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Importance of Early Season Copper Sprays for Protection of Hamlin Orange Fruit Against Citrus Canker Infection and Premature Fruit Drop

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Proper timing of copper sprays for protection of citrus fruit from infection by *Xanthomonas citri* subsp. *citri*, the cause of citrus canker, is important because early season lesions induce premature fruit drop. The objective of the trials reported herein was to evaluate early season sprays of copper for control of fruit infection and drop in 3- to 5-year-old *Citrus sinensis* 'Hamlin' trees in a south central Florida citrus grove. Soluble and fixed copper formulations were applied with an airblast sprayer at 21-day intervals. In 2011, early season infection occurred due to periodic rains in late March and early April before the initiation of copper sprays. Subsequently, nine sprays of copper formulations from April to September only marginally reduced the incidence of fruit lesions compared to the untreated checks (UTC). Fruit drop ranged from 69% of the tree crop in the UTC to an average of 45% in the copper treatments. In 2012 in the same location, five copper sprays of 5-year-old trees began before rains in March–April. Incidence of fruit lesions was substantially lower and fruit drop due to canker was 10 fold less than in 2011. In 2014, copper sprays of 3-year-old trees were initiated before below average March–April and above average May rainfall. In this season, incidences of fruit disease and fruit drop were very low. In 2015 in the same location, copper sprays of 4-year-old trees were initiated before above average April and below average May rainfall and the incidence of fruit disease and fruit drop were significantly reduced by copper sprays. Timing of sprays in advance of rains in late March and early April is critical for protecting fruit from 0.5–1.0 cm (0.25–0.50 inch) in diameter. Inoculum in form of infected leaves and stems from the previous season is always present in the spring. Early fruit infection resulting in fruit drop depends on coincidence of March-April rains with the most susceptible fruit stage. In June-July, infections of fruit larger than 4.0 cm (1.5 inch) result in smaller lesions that do not induce fruit abscission and premature drop.

Asiatic citrus canker, caused by *Xanthomonas citri* sbsp. *citri* (*Xcc*; syn. *X. axonopodis* pv. *citri*), is a serious disease of most commercial citrus cultivars. Severe infections cause defoliation, blemished fruit, premature fruit drop, twig dieback, and general tree decline (Graham et al., 2004). Among citrus cultivars, canker is most damaging on grapefruit, *Citrus* x*paradisi*, and early season sweet oranges, *Citrus sinensis*, including 'Hamlin', 'Pineapple', and Navels (Gottwald et al., 2002). These sweet orange cultivars are challenging to grow profitably in the presence of citrus canker in moist subtropical climates and are effectively managed with an integrated program including windbreaks and chemical control (Graham et al., 2013; 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 gaps between trees and wind penetration of the grove area (Graham et al., 2011). At this growth stage, trees require multiple insecticide applications to control citrus leafminer (*Phyllocnistis citrella*) damage on emerging leaf flush that predisposes the flushes to *Xcc* infection (Stein et al., 2007). As trees grow older they flush less frequently and their canopies grow together to form hedgerows that reduce windblown rain penetration of groves. The "internal" windbreak effect increases the effectiveness of copper sprays for control of canker (Bock et al., 2010; Graham et al., 2013).

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 no gaps in the coverage by the surface film (Behlau et al., 2008; 2010; Graham et al., 2010; 2011). Sweet oranges are most susceptible from the time fruit are 0.5–1.0 cm (0.25–0.50 inch) in diameter, as the stomates open until fruit reach 4.0 cm (1.5 inch) in diameter, the stage they become more resistant to infection (Graham et al., 1992). Copper should be applied before the fruit reach 0.5 cm diameter and reapplied at 21-day intervals due to the effect of fruit growth on coverage of the expanding surface film containing copper (Behlau et al., 2010; Graham et al., 2010; 2011). The average number of copper sprays needed to protect fruit depends on many factors including the susceptibility of the citrus cultivar, fruit growth rate and environmental conditions such as exposure of the grove site to wind. Recommendations are site specific ranging from two to seven sprays per season (Behlau et al., 2010; Graham et al., 2011).

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Protection of 'Hamlin' fruit from early season infection by *Xcc* is necessary to reduce premature fruit drop (Graham et al. 2011). Copper sprays initiated before significant spring rainfall reduce the incidence of fruit disease and fruit drop (Graham et al., 2011). Minor differences in efficacy of fixed, i.e. sparingly soluble, copper formulations have been reported (Stein et al. 2008), whereas soluble copper sulfate pentahydrate at lower rates of metallic copper are less effective than fixed coppers (Graham et al., 2010; 2011). In seasons with favorable early season rainfall, copper sprays reduce fruit drop by ~50% compared to non-sprayed trees (Graham et al. 2011).

The objective of the trials reported herein was to evaluate timing of copper sprays in relation to when the fruit reach the most susceptible stage for control of infection and subsequent drop in 3- to 5-year-old 'Hamlin' trees in a south central Florida citrus grove. The goal was to optimize the timing of sprays for most consistent and effective canker control.

Materials and Methods

Evaluation of copper spray timing. Blocks of 3- to 5-year-old bearing 'Hamlin' orange (*C. sinensis*) trees located in a grove in Hardee County, Florida were selected for the trials. The tree spacing was typical for 'Hamlin' orange trees on Swingle citrumelo (*C. paradisi* x *Poncirus trifoliata*) rootstock, 3.65 m x 7.62 m (358 trees/ha) (12 ft x 25 ft; 145 trees/acre). The experiment was set up as a randomized complete-block design with five blocks of five trees (25 trees/treatment). Applications were made with an airblast sprayer at a 21-d interval starting in early to mid-April. In 2011, 4-year-old trees received nine applications for each of 13 treatments at ~300 L/ha (80 gal/acre) on 15 Apr., 5 May, 27 May, 15 June, 7 July, 28 July, 18 Aug., 9 Sept., and 27 Sept. (Table 1). In 2012, 5-year-old trees received five applications for each of 13 treatments at ~300 L/ha (80 gal/acre) on 4 Apr., 25 Apr., 15 May, 4 June, and 1 July (Table 2). In 2014, 3-year-old trees received four applications for each of 13 treatments at ~400 L/ha (108 gal/acre) on 25 Apr., 19 May, 11 June, and 1 July (Table 3). In 2015, 4-year-old trees received four applications of 13 treatments at ~400 L/ha (108 gal/acre) on 7 Apr., 28 Apr., 21 May, and 17 June (Table 4).

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 2011, fruit drop was evaluated on 28 June, 9 Aug., 9 Sept., and 16 Oct. In 2012, fruit drop was evaluated on 2 Aug. and 9 Sept. In 2014, fruit drop was evaluated on 17 July and 7 Oct. In 2015, fruit drop was evaluated on 14 July, 4 Aug., and 16 Oct.

Fruit disease. Prior to harvest each season, the incidence of fruit with canker lesions (percentage of infected fruit) was evaluated. Lesion age was assessed for 100 fruit collected from both sides of the middle three trees (50 fruit/side). Each fruit was classified as either having "old" lesions if they were larger than 6 mm (0.24 inch) or larger in diameter, coalescing with surrounding lesions, or having a prominent yellow halo, or 'young' lesions if they were smaller than 6 mm (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. Fruit disease was evaluated on 6 Dec. 2011, 19 Dec. 2012, 11 Dec. 2014, and 8 Dec. 2015.

Rainfall. Monthly rainfall in 2011, 2012, 2014, and 2015 was recorded at the Florida Agricultural Weather Network (FAWN) site in Sebring, Florida, located 25.7 km (16 mi) from the trial site and compared with the average for the last 5 years (Table 5).

Statistical analyses. For each trial, incidence of fruit with old lesions, young lesions, and incidence or total number of fruit dropped were subjected to analysis of variance in PROC GLM (SAS, Cary, NC). Means were separated using Student Newman Keuls multiple range test at $P \leq 0.05$.

Results

2011 trial. Nine sprays beginning on 15 Apr. and ending 27 Sept. were applied to deal with an unusually severe epidemic of canker in 4-year-old 'Hamlin' orange. Ill-timed rains occurred in

Table 1. Effect of nine sprays of different copper formulations on the incidence of *Citrus sinensis* fruit with citrus canker, the incidence of fruit with old and young lesions, and on incidence of fruit dropped due to canker for 4-year-old 'Hamlin' orange trees in Hardee County, Florida in 2011. Means (n = 5) followed by different letters are significantly different at $P \leq 0.05$ as determined by Student Newman Keuls multiple range test.

Treatment (lb or oz/acre)	Copper formulation (% metallic Cu)	Rate (kg/ha)	Metallic Cu (kg/ha)	Incidence of old lesions (%)	Incidence of young lesions (%)	Incidence of total lesions (%)	Fruit drop incidence (%)
1) Kocide 2000 (4.0)	Copper hydroxide (35)	4.48	1.57	36.5a	37.9a	74.4a	39.5 cde
2) Kocide 3000 (3.0)	Copper hydroxide (30)	3.36	1.00	41.4a	31.8a	73.2a	39.2 de
3) Kocide 3000 (2.5)	Copper hydroxide (30)	2.80	0.84	43.4a	30.7a	74.1a	38.6 de
4) NuCop 50WP (2.0)	Copper hydroxide (50)	2.24	1.12	48.1a	27.6a	75.7a	34.4 e
5) Nordox 75G (3.0)	Cuprous oxide (75)	1.49	1.12	43.8a	28.2a	72.0a	41.7 cde
6) Cuprofix Ultra 40 (3.0)	Copper sulfate (40)	3.36	1.34	39.2a	34.7a	73.9a	47.3 bcde
7) Kentan DF (2.62)	Copper hydroxide (40)	2.93	1.16	41.9a	27.7a	69.6a	40.8 cde
8) Badge X2 (2.68)	Copper hydroxide/oxychloride (28)	3.00	0.84	47.4a	27.8a	75.2a	47.7 bcde
9) Americop 40 DF (2.5)	Copper hydroxide (40)	2.80	1.12	42.9a	32.3a	75.2a	43.9 bcde
10) Magna-Bon (50 oz)	Copper sulfate pentahydrate (5)	3.65[zy]	0.21	46.4a	38.3a	84.7ab	54.0 abcd
11) Magna-Bon (20 oz)	Copper sulfate pentahydrate (5)	2.92[zx]	0.17	54.1a	31.8a	85.9ab	48.9 bcde
12) Untreated check 1	--	--	--	56.0a	37.7a	93.7a	69.2 a
13) Untreated check 2	--	--	--	54.7a	31.0a	85.7ab	60.1 ab

[z]Liters/hectare (L/ha).
[y]Applications decreased from 3.65 L/ha (250 ppm), 2.92 L/ha (200 ppm), and 2.74 L/ha (150 ppm) in the first three sprays and 1.46 L/ha (100 ppm) for the rest of the applications.
[x]2.92 L/ha (200 ppm) for all applications.

Table 2. Effect of five sprays of different copper formulations on the incidence of *Citrus sinensis* fruit with citrus canker, the incidence of fruit with old and young lesions, and number of fruit dropped due to canker for 5-year-old 'Hamlin' orange trees in Hardee County, FL, in 2012. Means (n = 5) followed by different letters are significantly different at $P \leq 0.05$ as determined by Student Newman Keuls multiple range test.

Treatment (lb or oz/acre)	Copper Formulation (% metallic Cu)	Rate (kg/ha)	Metallic Cu (kg/ha)	Incidence of old lesions (%)	Incidence of young lesions (%)	Incidence of total lesions (%)	Total no. of canker fruit dropped
1) Kocide 2000 (4.0)	Copper hydroxide (35)	4.48	1.57	11.2 a	30.8 a	42.0 b	91
2) Kocide 3000 (3.0)	Copper hydroxide (30)	3.36	1.00	12.8 a	39.0 a	51.8 ab	107
3) Nordox 75WG (1.33)	Cuprous Oxide (75)	1.49	1.12	17.6 a	43.8 a	61.4 ab	72
4) Champ 30WP (3.0)	Copper hydroxide (30)	3.36	1.00	18.8 a	32.4 a	51.2 ab	100
5) NuCop 50HB (2.0)	Copper hydroxide (50)	2.24	1.12	15.8 a	43.8 a	59.6 ab	93
6) Quimetal CO (2.0)	Cuprous oxide (50)	2.24	1.12	7.4 a	47.2 a	54.6 ab	61
7) Quimetal CH (3.0)	Copper hydroxide 30	3.36	1.12	13.2 a	52.4 a	65.6 ab	55
8) Badge X2 (2.68)	Copper hydroxide/oxychloride (28)	3.00	0.84	11.0 a	52.2 a	63.2 ab	64
9) Americop 40 DF (2.5)	Copper hydroxide (40)	2.80	0.74	11.2 a	43.4 a	54.6 ab	71
10) Magna-Bon (50 oz)	Copper sulfate pentahydrate (5)	3.65[zy]	0.21	19.2 a	60.6 a	79.8 a	140
11) Magna-Bon (20 oz)	Copper sulfate pentahydrate (5)	2.92[zx]	0.17	16.6 a	58.6 a	75.2 a	85
12) Untreated check 1	--	--	--	15.2 a	57.0 a	72.2 a	177
13) Untreated check 2	--	--	--	18.8 a	45.6 a	64.4 a	250

[z]Liters/ha.
[y]Applications decreased from 3.65 L/ha (250 ppm), 2.92 L/ha (200 ppm), and 2.74 L/ha (150 ppm) in the first three sprays and 1.46 L/ha (100 ppm) for the rest of the applications.
[x]2.92 L/ha (200 ppm) for all applications.

Table 3. Effect of four sprays of different copper formulations on the incidence of Citrus sinensis fruit with citrus canker, the incidence of fruit with old and young lesions, and number of fruit dropped due to canker for 3-year-old 'Hamlin' orange trees in Hardee County, FL, in 2014. Means (n = 5) are not significantly different at $P \leq 0.05$ as determined by Student Newman Keuls multiple range test.

Treatment (lb or oz/acre)	Copper formulation (% metallic Cu)	Rate (kg/ha)	Metallic Cu (kg/ha)	Incidence of old lesions (%)	Incidence of young lesions (%)	Incidence of total lesions (%)	Total no. of canker fruit dropped
1) Kocide 2000 (4.0)	Copper hydroxide (35)	4.48	1.57	9.6	17.8	27.4	27
2) Kocide 3000 (3.0)	Copper hydroxide (30)	3.36	1.00	9.8	13.8	23.6	24
3) Nordox 75 WG (1.33)	Cuprous oxide (75)	1.49	1.12	9.8	13.6	23.4	23
4) Nordox 75 WG (2.66)	Cuprous oxide (75)	3.0	2.24	9.6	11.0	20.6	21
5) ChampION 30WDG (3.0)	Copper hydroxide (30)	3.36	1.00	8.2	12.8	21.0	21
6) NuCop 50HB (2.0)	Copper hydroxide (50)	2.0	1.12	14.8	15.0	29.8	30
7) NuCop 30HB (3.0)	Copper hydroxide (30)	2.99	1.0	10.2	10.8	21.0	21
8) Quimetal CO (1.4)	Cuprous oxide (50)	1.57	0.78	12.6	13.8	26.4	26
9) Quimetal CH (3.0)	Copper hydroxide (30)	3.36	1.12	8.2	9.6	17.8	18
10) Badge X2 (2.68)	Copper hydroxide/oxychloride (28)	3.00	0.84	14.6	15.2	29.8	30
11) Magna-Bon (37 oz)	Copper sulfate pentahydrate (5)	2.70[z]	0.16	13.2	15.6	28.8	29
12) Untreated check 1	--	--	--	14.4	16.2	30.6	31
13) Untreated check 2	--	--	--	18.8	12.0	30.8	31

[z]Liters/ha.

late March and early April when fruit were at the most susceptible stage of 0.5 to 1.0 cm diameter (Table 5). Intense rainfalls accompanied by wind led to very high incidence of early season fruit infection and premature fruit drop regardless of copper formulation (Table 1). Total fruit canker incidence exceeded ~80% in all treatments, the majority of which occurred early in the season. The preponderance of old lesions incited a very high incidence of premature fruit drop ranging from nearly 70% in the untreated checks (UTC)-1 to ~34% in the best copper treatment. Formulations of copper hydroxide, cuprous oxide, and copper hydroxide/copper oxychloride at similar metallic rate significantly reduced incidence of fruit infection and premature fruit drop compared to the UTC-1 (Table 1). Copper sulfate pentahydrate at lower metallic copper did not significantly reduce fruit disease incidence or fruit drop compared to the UTC-1. Across all treatments, incidence of fruit with old lesions was linearly correlated ($r = 0.45$; $P \leq 0.08$) with fruit drop incidence.

2012 TRIAL. April and early May, when fruit were at the most susceptible stage, were marked by the absence of significant rainfall events, and overall, conditions were drier than normal for this period (Table 5). Hence, incidence of early season fruit infection averaged less than 20% for both the UTCs and copper treatments. Later season canker, i.e., incidence of young lesions, ranged from ~47 to 57% in the UTCs and ~31 to 61% in the copper treatments. Young lesions represented infection that occurred after sprays stopped in July. Number of fruit dropped due to canker was low for all treatments (Table 2). Copper hydroxide, cuprous oxide, copper hydroxide/copper oxychloride at similar metal-

Table 4. Effect of four sprays of different copper formulations on the incidence of *Citrus sinensis* fruit with citrus canker, the incidence of fruit with old and young lesions, and number of fruit dropped due to canker for 4-year-old 'Hamlin' orange trees in Hardee County, FL, in 2015. Means (n = 5) followed by different letters are significantly different at $P \leq 0.05$ as determined by Student Newman Keuls multiple range test.

Treatment (lb or oz/acre)	Copper formulation (% metallic Cu)	Rate (kg/ha)	Metallic Cu (kg/ha)	Incidence of old lesions (%)	Incidence of young lesions (%)	Incidence of total lesions (%)	Total no. of canker fruit dropped
1) Nordox 75WG (1.33)	Cuprous oxide (75)	1.12	1.0	10 bc	18 a	28 bc	55 c
2) ChampION 30 WDG (3.0)	Copper hydroxide (30)	3.36	1.0	11 bc	16 a	27 bc	62 bc
3) NuCop 30HB (2.5)	Copper hydroxide (30)	2.8	0.84	7.6 bc	21 a	28 bc	55 c
4) NuCop 30HB (1.75)	Copper hydroxide (30)	1.96	0.59	13 abc	22 a	35 bc	53 c
5) NuCop 30HB (1.0)	Copper hydroxide (30)	1.12	0.34	14 abc	20 a	35 bc	76 bc
6) Quimetal CO (1.4)	Cuprous oxide (50)	1.57, 1.28,1.0[z]	0.79, 0.64, 0.53	8.8 bc	19 a	28 bc	87 bc
7) Quimetal CH (3.0)	Copper hydroxide (30)	3.36, 3.08,2.8[z]	1.12, 0.93, 0.84	5.8 c	16 a	22 c	61 bc
8) Kocide 3000 (3.0)	Copper hydroxide (30)	3.36	1.12	6.8 bc	21 a	27 bc	85 bc
9) Untreated check 1	--	--	--	20 ab	32 a	52 ab	174 a
10) Untreated check 2	--	--	--	24 a	35 a	59 a	150 ab

[z]Treatments 6 and 7 begin at high rate for two applications and for third and fourth applications drop 0.28 kg/ha.

Table 5. Rainfall from 2011–12 and 2014–15 at the Florida Agricultural Weather Network (FAWN) site in Sebring, FL.

Monthly rainfall (mm)	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.
2011	98	38	51	152	76	150	132	188	18
2012	51	46	89	302	218	259	91	130	46
2014	40	23	106	259	302	124	338	25	165
2015	38	135	46	152	320	170	304	51	38
Sebring average[z]	74	48	102	198	236	191	109	64	36

[z]Average monthly rainfall from 2005–10.

lic rate either slightly or did not reduce total incidence of fruit infection and premature fruit drop compared the UTCs (Table 2).

2014 TRIAL. In April 2014, fruit were at the most susceptible size while rainfall was well below average (Table 5). Although rainfall in May was above average, early season canker infection represented by incidence of fruit with old lesions ranged from ~14 to 19% in UTCs and from ~8 to ~15% in the copper treatments (Table 3). Young lesions on fruit represented infection that occurred after sprays stopped in July. Later season canker ranged from ~12 to 16% in the UTCs and ~10 to 18% in the copper treatments. Because incidence of early season fruit infection was relatively low, fruit drop due to canker averaged only 10 fruit per tree (Table 3).

2015 TRIAL. When fruit were at the most susceptible stage of fruit diameter, rainfall was higher than normal in April and lower in May (Table 5). Early season canker measured as incidence of fruit with old lesions ranged from 20% to 24% in UTCs and was substantially lower, from ~6% to ~14%, in the copper treatments (Table 4). Young lesions on fruit occurred after sprays stopped in July. July and September rainfall was well above average (Table 5) and canker incidence ranged from 32% to 35% in the UTCs and 16% to 22% in the copper treatments (Table 4). Quimetal copper hydroxide produced the lowest total incidence of canker fruit even though the rate of copper was reduced in the May and June sprays. The number of fruit dropped due to canker was substantially lower in the copper treatments than the UTCs (Table 4; Fig. 1).

Discussion

In our evaluation of 3- to 5-year-old 'Hamlin' trees, fruit drop was related to early season infection as fruit reached 0.5 cm to 4.0 cm diameter coincident with above average rainfall. This range of 'Hamlin' fruit size was previously determined to be most susceptible based on artificial inoculation (Graham et al., 1992). In 2011, windblown rain events in late March and early April produced the highest incidence of infected fruit and premature drop ever recorded for 'Hamlin' orange in Florida trials (Graham et al, 2011). Nine copper sprays applied after the March-April rains marginally reduced incidence of early season fruit infection and subsequent fruit drop. These results confirm that copper films on the surface of the fruit have no curative activity once bacteria penetrate the fruit rind (Graham et al., 2011). Therefore, copper sprays must be applied before spring rain events, otherwise they are ineffective for preventing early season infection and fruit drop (Dewdney and Graham, 2016; Graham et al., 2011).

As previously reported for 'Hamlin' trees, incidence of early season fruit infection is significantly related with fruit drop later in the season (Graham et al., 2011). Early season lesions 6 mm or greater in diameter release ethylene that induces abscission at the stem end of the fruit. In contrast, in 2012 and 2014, late season fruit lesions less than 6 mm, although higher in incidence compared to infections before July, did not result in fruit drop. Apparently, lesions less than 6 mm do not produce sufficient ethylene to reduce the detachment force requisite for premature fruit drop (Franklin Behlau, personal communication).

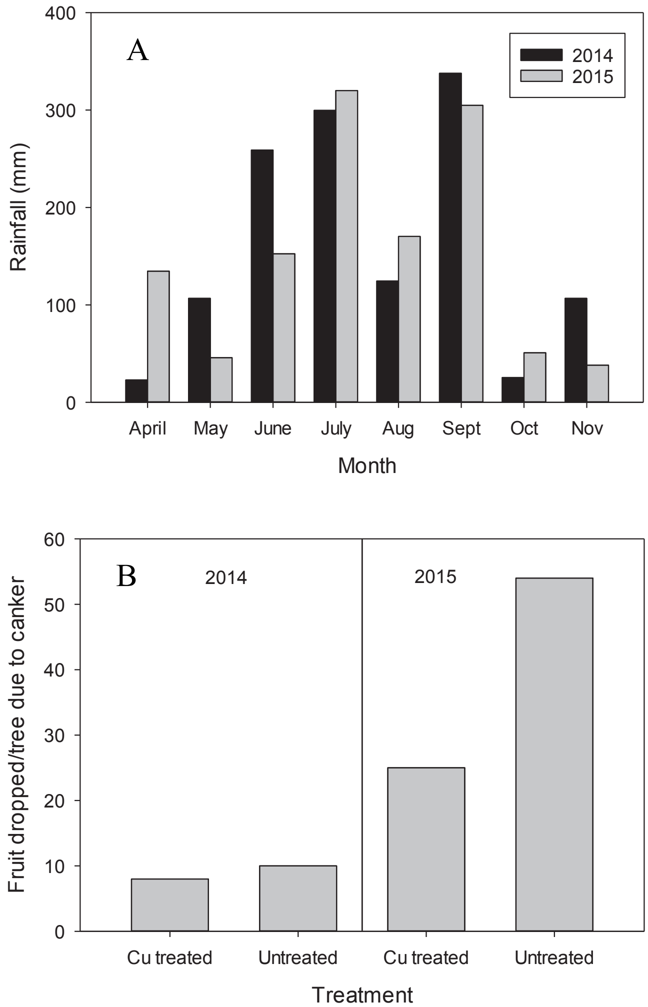

Fig. 1 (**A**) Rainfall at Sebring, FL (Florida Agricultural Weather Network). (**B**) The effect of four applications of copper formulations at 21-d intervals from April–July on the number of canker fruit dropped from 3- and 4-year-old *Citrus sinensis* 'Hamlin' trees in 2014 and 2015, respectively. In 2015, 120 mm of rain in April was conducive for fruit infection at the most susceptible size of development (6–13 mm diameter) resulting in premature fruit drop. Copper applications reduced fruit drop by 50%.

Based on comparison of monthly rainfall in the Sebring area in 2014 and 2015, April is the most important month for fruit protection to prevent drop due to citrus canker. Over 120 mm of rain in April 2015 resulted in early fruit infection and three times more fruit drop than in April 2014 when less than 25 mm of rain fell (Fig. 1A, 1B). In 2015, copper sprays reduced fruit drop by 50%, whereas copper sprays provided little benefit in the 2014 season with minimal fruit drop.

As previously reported for grapefruit in Florida and lemons in Argentina (Graham et al., 2010; Stein et al., 2007), copper formulations vary little in their effectiveness on 'Hamlin' orange when used at the proper rate and timing. Rates of 0.5–1.0 kg/ha (0.45–0.90 lb/acre) metallic copper were efficacious; whereas, copper sulfate pentahydrate at ~30% the metallic copper of the other materials was less effective. When applied in 11 sprays per season on grapefruit, copper sulfate pentahydrate was as effective for canker control as the standard copper formulations (Graham et al., 2010). Therefore, copper sulfate pentahydrate at a lower metallic rate per application may require more frequent early season sprays than the 21 day interval to achieve effective disease control on early season oranges.

Fewer copper sprays are needed after tree canopy closure creates an 'internal windbreak' effect (Bock et al., 2010; Graham et al., 2011). 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. As solid set blocks of 'Hamlin' oranges increase in age, the need for copper sprays should decrease to a few early season sprays. For example, in the 2015 trial, the best treatment in terms of prevention of fruit disease and drop was the copper hydroxide program that reduced copper rate in the May and June sprays. Minimizing the rate and/or number of copper applications provides benefits in terms of reduced pesticide and application costs (Behlau et al. 2010; Graham et al, 2010), copper loading of the soil and toxicity risk to the citrus tree (Alva et al., 1995).

Literature Cited

Alva, A.K., J.H. Graham, and C.A. Anderson. 1995. Soil pH and copper effects on young 'Hamlin' orange trees. Soil Sci. Soc. Amer. J. 59:481–487.

Behlau, F., J. Belasque Jr., A. Bergamin-Filho, J.H. Graham, R.P. Leite, Jr. and T.R. Gottwald. 2008. Copper sprays and windbreaks for control of citrus canker on young orange trees in southern Brazil. Crop Prot. 27:807–81.

Behlau F., J. Belasque Jr., J.H. Graham, and R.P. Leite Jr. 2010. Effect of frequency of copper applications on control of citrus canker and the yield of young bearing sweet orange trees. Crop Prot. 29:300–305.

Bock, C.H., J.H. Graham, T.R. Gottwald, A.Z. Cook, and P.E. Parker. 2010. Wind speed and wind-associated leaf injury affect severity of citrus canker on Swingle citrumelo. Eur. J. Plant Pathol. 128:21–38.

Dewdney, M.M. and J.H. Graham. 2016. Citrus canker. p. 93–96. In: M.E. Rogers and M.M. Dewdney, (eds.). Florida Citrus Pest Management Guide, SP-43. 182 p. University of Florida, IFAS, Gainesville.

Gottwald, T.R., J.H Graham, and T.S. Schubert. 2002. Citrus canker: The pathogen and its impact. <http://www.plantmanagementnetwork.org/pub/php/review/citruscanker/>.

Graham, J., C. Bock and B. Gruber. 2013. Integrated management of citrus canker. Citrus Ind. 94(4):12, 14–17.

Graham, J.H., M.M. Dewdney, and M.E. Myers, 2010. Streptomycin and copper formulations for control of citrus canker on grapefruit. Proc. Fla. State Hort. Soc. 123:92–99.

Graham, J.H., M.M. Dewdney, and H.D. Yonce. 2011. Comparison of copper formulations for control of citrus canker on 'Hamlin' orange. Proc. Fla. State Hort. Soc. 124:79–84.

Graham, J.H., T.R. Gottwald, J. Cubero, and D.S. Achor. 2004. *Xanthomonas axonopodis* pv. *citri*: Factors affecting successful eradication of citrus canker. Mol. Plant Pathol. 5:1–15.

Graham, J.H., T.R. Gottwald, T.D. Riley, and M.A. Bruce. 1992. Susceptibility of citrus fruit to citrus bacterial spot and citrus canker. Phytopathology 82:452–457.

Leite, R.P., Jr., and S.K. Mohan. 1990. Integrated management of citrus bacterial canker disease caused by *Xanthomonas campestris* pv. *citri* in the State of Paraná, Brazil. Crop Prot. 9:3–7.

Stein, B., J. Ramallo, L. Foguet, and J.H. Graham. 2007. Citrus leaf miner control and copper fungicide sprays for management of citrus canker on lemon in Tucumán, Argentina. Proc. Fla. State Hort. Soc. 120:127–131.