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Comparison of Copper Formulations for Control of Citrus Canker on 'Hamlin' Orange

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Protection of 'Hamlin' orange fruit from infection by *Xanthomonas citri* subsp. *citri*, the cause of citrus canker, is necessary to reduce premature fruit drop. The objective was to evaluate copper formulations for control of fruit infection and drop in 6- to 8-year-old 'Hamlin' trees. Copper sprays were applied at 21-day intervals after fruit reached 0.5- to 1.0-cm (0.25 to 0.50 inches) diameter. The period of susceptibility of fruit to canker infection and fruit drop was established by increasing the number of applications through the fruit growth period. Separate treatments ended at each 21-day interval so that there were four to seven applications per season. In 2008, early season infection occurred during rains before copper sprays commenced in late April. Subsequently, five sprays of copper formulations at rates exceeding 0.5 kg/ha (1.1 lb/acre) metallic copper significantly reduced incidence of lesions on fruit. Early season fruit disease and cumulative fruit drop were highly correlated among copper treatments (r = 0.95). Although a tropical storm in early August promoted disease on fruit late in the season, late season fruit disease and fruit drop were less well correlated (r = 0.78). In 2008 and 2009, additional sprays after the period of early fruit susceptibility did not further reduce canker incidence or fruit drop. In 2009, copper sprays were initiated before significant spring rainfall and the incidence of fruit disease and fruit drop were lower and the correlation of early season fruit disease was less positively correlated with fruit drop (r = 0.52) compared to 2008. In 2010, disease on fruit and premature drop were not significantly different from the untreated checks although fruit disease and early season infection were still significantly correlated (r = 0.70). Overall, there was little difference in efficacy among copper formulations, although control was reduced for treatments with copper sulfate pentahydrate at lower rates of metallic copper. In each season, copper treatments controlled fruit drop by ≈50% compared to the untreated check; however, as 'Hamlin' trees grew from 6 to 8 years of age, canker incidence dropped due to the development of hedgerows, which reduced windblown rain penetration into the grove. Hence, fewer copper sprays will be necessary after canopy closure promotes an internal windbreak effect.

Asiatic citrus canker, caused by *Xanthomonas citri* subsp. *citri* (*Xcc*; syn. *X. axonopodis* pv. *citri*), is a serious disease of most commercial citrus cultivars. Severe infections can cause defoliation, blemished fruit, premature fruit drop, twig dieback, and general tree decline (Graham et al., 2004). Among citrus cultivars, canker is most severe on grapefruit and early season sweet oranges including 'Hamlin', 'Pineapple', and navels (Gottwald et al., 2002). These sweet orange cultivars have proven challenging to grow profitably in the presence of citrus canker in moist subtropical climates and require an integrated program for disease management including windbreaks and chemical control (Gottwald and Timmer, 1995; Leite and Mohan, 1990). Trees are most susceptible in the young fruiting stages as they have the highest proportion of susceptible vegetative flush per volume of tree canopy and are vulnerable to windblown rain due to the wide spaces between trees and opportunity for wind penetration of the grove area (J.H. Graham, personal observations). At this stage, trees require multiple insecticide applications to control citrus leafminer (*Phyllocnistis citrella*) and prevent damage of emerging leaf flush that predisposes them to canker infection (Stein et al., 2007) and multiple copper bactericide sprays to protect the fruit (Behlau et al., 2008, 2010). Adult trees flush less frequently, reducing leafminer activity to an acceptable level and their canopies grow together to form hedgerows that reduce windblown rain penetration of the grove. This was confirmed in Parana State, Brazil, where the effectiveness of copper sprays for control of canker on mid-season 'Pera' sweet orange increased substantially as trees developed from 3 to 5 years of age (Behlau et al., 2010).

Copper bactericides for disease control are strictly preventive with no curative or systemic activity and provide satisfactory levels of canker control by protecting expanding fruit from infection as long as there are not gaps in the surface coverage (Behlau et al., 2008; Graham and Leite, 2004; Graham et al., 2008, 2010). Copper applications are made to sweet oranges from the time fruit are 0.5 to 1.0 cm (0.25 to 0.50 inches) in diameter as stomates open until fruit reach a diameter at which they become more resistant to infection (Graham et al., 1992). Copper should be applied at least every 21 d due to the effect of fruit growth on coverage of the surface with copper residues (Behlau et al., 2008; Graham et al., 2010). The average number of copper sprays needed depends on many factors, including the susceptibility of the citrus cultivar and environmental conditions such as wind exposure of the grove site, and may range from two to seven sprays per season (Leite and Mohan, 1990; Leite et al., 1987).

Several studies have compared the efficacy of different copper

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formulations for control of citrus canker and found only minor differences related to rate of metallic copper (McGuire, 1988; Stein et al., 2007; Timmer, 1988). Fixed forms of copper such as copper hydroxide, copper oxychloride, basic copper sulfate, and copper oxide are the formulations most widely used (McGuire, 1988; Stein et al., 2007; Timmer, 1988). Frequent copper applications for fungal and bacterial disease management in citriculture may have adverse effects on the environment as a result of accumulation in the soil and potential effects on tree health. Movement of copper through the soil profile is greater in sandy soils than soils higher in clay or organic matter (Alva et al., 1995). Copper availability in the soil is greatly increased as the soil pH decreases (Alva and Graham, 1991), whereas at higher pH, copper remains in precipitated and residual forms (Zhu and Alva, 1993).

The objective of this study was to compare the efficacy of copper formulations, rates and number of 21-d interval sprays for control of canker on 'Hamlin' orange, the most important early season orange cultivar in Florida. The goal is to minimize the amount of copper applied per season by using the most effective formulations and optimizing the frequency and duration of sprays.

Materials and Methods

Evaluation of copper formulations

2008 Trials. A grove of 6-year-old bearing 'Hamlin' orange (*C. sinensis*) trees located in Hardee County, FL, was selected for the trial. Canker was damaging to foliage and fruit in this location due to wind exposure. The southeast side of the grove was bordered by a pasture area devoid of forest vegetation that could act as a natural windbreak. The tree spacing was typical for 'Hamlin' orange trees on Carrizo citrange (*C. sinensis* × *Poncirus trifoliata*) rootstock, 3.65 m × 7.62 m (358 trees/ha) (12 ft × 25 ft; 145 trees/acre). The experiment was set up as a randomized complete block design with four blocks of five trees (20 trees/treatment). Sprays were applied at ~1500 L/ha (160 gal/acre) using an airblast sprayer at a 21-d interval from April to September depending on the experiment. In experiment 1, different formulations and rates of copper (Table 1) were compared with an untreated check (UTC) with five sprays/treatment applied on 29 Apr., 21 May, 12 June, 3 July, and 21 July. In experiment 2, either 4, 5, 6, or 7 sprays of Kocide 3000 at 2.24 kg/ha (2.0 lb/acre) were applied on 19 Apr., 21 May, 12 June, 3 July, 21 July, 13 Aug., and 1 Sept., respectively, compared with the UTC (Table 2).

2009 Trials. The same grove of 7-year-old 'Hamlin' orange trees was set up with an additional block per treatment and UTC to account for the variability in canker incidence due to the southeast wind exposure. The experimental design was five blocks of five trees (25 trees/treatment). In experiment 1, different formulations and rates of copper (Table 3) were applied in five sprays per treatment on 8 Apr., 29 Apr., 26 May, 9 June, and 1 July. In experiment 2, either 4, 5, 6, or 7 sprays of Kocide 3000 at 2.24 kg/ha (2.0 lb/acre) were applied on 8 Apr., 29 Apr., 25 May, 9 June, 1 July, 22 July, and 9 Aug. compared with the UTC (Table 4).

2010 Trial. Eight-year-old 'Hamlin' orange trees in five blocks of five trees were evaluated in one experiment with different formulations and rates of copper (Table 5) applied in five sprays/treatment, with the exception of one Kocide 3000 treatment at 1.12 kg/ha (1.0 lb/acre) in two sprays, on 28 Apr., 19 May, 9 June, 29 June, and 3 July. Trees in all trials received a rotation of foliar sprays of insecticides (abemectin, fenpropathrin, and dimethoate) coincident with leaf flushing activity for control of citrus leafminer (*Phyllocnistis citrella*) to minimize leaf damage and interaction with canker infection (Stein et al., 2007).

Disease evaluations

Fruit drop. All fruit on the ground under the middle three trees in each block were collected periodically and evaluated for the presence or absence of canker lesions on dropped fruit. In 2008, dropped fruit were counted on 4 June, 23 July, 20 Aug., and 17 Sept. In 2009, dropped fruit were counted on 16 June, 18 Aug., and 19 Nov. In 2010, dropped fruit were counted on 11 Aug. and 8 Oct.

Fruit disease. Prior to harvest, the incidence of fruit with canker lesions (percentage fruit infected) was evaluated each season. The lesion age was assessed for 100 fruit collected from both sides of

Table 1. Effect of sprays of different copper formulations on the incidence of fruit with canker, the incidence of fruit with old and young lesions, and on cumulative number of fruit dropped due to canker from June to September for 6-year-old 'Hamlin' orange trees in Hardee County, FL, in 2008. Means followed by different letters are significantly different at $P \leq 0.05$ as determined by a *t*-test for pair-wise comparisons.

Treatment (lb/acre)	Copper formulation (% Metallic Cu)	Rate (kg/ha)	Metallic Cu (kg/ha)	Fruit w/lesions (%)	Fruit w/old lesions (%)	Fruit w/young lesions (%)	Cum. fruit drop (no. of fruit)
Untreated check	---	---	---	71.8 e	18.5 c	53.3 c	830 d
Kocide 3000 (2.0)	Copper hydroxide (0.30)	2.24	0.67	54.0 abcd	11.5 b	42.5 abc	503 abc
Kocide 3000 (1.5)	Copper hydroxide (0.30)	1.68	0.50	40.8 a	4.3 a	36.5 a	210 a
Kocide 3000 (1.0)	Copper hydroxide (0.30)	1.12	0.34	52.5 abcd	7.3 ab	45.2 abc	432 ab
Cuprofix Ultra 40 (1.75)	Copper sulfate (0.40)	1.96	0.78	44.3 ab	6.5 ab	37.8 a	357 ab
Cuprofix Ultra 40 (1.5)	Copper sulfate (0.40)	1.68	0.67	64.3 de	11.0 b	53.3 c	768 cd
Cuprofix Ultra 40 (1.125)	Copper sulfate (0.40)	1.26	0.50	61.5 cde	10.8 ab	50.8 bc	529 bcd
Champ DP (1.6)	Copper hydroxide (0.375)	1.8	0.67	50.1 abcd	9.0 ab	41.1 abc	437 ab
Kentan DF (1.5)	Copper hydroxide (0.40)	1.68	0.67	42.8 ab	6.3 ab	36.5 a	483 abc
Badge SC (2.1 pt)	Copper hydroxide/Copper oxychloride (0.20)	2.46 L[z]	0.67	49.0 abcd	6.0 ab	43.0 abc	402 ab
Badge X2 (2.14)	Copper hydroxide/Copper oxychloride (0.28)	2.4	0.67	48.0 abc	9.5 ab	38.5 ab	429 ab
Magna-Bon	Copper sulfate pentahydrate	2.5 L	0.16	58.3 bcde	9.8 ab	48.5 abc	456 ab

[z]Liters/ha.

Table 2. Effect of number of applications of Kocide 3000 at 2.24 kg/ha (2.0 lb/acre) on the incidence of fruit with canker, the incidence of fruit with old and young lesions, and on the cumulative number of fruit dropped due to canker from June to October for 6-year-old 'Hamlin' orange trees in Hardee County, FL, in 2008. Means followed by different letters are significantly different at $P \leq 0.05$ as determined by a *t*-test for pair-wise comparisons.

Treatment	Fruit w/lesions (%)	Fruit w/old lesions (%)	Fruit w/young lesions (%)	Cumulative fruit drop (no. of fruit)
Untreated check	50.8 b	4.0 a	46.8 b	759 a
4 applications	32.5 a	3.5 a	29.0 a	791 a
5 applications	39.8 ab	2.8 a	37.0 ab	671 a
6 applications	42.8 ab	3.3 a	39.5 ab	789 a
7 applications	38 ab	1.8 a	36.3 ab	783 a

Table 3. Effect of sprays of copper formulations on the incidence of fruit with canker, the incidence of fruit with old and young lesions, and on the cumulative number of fruit dropped due to canker from June to September for 7-year-old 'Hamlin' orange trees in Hardee County, FL, in 2009. Means followed by different letters are significantly different at $P \leq 0.05$ as determined by a *t*-test for pair-wise comparisons.

Treatment (lb/acre)	Copper formulation (% Metallic Cu)	Rate (kg/ha)	Metallic Cu (kg/ha)	Fruit w/lesions (%)	Fruit w/old lesions (%)	Fruit w/young lesions (%)	Cum. fruit drop (no. of fruit)
Untreated check 1	---	---	---	45.2 d	11.0 d	34.2 c	130 bcd
Untreated check 2	---	---	---	33.0 bcd	7.4 abcd	25.6 abc	183 d
Kocide 3000 (2.5)	Copper hydroxide (0.30)	2.80	0.84	22.4 ab	5.4 abc	17.0 a	98 ab
Kocide 3000 (2.0)	Copper hydroxide (0.30)	2.24	0.67	23.6 ab	5.6 abcd	18.0 a	82 ab
Kocide 3000 (1.5)	Copper hydroxide (0.30)	1.68	0.50	21.4 ab	5.6 abcd	15.8 a	115 abc
Kocide 2000 (3.0)	Copper hydroxide (0.35)	5.04	1.76	21.4 ab	4.0 ab	17.4 a	95 ab
Kocide 2000 (2.5)	Copper hydroxide (0.35)	4.20	1.47	21.8 ab	4.4 ab	17.4 a	75 a
Cuprofix Ultra 40 (1.875)	Copper sulfate (0.40)	2.10	0.84	19.2 a	5.6 abcd	13.6 a	69 a
Cuprofix Ultra 40 (1.5)	Copper sulfate (0.40)	1.68	0.67	27.4 abc	8.0 abcd	19.4 ab	86 ab
Cuprofix Ultra 40 (1.125)	Copper sulfate (0.40)	1.26	0.50	20.0 ab	2.4 a	17.6 a	90 ab
Champ DP (2.0)	Copper hydroxide (0.375)	2.24	0.84	28.0 abc	6.4 abcd	21.6 ab	89 ab
Kentan DF (1.5)	Copper hydroxide (0.40)	1.68	0.67	21.6 ab	3.8 ab	17.8 a	89 ab
Badge X2 (2.68)	Copper hydroxide/Copper oxychloride (0.28)	3.0	0.84	22.6 ab	6.8 abcd	15.8 a	120 abc
Magna-Bon[z]	Copper sulfate pentahydrate	6.27 L[w]	0.40	40.8 cd	9.8 cd	31 bc	91 ab
Magna-Bon[y]	Copper sulfate pentahydrate	6.27 L	0.40	40.6 cd	10.4 d	30.2 bc	164 cd
Magna-Bon[x]	Copper sulfate pentahydrate	2.5 L	0.16	33.2 bcd	9.2 bcd	24 abc	120 abc

[z]250 ppm for all applications.
[y]250 ppm on 8 Apr., applications alternated with Magna-Bon 47 nutritional.
[x]250 ppm on 8 Apr., 200 ppm on 29 Apr., 100 ppm for rest of applications.
[w]Liters/ha.

Table 4. Effect of the number of applications of Kocide 3000 at 2.24 kg/ha (2.0 lb/acre) on the incidence of fruit with canker, the incidence of fruit with old and young lesions, and on cumulative number of fruit dropped due to canker from June to October for 6-year-old 'Hamlin' orange trees in Hardee County, FL, in 2009. Means followed by different letters are significantly different at $P \leq 0.05$ as determined by a *t*-test for pair-wise comparisons.

Treatment	Fruit w/lesions (%)	Fruit w/old lesions (%)	Fruit w/young lesions (%)	Cumulative fruit drop (no. of fruit)
Untreated check	24.5 a	20.8 b	4.2 ab	76.4 a
4 applications	14.6 a	12.2 ab	2.6 ab	67.8 a
5 applications	11.7 a	3.6 ab	7.8 b	79.4 a
6 applications	10.5 a	7.8 ab	2.4 ab	101.6 a
7 applications	17.0 a	13.3 ab	3.6 ab	71.2 a

the middle three trees (50 fruit/side). Each fruit was classified as either having 'old' lesions if they were larger than 0.6 cm (0.24 inch) in diameter, coalescing with surrounding lesions, or having a prominent yellow halo, or 'young' lesions if they were smaller than 0.6 cm (0.24 inch) in diameter, brown, and not coalescing with surrounding lesions. If both sizes of lesions were present, a fruit was classified as having 'old' lesions.

Rainfall

Monthly rainfall in 2008, 2009, and 2010 was recorded at the FAWN site in nearby Sebring, FL, and compared to the average for the last 5 years (Table 6).

Statistical analyses

For each trial, incidence of fruit with old lesions, young lesions, and total fruit disease incidence and cumulative drop were subjected to analysis of variance in PROC MIXED (SAS, Cary, NC) with block as a random variable. Means were separated using *t*-test for pair-wise comparisons at $P \leq 0.05$. The relationship between early and late season fruit disease incidence and cumulative fruit drop was examined for all the treatments using Spearman's correlation analysis and *t*-test for significance at $P \leq 0.05$.

Results

2008 Trials. Before copper sprays were initiated, infection of 'Hamlin' fruit occurred during rains in late March and early April (Table 1). In experiment 1, all copper formulations, except Cuprofix at the 1.26 kg/ha (1.125 lb/acre) and 1.68 kg/ha (1.5 lb/acre) rates and Magna-Bon, significantly reduced the incidence of fruit with total and old lesions compared to the UTC (Table 2). Reduction of young lesions was much more variable. Treatment blocks with highest fruit infection were those exposed to early season wind-blown rains from the southeast direction. Early season rainfall produced infection of very small fruit (0.6- to 1.0-cm diameter; 0.25- to 2.5-inch diameter) that resulted in heavy premature fruit drop in May (data not shown). Most of the copper treatments except Cuprofix at the 1.26 and 1.68 kg/ha (1.125 and 1.5 lb/acre) rates significantly reduced cumulative fruit drop due to canker. Early season fruit disease, i.e., incidence of fruit with old lesions and cumulative fruit drop were more highly correlated (r = 0.95, t = 9.72, $P \leq 0.05$) than the late season fruit disease (r = 0.78; t = 3.94, $P \leq 0.05$). The estimated fruit loss in the UTC trees was one 40-kg box/tree and on average the copper treatments reduced fruit drop to 0.5 box/tree (Fig. 1).

In experiment 2, four sprays of Kocide 3000 at 2.24 kg/ha (2.0 lb/acre) rate significantly reduced the incidence of total infected fruit and fruit with young lesions whereas, five to seven sprays did not (Table 3). The majority of the fruit infection was early and no treatment reduced incidence of fruit with old lesions or cumulative fruit drop compared to the UTC.

2009 Trials. In experiment 1, applications of copper formulations significantly reduced incidence of total fruit infection compared to UTC-1, but not UTC-2 (Table 4). No copper formulation or rate treatment differed from the others except the three Magna-Bon treatments, which were not significantly different ($P \leq 0.05$) from either UTC. Cumulative fruit drop was significantly reduced by copper treatments compared to UTC-2 but not UTC-1. As in 2008, there was a significant correlation between early fruit disease and cumulative fruit drop (r = 0.52, t = 2.77, $P \leq 0.05$) but the correlation between late fruit disease and cumulative fruit drop was not significant (r = 0.42, t = 1.73, $P \leq 0.05$). The estimated fruit loss due to canker in the two UTCs

Table 5. Effect of sprays of copper formulations on the incidence of fruit with canker, the incidence of fruit with old and young lesions, and on cumulative number of fruit dropped due to canker from June to September for 8-year-old 'Hamlin' orange trees in Hardee County, FL, in 2010. Means followed by different letters are significantly different at $P \leq 0.05$ as determined by a *t*-test for pair-wise comparisons.

Treatment (lb/acre)	Copper formulation (% Metallic Cu)	Rate (kg/ha)	Metallic Cu (kg/ha)	Fruit w/lesions (%)	Fruit w/old lesions (%)	Fruit w/young lesions (%)	Cum. fruit drop (no. of fruit)
Untreated check 1	---	---	---	48.8 c	17.2 bc	31.6 c	105 a
Untreated check 2	---	---	---	40.8 abc	20.4 c	20.4 abc	108 a
Kocide 3000 (2.5)	Copper hydroxide (0.30)	2.80	0.84	25.8 ab	8.8 a	17.0 abc	78 a
Kocide 3000 (2.0)	Copper hydroxide (0.30)	2.24	0.67	23.2 a	9.8 a	13.4 a	76 a
Kocide 3000 (1.5)	Copper hydroxide (0.30)	1.68	0.50	28.4 ab	10.8 ab	17.6 abc	113 a
Kocide 3000 (1.0) - 2 apps	Copper hydroxide (0.30)	1.12	0.34	42.2 bc	12.2 ab	30.0 bc	97 a
Kocide 2000 (3.0)	Copper hydroxide (0.35)	4.20	1.47	30.6 abc	10.0 ab	20.8 abc	94 a
Cuprofix Ultra 40 (1.875)	Copper sulfate (0.40)	2.10	0.84	24.2 ab	11.6 ab	12.6 a	80 a
Cuprofix Ultra 40 (1.5)	Copper sulfate (0.40)	1.68	0.67	27.4 ab	10.8 ab	16.6 ab	109 a
Cuprofix Ultra 40 (1.125)	Copper sulfate (0.40)	1.26	0.50	40.6 abc	11.8 ab	28.8 bc	99 a
Champ 30 DP (2.5)	Copper hydroxide (0.30)	2.80	0.84	29.0 ab	9.2 a	20.0 abc	83 a
Champ 30 DP (2.0)	Copper hydroxide (0.30)	2.24	0.67	29.8 ab	8.8 a	21.0 abc	75 a
Kentan DF (2.625)	Copper hydroxide (0.40)	2.94	1.18	32.8 abc	8.4 a	24.4 abc	78 a
Badge X2 (2.68)	Copper hydroxide/Copper oxychloride (0.28)	3.0	0.84	29.0 ab	9.0 a	20.0 abc	77 a
Magna-Bon[z]	Copper sulfate pentahydrate	6.27 L[x]	0.40	35.8 abc	11.6 ab	24.2 abc	108 a
Magna-Bon[y]	Copper sulfate pentahydrate	2.5 L	0.16	41.8 abc	14.4 abc	27.4 abc	108 a

[z]250 ppm on 8 Apr., 200 ppm on 29 Apr., 100 ppm for rest of applications.
[y]250 ppm for all applications.
[x]Liters/ha.

Table 6. Rainfall from 2008 to 2010 in Sebring, FL, FAWN site.

Monthly rainfall (cm)	March	April	May	June	July	August	September	October	November
2008	12.2	10.7	1.0	24.9	19.8	11.8	30.0	8.4	1.0
2009	2.0	0.8	30.0	24.9	13.0	7.1	5.3	0.5	1.8
2010	17.0	7.1	3.5	8.9	10.4	26.4	10.7	0.0	6.4
Avg[z]	7.4	4.8	4.0	10.1	23.6	7.5	19.1	6.4	3.6

[z]Average monthly rainfall from 2005 to 2010.

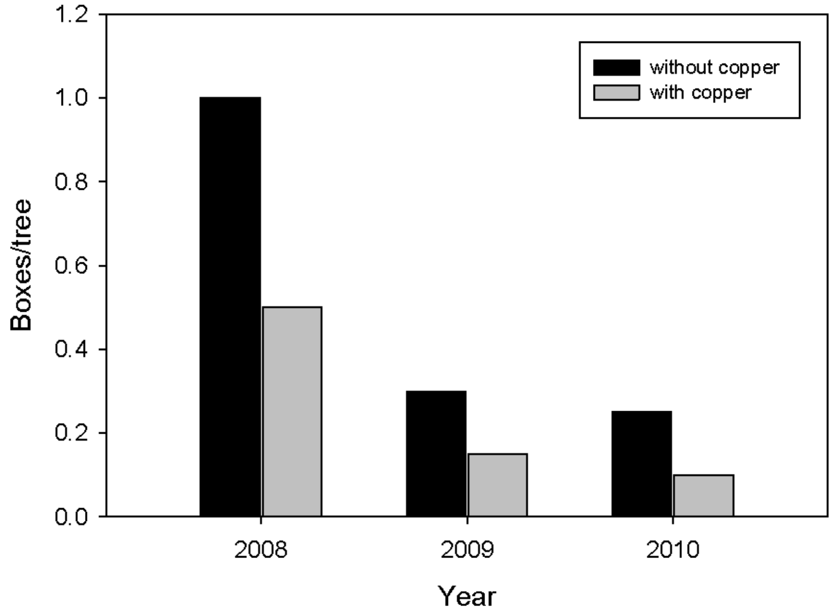

Fig. 1. Crop loss in 40-kg boxes for 6- to 8-year-old 'Hamlin' orange trees sprayed with various copper formulations and rates (with copper) or left untreated (without copper).

was 0.3 box/tree, and on average, the copper treatments reduced fruit drop to ≈0.15 box/tree.

In experiment 2, four to seven applications of Kocide 3000 at the 2.24 kg (2.0 lb/acre) rate did not reduce fruit lesion incidence or fruit drop due to canker compared to the UTC (Table 5). Overall in this area of the grove, fruit canker incidence was low and highly variable.

2010 Trial. Several of the copper formulations treatments significantly reduced the incidence of total, young and old lesions on fruit compared to UTC-2 whereas none were different from UTC-1. The least effective treatments were Kocide 3000 applied twice at 1.12 kg/ha (1.0 lb/acre), Cuprofix at 1.26 kg/ha (1.125 lb/acre) and the two Magna-Bon treatments (Table 2). Cumulative fruit drop due to canker was not significantly different from the two UTCs. Nevertheless, a significant correlation occurred between early fruit disease and cumulative fruit drop ($r = 0.70$, $t = 3.66$, $P \leq 0.05$) but not between late fruit disease and cumulative fruit drop was detected ($r = 0.15$, $t = 0.59$, $P \leq 0.05$). The estimated fruit loss due to canker in the UTC trees was approximately 0.25 box/tree. On average the standard copper treatments reduced fruit drop to ≈0.1 box/tree.

Discussion

In our evaluation of 6- to 8-year-old 'Hamlin' trees, fruit drop was related to early season infection that occurred as fruit reached 0.5-cm to 4.0-cm diameter. This range of fruit size was previously determined to be most susceptible based on artificial inoculation (Graham et al., 1992). As recommended for early season oranges, copper sprays applied during this fruit development period and before early rain events in the spring were effective for reducing early season infection and fruit drop (Dewdney and Graham, 2011; Graham and Dewdney, 2011). In contrast, copper sprays applied after March–April rains in 2008 were ineffective for preventing early season fruit drop, confirming that copper films on the surface of the fruit have no curative activity once bacteria penetrate the fruit rind.

No more than four sprays were necessary to achieve control and prevent crop loss because later season fruit infections, although higher in incidence, did not cause fruit drop compared to infections that occurred before July. In early Aug. 2008, Tropical Storm Fay produced several hours of windblown rain and as predicted, high levels of fruit infection (Bock et al., 2010). The resulting high incidence of late season fruit infection did not cause appreciable premature drop when fruit on the ground were inspected according to age (size) of the lesions. This confirms our recommendation that well-timed early season sprays are most important and that sprays after July are not necessary for prevention of crop loss (Dewdney and Graham, 2011; Graham and Dewdney, 2011).

As previously reported for grapefruit in Florida and lemons in Argentina (Graham et al., 2010; Stein et al., 2007), copper formulations varied little in their effectiveness on 'Hamlin' orange when used at the proper rate and timing. Rates of 0.5 to 1.0 kg/ha (1.1 to 2.2 lb/acre) metallic copper were efficacious, whereas, Magna-Bon at ≈30% the metallic copper of the other materials was less effective. When applied in 11 sprays per season on grapefruit, Magna-Bon was as effective for canker control as the standard copper formulations (Graham et al., 2010). Therefore, Magna-Bon at a lower metallic rate per application may require more frequent sprays than every 21 d to obtain effective disease control on early season oranges.

As trees developed hedgerows from age 6- to 8-years-old, they became more resistant to canker probably due to reduction in flush per volume of tree and penetration of the grove by windblown rain. Fewer copper sprays are needed after tree canopy closure creates an 'internal windbreak' effect. Hence, optimal spacing of trees according to rootstock vigor and site conditions for tree development is important to promote canopy closure as rapidly as possible.

Fruit drop due to canker was greatest in the 2008 season and decreased in the subsequent seasons as previously observed for 3- to 5-year-old 'Pera' orange trees in southern Brazil (Behlau et al., 2010). In 2008, the crop loss due to canker amounted to 1.0 box/tree and five copper sprays reduced fruit drop to 0.5 box/tree. The costs for canker control are estimated to be $45.99/acre for the additional copper material in three sprays and $39.67/acre for one additional copper application for a total of $85.66/acre. The increase in yield of 0.5 box/tree at 145 trees/ acre amounts to 72.5 boxes/acre. At $6.22/box for processed 'Hamlins' (2010, USDA, National Agricultural Statistics Service), the profit is $450.95/acre minus the cost of the additional sprays for a net profit of $365.29/acre. Using the same calculation, the net profit from preventing crop loss in the 2009 and 2010 seasons drops to ~$50 and ~$5, respectively. Thus, we predict that as solid set blocks of 'Hamlin' oranges increase in age, the need for copper sprays will decrease to a few early season sprays. Minimizing the number and rate of copper applications is of direct benefit by reducing pesticide and application costs, copper loading of the soil and lowering risk of toxicity to the citrus tree.

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