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Tree-row-volume-based sprays of copper bactericide for control of citrus canker

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ABSTRACT

Commonly, pre-determined copper spray volumes are indiscriminately applied to citrus orchards of different ages and sizes for control of citrus canker (*Xanthomonas citri* subsp. *citri*) leading to a waste of resources, such as water, energy, and chemicals. This study evaluated the effectiveness of copper applied following the tree-row-volume (TRV) methodology for control of citrus canker on sweet orange trees. Treatment design was based on the theoretical runoff volumes previously determined for the exterior and interior of a citrus tree. The volumes 150 (standard), 100 (internal runoff point), 70 (intermediate) and 40 mL (external runoff point) of spray mixture/m^3 of tree canopy were tested at the standard copper rate of 0.525 g metallic copper/L. Additionally, 70 and 40 mL/m^3 were also tested with copper rate correction by leveling up the theoretical deposition of copper bactericide to that obtained with 100 mL/m^3.

Untreated control trees (UTC) were not sprayed with copper. Reduction of the spray volume did not affect disease control. While UTC trees presented a peak incidence of citrus canker on leaves of 30% in both years, copper-treated trees showed significantly lower peak incidences of 5–10%. Likewise, the average number of dropped fruits with citrus canker for the UTC was 2.0- to 1.5-fold higher than for copper treatments. At harvest, 30% of fruits from the UTC trees showed citrus canker symptoms. Conversely, only 3.3–9.8% of the fruits from the copper treatments were symptomatic. Moreover, using 40 mL/m^3 without adjusting the amount of metallic copper diminished disease control efficiency on leaves. Reduction of spray costs and water needs amounted to 40 and 73%, respectively. In addition to keeping effectiveness of disease control and being more environmentally friendly, the adaptation of the spray volumes and copper rates to the TRV may contribute to reducing production costs.

1. Introduction

Application of copper-based bactericides is the main measure for the chemical control of citrus canker (*Xanthomonas citri* subsp. *citri*) in regions where this disease is endemic. Sprays are usually performed in spring and summer when young and susceptible tree tissues develop, and the climatic conditions are favorable to the pathogen (Behlau et al., 2010; Gottwald et al., 2002; Leite and Mohan, 1990). These chemicals are intended to protect developing sprouts and fruits, which have unprotected tissues due to continuous expansion (Albrigo et al., 1997; Timmer, 1988). Therefore, this disease is controlled following the first deposition of copper on leaves and fruits and then through the maintenance of this protective layer through frequent applications that are carried out while the tree tissue develops (Albrigo et al., 1997).

The role of these bactericides is strictly preventive. They do not cure the disease or have any systemic activity in trees. Fixed or insoluble copper, such as copper hydroxide, copper oxychloride, or cuprous oxide are the most commonly used forms in sprays, which aim to form a film on tree tissues and from which copper ions are slowly released. The concentration of metal ions on the tree surface depends on the equilibrium between complexed and soluble forms of copper (Menkissoglu and Lindow, 1991). These characteristics reduce the risk of phytotoxicity and increase the residual activity of the pesticide (Menkissoglu and Lindow, 1991). The fixed copper

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film act as a reservoir, from which copper ions that are toxic to bacteria are gradually released under conditions of low pH at the tree surface due the presence of acidic exudates of the tree itself or microorganisms and rainfall (Arman and Wain, 1958; Gadd and Griffiths, 1978; Zevenhuizen et al., 1979).

The use of copper bactericides to control citrus canker is essential. Nonetheless, copper sprays are complementary and should not be used as a standalone measure (Leite and Mohan, 1990). Moreover, its appropriate use does not necessarily guarantee disease control. When the environmental conditions are highly favorable for bacterial infection (rain associated with gusty winds), citrus canker may lead to substantial yield losses by the premature drop of symptomatic fruits even upon successive applications of this bactericide (Behlau et al., 2008, 2010; Graham et al., 2010, 2011). Besides the limited effectiveness, the excessive use of this product, usually associated with excessive spray volumes, can also lead to environmental pollution and phytotoxicity caused by the accumulation of copper in the soil over years, which may affect the development of tree roots (Alva et al., 1995). Another problem caused by the excessive and prolonged use of copper bactericides is the risk for *X. citri* subsp. *citri* to develop copper resistance, which has already occurred in Argentina (Behlau et al., 2011, 2012; Canteros, 1999). With all the above, it is reasonable for sustaining this measure as a key component of the disease management program and for reducing its impact on environment that the amount of the metal deposited on orchards be optimized without compromising the quality of disease control.

In citrus, it is common to use pre-determined volumes, which are indiscriminately applied to orchards of different ages and sizes and lead to a waste of resources, such as water, energy, and chemicals. However, as a perennial tree crop, the determination of the spray volume should be based on the volume of the tree canopy or the tree-row-volume (TRV) to be treated per hectare (Gil and Escolà, 2009; Pergher and Petris, 2008; Ruegg et al., 1999; Sánchez-Hermosilla et al., 2013; Siegfrieda et al., 2007; Sutton and Unrath, 1984, 1988), taking into account factors such as target to be reached, equipment, time of application, and overall environmental conditions (Joyce and Parkin, 1977; Matthews, 1992; Ramos et al., 2007). If these factors are not observed, the consequences may vary from ineffective control of pests and diseases due to insufficient spray volumes, to loss of chemical and water due to drift and runoff caused by excessive volumes. TRV is a simple and objective method used to determine the canopy volume in a hectare of orchard that can be applied to crops with different row spacing, tree sizes, ages, and other factors. TRV can be calculated by multiplying the following parameters: (1) tree average height in m, (2) tree average width in m, and (3) row length per hectare in m, which is determined by dividing 10,000 m^2 by the distance between rows in m (Sutton and Unrath, 1984).

Besides assessing disease or pest control, coverage and deposition should be complementarily evaluated when adjusting spray volumes. Coverage refers to the area of the tree tissue that is effectively reached by the spray mixture, and is determined by the number of spray drops per unit area or the percentage of the target area covered by the spray (Carvalho and Furlani Junior, 1997). In general, pesticides that present low or no redistribution capacity, such as fixed copper-based bactericides, require better target coverage, whereas systemic products are effective under conditions of lower coverage (Delgado, 1999). The coverage increases with spray volume until runoff point is reached ($\approx$100% of the treated surface is covered). From this point on, increasing the spray volume results in losses due to runoff. Conversely, it is possible to maintain quality of control by using a coverage that is below the runoff point, which can be achieved by applying reduced spray volumes associated with small droplets (100–200 μm) uniformly distributed over the target area (Matthews, 1992; Silveira et al., 2006). The deposition corresponds to the amount of active ingredient transferred to the treated tree surface (Carvalho and Furlani Junior, 1997). For spray mixtures at the same concentration, application of pesticides at volumes below the runoff point lead to decreased deposition, but not necessarily to decreased quality of pest or disease control (Hoffmann and Salyani, 1996; Salyani, 1994). On the other hand, deposition can be increased only up to the runoff point, after which the accumulation of the active ingredient on the tree is constant and waste of water and chemical to the ground starts to occur (Cunningham and Harden, 1998).

In citrus and other crops of commercial and economic interests, studies that seek to adapt different factors to reduce the costs and environmental impact of chemical treatments are of great importance. The effectiveness of using copper-based bactericides to reduce citrus canker on leaves and fruits has been widely proven (Behlau et al., 2008, 2010; Graham et at., 2010, 2011; Stein et al., 2007). However, in all of the studies the copper amount was based on fixed rates per area to be treated (e.g. kg metallic copper/ha) or fixed volume of water (e.g. g metallic copper/liter of water or/tank). These methods neglect tree size and spray volume per tree. None of these studies consider the TRV to be sprayed in order to standardize the application. TRV-based sprays allow for the rates to be adapted for use in a wide range of orchards, thus avoiding the waste of water and chemicals and maintaining the level of pesticide residue within pre-established limits (Rüegg et al., 1999; Rüegg and Viret, 1999). Thus, the aim of this study was to evaluate for the first time, the volume of copper mixtures required for the control of citrus canker based on the TRV. Moreover, product deposition, leaf coverage, and cost-effectiveness provided by the different treatments tested were also evaluated.

2. Materials and methods

2.1. Experimental area

The study was carried out during the seasons of 2012/2013 (trial 1) and 2013/2014 (trial 2) in a commercial citrus orchard planted in 2006 in the municipality of Paranavaí, State of Paraná, Brazil (22°59′34″ S, 52°36′23″ W, altitude: 503 m a.s.l.). The grove was composed of sweet orange Valencia (*Citrus sinensis*) grafted on Rangpur lime (*Citrus limonia*) with 416 trees per hectare.

2.2. Determination of tree-row-volume

The TRV/ha of the experimental area was calculated by dividing the area of 1 ha (in m^2) by the tree row spacing (in m) and multiplying by the average canopy height (in m) and width (in m). The average tree height and width was obtained by random measurement of 10% of trees in the experimental area. Based on the row distance of 6.5 m, height of 3.6 m, and depth of 3.7 m, the calculated TRV for the studied grove was 20,492 m^3/ha (49.3 m^3/tree). The TRV was constant in the two experiments due to orchard pruning carried out on the top and laterally along the trees in June 2013.

2.3. Treatments

Treatment design was based on the theoretical runoff points previously determined for the exterior and interior of a citrus tree (Ramos, H.H. et al., unpublished results) and the correction of the copper rates for the reduced volumes. The experiments were composed of seven treatments: (i) 150 mL of spray mixture/m^3 of tree canopy, which corresponds to approximately 3000 L/ha and was the standard volume applied by citrus growers in the region where the test was carried out; (ii) 100 mL/m^3, the internal runoff