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Soluble and insoluble copper formulations and metallic copper rate for control of citrus canker on sweet orange trees

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ABSTRACT

Copper bactericides have been widely studied and used for control of citrus canker caused by *Xanthomonas citri* subsp. *citri*. New formulations become available periodically, however, little is known about the relative efficacy of insoluble (ICuF) and soluble (SCuF) copper formulations and the performance of ICuF at the same metallic copper rates. In the present study, we compared three rates of five ICuF (syn. fixed copper) and two SCuF for control of citrus canker during two seasons in a commercial orchard of 'Valencia' sweet orange located in Paranavaí, Paraná, Brazil. Control of citrus canker was evaluated as the temporal progress of canker incidence on leaves, cumulative dropped fruit with canker, and incidence of diseased fruit at harvest. All copper formulations and rates reduced the progress of citrus canker incidence on leaves. However, SCuF were not as effective as the ICuF. The incidence of leaves with canker on trees treated with ICuF never exceed 7.3%. In contrast, incidence of leaf canker on trees treated with SCuF ranged from 9.9 to 44.8%. Fruit drop per tree due to citrus canker for trees treated with ICuF did not exceed 6.2 and 17.3 in seasons 1 and 2, respectively. These losses were significantly lower than 20.4 and 38.6, observed for the untreated trees. Fruit drop was 10.4 and 20.9 for trees treated with SCuF in seasons 1 and 2, respectively. The citrus canker incidence on harvested fruit followed the same trend observed for other variables assessed. A non-linear regression analysis showed that the metallic copper rate accounted for a large proportion of the variation in incidence of citrus canker on leaves, fruit and premature fruit drop up to 1 kg of metallic copper/ha/application. Rates exceeding l kg/ha of metallic copper did not consistently improve disease control or reduce the fruit loss.

1. Introduction

Successful management of citrus canker (*Xanthomonas citri* subsp. *citri*) in endemic areas is highly dependent on copper sprays. The use of less susceptible species and cultivars, arboreal windbreaks, systemic acquired resistance inducers, and control of the citrus leafminer (*Phyllocnistis citrella*) are other measures used to reduce the impact of citrus canker outbreaks (Behlau et al., 2008, 2010; Gottwald et al., 2002; Gottwald and Timmer, 1995; Graham et al., 2010, 2011; Graham et al., 2011; Leite and Mohan, 1990; Stein et al., 2007). These measures do not prevent the entry or elimination of the pathogen from the orchard, but significantly reduce crop loss by decreasing disease incidence.

Insoluble copper formulations (ICuF) (syn. fixed copper), containing copper oxychloride, copper hydroxide, or cuprous oxide, are the most studied and commonly used forms of copper for control of citrus canker (Behlau et al., 2010; Graham et al., 2010, 2011) and other diseases affecting citrus (Schutte et al., 1997; Silva Junior et al., 2016; Timmer et al., 1998; Timmer and Zitko, 1996; Vicent et al., 2009). Conversely, the evaluation of soluble copper formulations (SCuF) for citrus protection is limited. Only recently, the first studies on the effectiveness of copper sulfate-based formulations for citrus canker control became available (Graham et al., 2011, 2016).

Compared to SCuF, the ICuF reduce the risk of phytotoxicity on plant surfaces and increase chemical residue after application, which extends the period of protection irrespective of rain events (Menkissoglu and Lindow, 1991a, 1991b). ICuF do not have systemic activity in trees or redistribute on the surface after application (Whiteside, 1977). In turn, SCuF may allow for a lower metallic rate of copper per area season long and reduce environmental impact of

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applications. However, because an important part of the ionic copper from the SCuF may enter the plant tissue following application, these formulations may increase the likelihood of leaf and fruit burn (Graham et al., 2010; Schutte et al., 1997; Timmer and Zitko, 1996). Copper ions are not stable in the environment and are prone to bind to environmental constituents. Thus, copper from SCuF and ICuF is deposited predominantly as a complexed form after sprayed, forming a protective film on fruit and leaves, where copper ions are slowly released (Menkissoglu and Lindow, 1991a, 1991b; Torgeson, 1967). Because copper ions are more toxic to microorganisms than the complexed forms (Gadd and Griffiths, 1978; Menkissoglu and Lindow, 1991b; Zevenhuizen et al., 1979), the insoluble film prevents new infections either by impeding the bacteria to gain access to the susceptible plant tissue or by killing the bacteria on the treated surface (Graham et al., 2010; Menkissoglu and Lindow, 1991a).

The effectiveness of copper bactericides for citrus disease control has been comprehensively evaluated over the last three decades. However, new formulations, including those with suspension concentrates of ICuF and SCuF, periodically become available in the marketplace with claims of being more bioactive, easier to apply and more efficient at lower rates when compared to preexisting formulations. This scenario makes the evaluation of copper formulations for disease control into a continuous process. In most of previous research, which has demonstrated the effectiveness of insoluble copper-based bactericides for control of citrus canker, the copper rates assessed were based on recommendations for other citrus diseases (Behlau et al., 2008, 2010; Graham and Leite, 2004; Graham et al., 2010, 2011, 2016; Scapin et al., 2015; Stein et al., 2007). Moreover, rates have been based on the copper source, e.g. copper oxychloride, copper hydroxide, or cuprous oxide, rather than the metallic copper content. For example, based on empirical recommendations of copper usage (Kimati et al., 1986), formulations containing copper oxychloride have been tested and used at higher rates than copper hydroxide (Graham and Leite, 2004; Graham et al., 2006; Leite, 1990). No research has systematically focused on the evaluation of the efficacy of copper formulations for citrus canker control based on the equivalent metallic copper rates of all ICuF tested, as previously reported for melanose on citrus (Timmer and Zitko, 1996), nor has an optimal rate of metallic copper been established for citrus canker control.

Although copper sprays contribute significantly to control of citrus canker on leaves and fruit, and reduce crop loss, over rated applications of copper-based bactericides may also pose adverse effects to both the environment and the citrus trees. After sprayed copper accumulates in the soil, where it may negatively affect root growth and nutrient uptake by the citrus trees (Alva et al., 1995; Fan et al., 2011). In addition, copper may cause spray burn on the fruit surface (Albrigo et al., 1997; Graham et al., 2008) and may favor the development of copper resistant strains in xanthomonad populations (Behlau et al., 2011), which may impair disease management with these bactericides as observed in Argentina (Canteros, 1999). Thus, determination of copper rate with the highest cost-benefit should be based on a strategy to reduce the impact of the frequent sprays needed for protection of susceptible expanding citrus leaves and fruit as previously demonstrated by adjusting the copper spray volume (Scapin et al., 2015). Besides pursuing other chemicals to aid with the control as attempted previously (Graham et al., 2006, 2008, 2010), it is also necessary to determine the most sustainable copper rate, at which the disease is satisfactorily controlled with the least environment impact.

Therefore, the aim of the study presented herein was to evaluate the effectiveness of SCuF and ICuF and determine the optimal metallic copper rate for citrus canker control on sweet orange

Table 1
Copper formulations and rates assessed for citrus canker control.

Commercial name	Manufacturer	Formulation type	Copper source and concentration (%)	Metallic copper content (%)	Solubility in water	Metallic copper rate (kg/ha/application)
Copper Crop	Alltech	solution	copper nitrate (35.4)	12	soluble	0.06, 0.10, 0.14
Magna-Bon CS 2005	Magna-Bon	solution	copper sulfate petahydrate (19.8)	5	soluble	0.15, 0.30, 0.60
Difere	Oxiquímica	suspension concentrate	copper oxychoride (58.8)	35	insoluble	1, 2, 3
Supera	Oxiquímica	suspension concentrate	copper hydroxide (53.8)	35	insoluble	1, 2, 3
Kocide WDG	Mitsui	water dispersible granules	copper hydroxide (53.8)	35	insoluble	1, 2, 3
Cuprogarb 350	Oxiquímica	wettable powder	copper oxychloride (58.8)	35	insoluble	1, 2, 3
Redshield 750	Agrovant	wettable powder	cuprous oxide (86.0)	75	insoluble	1, 2, 3