Injurious Effects of Metsulfuron-methyl When Used to Stimulate Abscission of 'Hamlin' Oranges

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Abstract. A field experiment was conducted to determine effects of concentration and spray volume of metsulfuron-methyl as an abscission aid for mechanical harvesting of citrus. Concentrations of 1, 2, and 4 mg·L⁻¹ metsulfuron-methyl were applied to 'Hamlin' orange [*Citrus sinensis* (L.) Osbeck] trees at 470, 1900, and 4700 L·ha⁻¹ (0.5 to 19 g·ha⁻¹ a.i.). Effective fruit loosening was achieved with all applications >1.9 g·ha⁻¹ (4 mg·L⁻¹ at all volumes, 2 mg·L⁻¹ at 1900 and 4700 L·ha⁻¹, and 1 mg·L⁻¹ at 4700 L·ha⁻¹). Heavy defoliation and twig dieback were observed on trees receiving 2 and 4 mg·L⁻¹ at all volumes. Defoliation and dieback became more severe and flower development and fruit set were inhibited as fruit loosening increased. The use of metsulfuron-methyl as an abscission agent for 'Hamlin' oranges is not recommended until conditions for its safe application can be determined. Chemical names used: methyl 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl) amino] carbonyl] amino] sulfonyl] benzoate (metsulfuron-methyl).

Mechanized harvesting of citrus fruit has been researched in Florida since the 1960s with limited success (Whitney and Harrell, 1989). Recently, trunk shakers have been developed and are being evaluated on a commercial scale for oranges intended for juice (Brown, 1998). Since mechanical harvesters seldom remove all of the fruit on a tree, chemicals that increase the harvesting efficiency have been evaluated (Wilson, 1978). Chemical looseners, such as glyoxal dioxime (5-chloro-3-methyl-4-nitro-1H-pyrazole) and cycloheximide, have been tested but none has been developed because of phytotoxicity, failure to gain registration, or lack of efficiency (Kender, 1998).

Wilcox and Taylor (1997) reported that metsulfuron-methyl ("WTX-901") effectively loosened citrus fruits with no detrimental side effects. In studies on 11 citrus varieties, however, we observed variable loosening effects of metsulfuron-methyl and some defoliation (Kender et al., 1998). Differences in environmental and physiological factors, fruit respon-

siveness, cultivar, and application method, including dosage, may account for the difference in response.

This study was conducted to determine to what degree the concentration of metsulfuron-methyl and spray volume affect fruit loosening and phytotoxicity in 'Hamlin' oranges.

Materials and Methods

A field trial was conducted in Jan. 1998 to evaluate rates and volume of application of metsulfuron-methyl on 'Hamlin' orange trees. Seventy-two trees, spaced at 7.3 × 7.3 m (185 trees/ha), were selected in a grove of the Florida Dept. of Agriculture and Consumer Services, Division of Plant Industry, in Dundee, Fla. A group of 36 of these trees were 10 years old, averaged 3.7 m in height, and yielded an average of 196 kg/tree. The other 36 trees were 23 years old, averaged 7 m in height, and yielded 660 kg/tree. Brix-acid ratio of fruit from the two groups of trees were 15.7 and 18.0, respectively.

Metsulfuron-methyl (Ally®, DuPont Co., Wilmington, Del.) was applied at concentrations of 0, 1, 2, and 4 mg·L⁻¹ at three volumes (470, 1900, and 4700 L·ha⁻¹) on 6 Jan. 1998 using a commercial Power Takeoff airblast sprayer (Rear's Manufacturing Co., Eugene, Ore.). Kinetic®, a 25% organosilicone-75% nonionic-oil adjuvant (Setre Chemical Co., Memphis, Tenn.), at 0.125% was included with all treatments, as well as Buffer Xtra Strength® (Setre Chemical Co.) at 0.027% to adjust solution pH to 6.5. All 12 treatment combinations were replicated six times (three

Fig. 1. Fruit detachment force of 'Hamlin' oranges following applications of metsulfuron-methyl at three concentrations and spray volumes on 6 Jan. 1998, Dundee, Fla. Vertical lines indicate the standard errors of the means.

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Table 1. F-statistics from analyses of variance for parameters measured following application of metsulfuron-methyl at four solution concentrations and three spray volumes to 'Hamlin' oranges in Dundee, Fla., 1998. Interactions of age with other factors were nonsignificant.

Parameter	F _{Volume}	F _{Concn}	F _{Vol*concn}	F _{Age}
FDF ^a d 10	87.7	183.8	7.9	4.5
Fruit drop d 10	226.1	106.3	59.9	4.2 ^{xy}
Fruit removal d 10	14.0	10.0	3.16 [*]	---
Peduncle removal d10	60.0	41.4	9.6	---
FDF d 14	39.3	44.3	13.4	---
Fruit drop d 21	129.1	90.7	23.8	---
Fruit pitting d 21	36.4	32.7	2.7 [*]	---
Leaf loss d 21	5.1 [*]	4.7 [*]	2.7 [*]	---
Defoliation d 60	46.4	37.0	4.5 [*]	NS
Flush status d 60	64.4	83.1	13.9	6.4 ^{**}
Canopy status d 120	2.5	26.2	8.5	8.2 ^{**}
Fruit set d 120	10.3	25.8	NS	7.9 ^{**}

^aFDF = fruit detachment force.

^yF-values are significant at $P \leq 0.05$ (*) or 0.01 (**); all others are significant at $P < 0.001$; NS = nonsignificant.

^xNot applicable (older trees mechanically harvested on d 10).

Fig. 2. Cumulative mature fruit drop of 'Hamlin' oranges following application of metsulfuron-methyl at three concentrations and spray volumes on 6 Jan. 1998, Dundee, Fla. Vertical lines indicate the standard errors of the means.

in each age group) in a randomized complete-block design.

The ground under each tree was cleared of debris and fruit drop was recorded twice per week during the course of the experiment. At the same intervals, fruit detachment force (FDF) of mature fruit was measured using a digital force gauge ("Force Five"; Wagner Instruments, Greenwich, Conn.). Fruit were clipped to leave 3 cm of stem, inserted into the gauge, and the stem was pulled parallel to the fruit axis until it separated from the fruit.

Ethylene concentration in the evacuated internal air space was measured by gas chromatography, as previously described (modified after Sawamura, 1981) in five fruit per treatment 3, 7, 10, and 14 d after spraying.

Ten days after application, the older group of 36 trees were mechanically harvested using a trunk shaker (Fruit Harvesters International, Alva, Fla.). Shaking time and energy input was constant for all trees. Fruit removal as a percentage of total tree yield was determined after hand picking the remaining fruit from each

tree. The degree of complete abscission (calyx or stem fully abscised) was measured on a subsample of 100 fruit shaken from the tree.

Observations were continued on the younger group of 36 trees. Fruit quality parameters (sugar, acid, juice content, fruit, and juice color) were determined after 14 d (Wardowski et al., 1995) and fruits were harvested by hand 21 d after application. The incidence of pitting of the fruit peel at harvest was visually rated on a scale of 0 to 10 (0 = none; 10 = severe). Leaf loss was measured by recording the weight of leaves accumulated under the canopy within the 3-week period. Overall injury to the canopy was visually assessed 2 months, and development of the new crop was rated 4 months, after treatment with metsulfuron-methyl. Flush intensity, canopy appearance, and intensity of fruit set were graded on a scale of 0 (no flush or fruit) to 10 (full canopy, normal flush and fruit set).

The experiment was analyzed as factorial (concentration, volume, and tree age) with three replications per treatment per tree age using variance and regression analyses and SAS procedures (SAS Institute, Cary, N.C.).

Results

All dosages of metsulfuron-methyl significantly reduced FDF 7 d after application (Fig. 1) and FDF decreased as concentration of metsulfuron-methyl and spray volume increased. Analysis of variance for all parameters of fruit loosening consistently attributed a larger proportion of the effects to spray volume than to solution concentration (Table 1). At application volumes of 1900 and 4700 L·ha⁻¹, concentrations of 1, 2, and 4 mg·L⁻¹ metsulfuron-methyl loosened fruit significantly, but at 470 L·ha⁻¹, only the 4 mg·L⁻¹ treatment was effective. The minimum FDF was attained on day 14 and did not change substantially thereafter. Fruit internal ethylene concentrations were significantly correlated with FDF on day 10 and 14 ($r = -0.844$ and -0.875). Fruit drop caused by metsulfuron-methyl treatment followed the trends in FDF (Fig. 2). At the lowest volume (470 L·ha⁻¹) fruit drop remained low at all concentrations of metsulfuron-methyl. At the medium volume, 2 and 4 mg·L⁻¹ caused 30% to 55% fruit drop. Only at the highest volume did 1 mg·L⁻¹ induce significant drop.

Removal of fruit by trunk shaker ranged from 69% to 98% and was correlated with dosage of metsulfuron-methyl (Fig. 3A), FDF ($r = -0.900$), and internal ethylene concentration ($r = 0.808$) 10 d after application. At the high volume, 1, 2, and 4 mg·L⁻¹ metsulfuron-methyl significantly improved harvesting efficiency. Some fruit were removed with parts of the stem still attached. The degree of complete fruit abscission at the calyx increased with dosage (Table 2).

Application of metsulfuron-methyl caused pitting of the fruit surface, which was correlated with dosage (Fig. 3B). Neither peel color nor Brix-acid ratio were affected by any treatment (data not presented).

Severe defoliation and twig dieback were

Table 2. Effects of application rate (a.i./ha) of metsulfuron-methyl on cumulative fruit drop 21 d after application, complete peduncle removal from mechanically harvested fruit (day 10), and flush and flower intensity of 'Hamlin' orange trees 2 months after treatment. All spray solutions included the adjuvant Kinetic (0.125%), and were buffered to pH 6.5 with BufferXtra Strength.

Application rate g·ha ⁻¹	Concn (mg·L ⁻¹)	Spray volume (L·ha ⁻¹)	Fruit drop (%)	Peduncle removal (%)	Flush intensity Score ^a	Flower intensity Score ^a
0.0	0	470	4.7	4.4	10.0	8.3
0.0	0	1900	3.8	14.1	10.0	7.8
0.0	0	4700	5.7	11.8	10.0	8.9
0.47	1	470	2.3	18.5	10.0	6.1
0.94	2	470	4.4	11.6	10.0	7.2
1.88	4	470	10.7	24.1	7.8	0.5
1.90	1	1900	8.2	40.5	9.4	5.5
3.80	2	1900	34.2	86.9	5.6	3.9
4.70	1	4700	31.2	62.5	6.1	5.0
7.60	4	1900	61.3	47.6	3.9	1.7
9.40	2	4700	80.5	81.5	0.0	2.8
18.8	4	4700	74.9	73.1	0.0	0.0
SD			6.19	9.56	1.49	2.08
CV (%)			24.5	24.5	21.5	43.2
r ^b			0.893	0.710	-0.915	-0.750

^aScore of 10 indicates full flush or flowering; 0 = complete abscission of young leaves or flowers.

^bLinear correlations with application rate are significant at $r > 0.576$ ($P = 0.05$) for flush intensity or $r > 0.708$ ($P = 0.01$) for flower intensity.

observed on trees treated with metsulfuron-methyl at 2 and 4 mg·L⁻¹ and to a lesser degree at 1 mg·L⁻¹, regardless of volume (Fig. 3B), and increased with dosage. Flush development and flowering 2 months after treatment were suppressed (Table 2), and subsequent fruit set declined with dosage (Fig. 3B). Analyses of variance indicated that solution concentration was more important than spray volume in determining injury level (Table 1).

Despite the large difference in tree size, fruit loosening up to day 10 was similar for both tree groups (separate data not presented). When scored after 2 months, canopy injury at the highest application rate (>18.8 g·ha⁻¹ a.i.) was equal for both age groups, but at the medium rates (1.9–7.6 g·ha⁻¹) the younger trees appeared to be more affected. After 4 months, however, the older trees had lower scores for fruit set and canopy status than did younger trees, which recovered slightly better (data not presented).

Discussion

The rate of application of metsulfuron-methyl is critical to its performance as an abscission agent (Hartmond et al., 1999; Wilcox and Taylor, 1997). In this study, metsulfuron-methyl loosened 'Hamlin' oranges at a wide range of dosages. Increases in both the solution concentration and the spray volume improved fruit loosening, fruit drop, and fruit removal with a trunk shaker in proportion to the dosage (Fig. 3A). The analyses of variance consistently implied a larger effect of volume than of concentration on fruit loosening, demonstrating the importance of adequate coverage with higher volume sprays (Table 1). Interactions between volume and concentration were caused mostly by the experimental design that included three levels of controls.

Peel pitting and canopy injury also intensified with increasing dosage of metsulfuron-methyl (Fig. 3B). While leaf loss up to day 21 was not severe, the phytotoxic effects of metsulfuron-methyl became excessive over the following weeks. Two months after spraying, flush and flowering were strongly reduced or completely suppressed at 2 and 4 mg·L⁻¹, respectively. The smaller trees, which received relatively more of the spray solution per unit of canopy volume, initially exhibited more injury (2 months after spray). Because they were growing more vigorously, their recovery was slightly better than that of older trees. Although all trees flushed, fruit set, and thus the 1998–99 crop, was either strongly reduced or completely lost depending on dosage.

Decreasing dosages reduced phytotoxicity, but reduced fruit loosening as well. A dosage of 1.9 g·ha⁻¹ (10 mg/tree) was the maximum amount of metsulfuron-methyl that could be applied safely. Dosages between 1 and 1.9 g·ha⁻¹ gave acceptable combinations of phytotoxicity and fruit abscission in 'Hamlin' trees, while dosages <1 g·ha⁻¹ typically gave no response.

Based on limited studies with branches and

Fig. 3. Effect of application rate of metsulfuron-methyl (g·ha⁻¹ of a.i.) on (A) fruit internal ethylene content (day 14), fruit detachment force (FDF, day 14), and fruit removal with a trunk shaker (day 10), and (B) on peel pitting of the fruit (day 21), canopy appearance (after 2 months), and fruit set (after 4 months) of 'Hamlin' oranges. Dundee, Fla., 1998.

very young trees, Wilcox and Taylor (1997) reported that metsulfuron-methyl effectively loosened citrus fruit (including 'Hamlin') with no deleterious side effects when applied to incipient runoff. Their recommended safe dosage of metsulfuron-methyl ($2 \text{ mg} \cdot \text{L}^{-1}$ applied in $1900 \text{ L} \cdot \text{ha}^{-1}$) consistently caused fruit pitting, defoliation, twig dieback, and flower inhibition in this and our follow-up experiments. Other factors may be responsible for the disparity between our results, specifically, grove conditions and environmental stresses. However, the severity of lasting side effects that are consistent with the manufacturer's label as a herbicide exclude metsulfuron-methyl from further consideration as an abscission chemical for citrus.

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