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Spray volume and fungicide rates for citrus black spot control based on tree canopy volume

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ABSTRACT

The control of citrus black spot (CBS) caused by *Phyllosticta citricarpa* relies mainly on fungicide sprays. Generally, high and non-standardized spray volumes are adopted and the sprays are based on litre per tree or per hectare. However, the tree canopy volume may vary with age, density and variety, and this is expected to impact on the spray volume and fungicide rates needed for disease control. This study evaluated the efficacy of different fungicide spray volumes and rates for CBS control based on the tree-row-volume (TRV) concept. Two field trials were carried out during three seasons in São Paulo state, Brazil. Trials were set up in commercial orchards of late-maturing 'Valencia' sweet orange grown for juice production. In field trial 1, the volumes tested were 125 (standard), 100 (internal runoff point), 75 (intermediate) and 50 (half the internal runoff point) mL of spray mixture/m^3 of the tree canopy. In field trial 2, 100 and 50 mL/m^3 were evaluated. The fungicide rates ranged from 40 to 110 mg of metallic copper/m^3 and from 1.9 to 4.7 mg of pyraclostrobin/m^3. Untreated control trees (UTC) were kept unsprayed. CBS incidence and severity, premature fruit drop, yield, fungicide deposition and spray coverage were evaluated. All spray volumes tested reduced CBS incidence and severity on fruit at 75–95% and resulted in 1.6–3.0-fold higher yields than the UTC. However, a slight trend of more CBS symptoms and fruit drop, and lower yield was observed for trees treated with 50 mL/m^3 compared to those treated with higher volumes. Spray volume change, from 125 to 75 mL/m^3, irrespective of fungicide rate correction, led to a 40% reduction of CBS spray costs and water usage and increased the financial return of the control by up to 35%. TRV-based sprays may contribute to sustainable citrus production by reducing costs and environment impacts while maintaining efficient CBS control.

1. Introduction

Citrus black spot (CBS) caused by *Phyllosticta citricarpa* (syn. *Guignardia citricarpa*) is one of the most important diseases of citrus in humid subtropical regions of Africa, Asia, Oceania and the Americas (Kotzé, 2000; EPPO, 2015). This disease causes fruit blemishes (Kotzé, 1981) and premature fruit drop, leading to yield loss in lemons and late-maturing sweet orange varieties only in highly favourable climates (Kotzé, 2000; Spósito et al., 2007). CBS lesions on fruit are diverse and generally classified into six types, i.e. hard spot, freckle spot, virulent spot, false melanose, lacy spot and cracked spot. On leaves, false melanose and hard spot lesions may occur in lemon or in old sweet orange orchards (Kotzé, 1981, 2000; Silva Junior and Spósito, 2014).

In endemic areas, CBS is mainly controlled by fungicide sprays during the critical period of fruit infection, which lasts from four to five months after fruit set (Kiely, 1948; Kotzé, 1981; Schutte et al., 1997, 2003; 2012; Miles et al., 2004; Spósito et al., 2008, 2011). The number of applications is usually three or less in young orchards with low inoculum pressure and four or more in older orchards, where the inoculum has built up (Kotzé, 1981). Currently, in São Paulo state (SP), Brazil, the only chemicals used for CBS control are strobilurins (quinone outside inhibitors, QoI) and fixed copper-based fungicides, which are applied singly or in mixture with oil. In

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general, the CBS spray program in SP starts with copper sprays early after blooming followed by strobilurin applications throughout the rainy season (Scaloppi et al., 2012; Silva Junior and Spósito, 2014). Until 2012, methyl benzimidazole carbamates (MBC-fungicides) and dithiocarbamates were used on citrus orchards in SP for controlling CBS and other diseases. However, these fungicide groups were withdrawn by the Brazilian Citrus Pesticide Board after there were regulatory changes in some export markets (Silva Junior et al., 2014).

In citrus, pesticides are generally applied using pre-determined spray volumes in orchards with different sizes and ages, leading to a waste of chemicals and water. In South Africa, where the citrus production is destined mainly for fresh fruit export to Europe, the spray volumes adopted for CBS control are considered high, ranging from 6000 to 16000 L/ha (Schutte et al., 1997, 2012; Fourie et al., 2009). These volumes are up to three-fold higher than those used in citrus orchards of Spain and Florida, USA (Vicent et al., 2009; Van Zyl et al., 2014; Dewdney et al., 2015). In SP, where the crop is aimed at juice production, the spray volume ranges from 3000 to 6000 L/ha (Araújo et al., 2013).

Establishing spray volumes and fungicide rates per treated area, e.g. litre or kilogram per hectare, is not an appropriate strategy for CBS control as citrus trees present variable sizes depending on age, cultivar, rootstock, planting density and location (Cunningham and Harden, 1999; Fourie et al., 2009; Van Zyl et al., 2014; Scapin et al., 2015). For greater accuracy and fewer wasted resources in perennial tree crops, such as apple, stone fruit, citrus orchards and vineyards, it would be more reasonable if the spray volume was based on the canopy volume or the tree-row-volume (TRV) (Sutton and Unrath, 1984, 1988; Siegfried et al., 2007; Pergher and Petris, 2008; Gil and Escolà, 2009; Scapin et al., 2015). TRV is calculated by multiplying tree average height in m, tree average depth in m and row length per hectare in m. The latter is determined by dividing 10,000 m^2 by the distance between rows in m. This concept was validated for apple orchards (Sutton and Unrath, 1984). These authors showed that half of growers were using a volume higher than that indicated by the TRV method. In citrus, TRV-based sprays of copper were evaluated for the control of citrus canker, and the results showed that, besides maintaining the quality of control, this methodology contributed to the reduction of spray costs and water usage at up to 40 and 73%, respectively (Scapin et al., 2015).

In addition to disease control, sprays may also be assessed by measuring surface coverage and chemical deposition (Scapin et al., 2015). The first may be determined by the proportion of the target area covered with the spray mixture. The second is measured by the amount of an active ingredient or a marker present on the targeted plant surface (Albrigo et al., 1997; Schutte et al., 2012). Coverage and deposition increase with volume up to the point of runoff. Above this point, increasing the spray volume results in losses of chemicals and water (Cunningham and Harden, 1998; Fourie et al., 2009). On the other hand, spraying at volumes below the point of runoff may reduce the coverage and pesticide deposition and does not necessarily affect the efficacy of disease control (Matthews, 1992; Salyani, 1994; Scapin et al., 2015).

TRV-adjusted spray volumes have the potential to reduce the costs of pest control and its environmental impacts (Cunningham and Harden, 1998, 1999). This strategy is required for sustainable crop production. Although the spray volume per hectare in SP is already significantly lower than that practiced elsewhere as mentioned, it could be excessive since the canopy volume is not taken into account. Thus, this study aimed to establish optimal spray volumes based on the TRV methodology for CBS control in sweet orange orchards. Moreover, we assessed the need of fungicide rate correction for reduced volumes, and determined the cost-benefit of the different treatments tested.

2. Materials and methods

2.1. Experimental areas

Two field trials were carried out during three seasons (2012/2013, 2013/2014 and 2014/2015) in non-irrigated, commercial orchards located in eastern SP, where CBS was first reported and frequently occurs. Field trial 1 was conducted in the municipality of Mogi Guaçu (22°17′28″S and 47°7′49″W). The orchard was composed of late-maturing 'Valencia' sweet orange [*Citrus sinensis* (L.) Osbeck] grafted onto Rangpur lime (*Citrus limonia* Osbeck) with 549 trees per hectare (6.5 m × 2.8 m), planted in 2001. Field trial 2 was conducted in the municipality of Tambaú (21°30′52″S and 47°12′1″W) on 'Valencia' sweet orange grafted onto Rangpur lime with 476 trees per hectare (7.0 m × 3.0 m), planted in 1999.

2.2. Determination of tree-row-volume

In both field trials, the spray volumes and chemical rates tested were based on the TRV methodology proposed by Sutton and Unrath (1984). There were no empty spaces between trees in the rows; thus, the trees within planting lines were considered as continuous canopy volumes. The TRV per hectare 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 depth (in m). The average tree height and depth (i.e. limb spread) was obtained measuring 20 trees at random in each experimental area. For field trial 1, the TRV in three consecutive seasons were 24,180 m^3/ha (44 m^3/tree), 28,020 m^3/ha (51 m^3/tree), and 31,870 m^3/ha (58 m^3/tree). For field trial 2, the TRV were 16,050 m^3/ha (34 m^3/tree), 21,430 m^3/ha (45 m^3/tree), and 28,100 m^3/ha (59 m^3/tree).

2.3. Experimental design and treatments

The treatments were arranged in a randomized complete block design with four replicates of 21 (field trial 1) and 39 (field trial 2) trees per plot in three rows. A guard row between treated blocks was left unsprayed. The spray volumes tested in this study were established considering the theoretical internal runoff point of 100 mL of spray mixture/m^3 of canopy. This reference volume was previously determined using different spray technologies in 10 field trials conducted in SP sweet orange orchards (Ramos, H.H. et al., unpublished results), and are based on the concept that the chemical deposition is increased up to the runoff point, after which the amount of the active ingredient on the tree is constant (Cunningham and Harden, 1998).

In field trial 1, seven treatments were evaluated: (i) 125 mL of spray mixture/m^3 of tree canopy, the standard volume applied by growers for CBS control in orchards for juice production in SP; (ii) 100 mL/m^3, the internal runoff point; (iii) 75 mL/m^3, an intermediate volume; (iv) 75C mL/m^3, treatment iii with correction of fungicide rates to that applied with treatment ii (100 mL/m^3); (v) 50 mL/m^3, half of the internal runoff point; (vi) 50C mL/m^3, treatment v with correction of the fungicide rates to that applied with treatment ii; and (vii) untreated control (UTC), with no fungicide sprays. In field trial 2, the treatments tested were: (i) 100 mL/m^3, (ii) 50C mL/m^3 and (iii) UTC. The volume sprayed per hectare increased during the three seasons due to tree growth (Table 1).

The fungicides used were copper oxychloride (Recop 840 PM, 50% metallic copper, Atar), at a standard rate of 90 g of metallic copper/100 L of water and strobilurin (Comet, 25% pyraclostrobin, BASF), at a standard rate of 3.8 g of pyraclostrobin/100 L of water. Mineral oil (Argenfrut, 85%, Agrovant) at 0.25% (v/v) was added to the fungicide tank mixture, from the second to the last sprays. Copper and strobilurin rate correction was determined by dividing