our research group, which is illustrated in Fig. 2. The sensing system was developed based on a data logger (CR1000, Campbell Scientific, Logan, Utah, USA), which consisted of an on-board controller (processor), memory and clock to make it work as an independent system. The data logger was able to collect analogue and digital signal from multiple types of sensors, including leaf wetness sensor (LWS, Decagon Device, Pullman, WA, USA), sonic anemometer (DS-2, Decagon Devices, Pullman, WA, USA), and temperature and humidity sensor (VP-3, Decagon Devices, Pullman, WA, USA). In the system, leaf wetness sensors (LWSs) were used to quantify the wetness of tree canopies by measuring the dielectric constant of the sensor upper surface, which is sensitive to moisture level. Integrated with conditioning circuits, the output voltage of a LWS is proportional to the surface wetness (LWS Operation Manual, 2014). As shown in Fig. 2a, all LWSs were connected to different analogue inputs of the data logger, and excitation voltage of LWSs was provided by the data

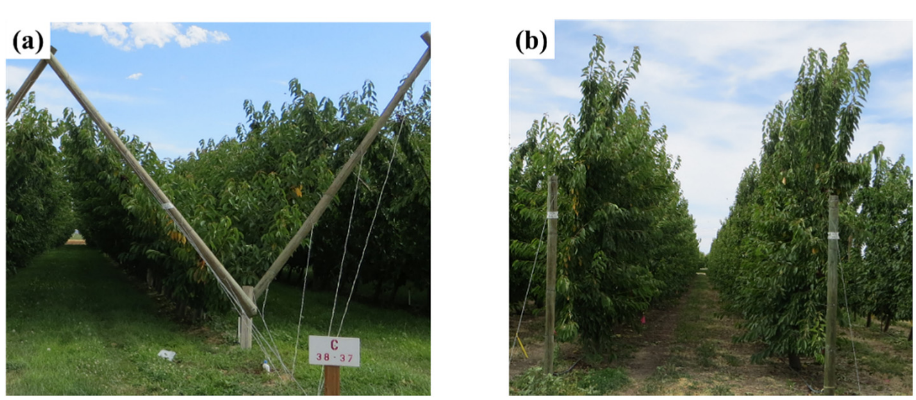

Fig. 1. The canopy architectures of the cherry trees used in this research. (a) "Skeena" cherry trees trained as Y-trellised canopy architecture have three to five branches in each side at 55° to the ground level and (b) "Selah" cherry trees trained as vertical canopy architecture have branches growing vertically.