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In-place Elimination of HLB-infected Trees through Application of Phytotoxic Chemicals

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Current recommendations for dealing with huanglongbing (HLB) affected trees call for scouting four times per year and clipping or chain-sawing the trunk (stumping) for removal of the infected trees as soon as possible after each scouting. Tree removal is labor intensive, costly, and difficult to schedule during the harvest season. An alternative method would be to kill the infected trees in-place and remove them at a convenient time and not more than once per year. Experiments were conducted to determine the effectiveness of herbicides and their method of application for killing mature citrus trees in situ. Canopy sprays that included Remedy (trichlorpyr) were effective, but Landmaster II (glyphosate + 2,4-D) did not kill the trees, but both resulted in canopy damage to adjacent trees. Spraying the inside canopy from under the tree was effective if the spray covered the more distal growth towards the row middle. Again, Remedy was more effective than Landmaster II. Cutting four sides of the trunk with 10 cuts from a hand hatchet and spraying the cuts with concentrated herbicide worked well with Arsenal (imazapyr) or Clearstand (imazapyr + metsulfuron methyl), but Remedy, Landmaster II, and 2,4-D alone were not very effective. Commercialization of this method will probably require a vehicle-mounted attachment to make the cuts and spray the chemical. Tests were also conducted with soil injection of the fumigant Midas (iodomethane). This procedure worked fairly well on small to medium size trees, but further testing is needed to increase consistent tree kill on large trees. Successful application of the trunk herbicide or soil fumigant method should be a cost-effective replacement for stumping HLB affected trees, but these chemicals are not cleared for use in citrus and require pesticide use labels.

Because huanglongbing (HLB) affected trees can serve as inoculum sources for further spread of the causal agent (*Candidatus* Liberibactor asiaticus) by the Asian citrus psyllid (*Diaphorina citri* Kuwayama), current recommendations call for good psyllid control and removal of HLB infected trees as soon as possible after each scouting, three to four times per year (<http://www.crec.ifas.ufl.edu/extension/greening/management.htm>). Using a clip-shear unit with sprout inhibiting herbicide (stumping) is estimated to cost from $8.50 to $5.70 per tree as number of trees removed increases up to 10% (Muraro, 2008a). A lower cost alternative would be beneficial for citrus growers, particularly since psyllid control and HLB scouting increase production costs by $200 to $500/acre (Muraro, 2008b).

One of the options would be to kill the HLB infected trees in-place and remove them only once every year or two. Besides reducing clipping costs by increasing the number of trees per clipping, some scouting costs for secondary flagging and tree marking for the stumping operation also might be eliminated. Herbicides are a standard part of citrus production practices with a goal of effective weed control with minimal damage to the citrus tree. Glyphosate and 2,4-D appeared to be reasonable candidates for testing their ability to kill HLB infected trees as they are systemic and in combination are registered for citrus grove use (Landmaster II; Futch and Singh, 2009). In addition, chemicals used to kill invasive plant species such as imazapyr are good candidates for testing. (DiTomaso, 2000).

While testing methyl bromide soil fumigation, workers have reported killing citrus trees (personal communication). Another fumigant, Midas (iodomethane), also was of interest due to the reduced use and availability of methyl bromide. This product also was included in the trials.

The purpose of this study was to examine possible chemicals, herbicides, and one soil fumigant, along with methods of application in order to find chemicals that would effectively kill HLB infected citrus trees in place. This would reduce the frequency of tree stumping and overall costs of HLB infected tree removal.

Materials and Methods

Initial tests for killing mature citrus trees with herbicides evaluated full canopy sprays. Landmaster II (glyphosate and 2,4-D) was selected as a herbicide that is registered for citrus use. Remedy was selected as a herbicide that in combination with diesel, is known from some experimental use to be fairly phytotoxic to citrus and is labeled for sprout inhibition after stumping (Anon, 2008). These materials were sprayed at 1.25% and 2.5% (v/v) product in water with a surfactant-spreader and at 1 gal per tree in a pressurized sprayer (125 psi) using a hand spray gun. Some herbicide mixtures included urea or phosphorous acid as they are often phytotoxic in high concentrations. Trees were evaluated at 2, 4, and 6 weeks after application. Three tests were done on different dates from spring through fall of 2007 on healthy mandarin seedling trees near Lake Alfred, FL.

Based on these results, a U-shaped inverted spray boom manufactured by Chemical Containers (Lake Wales, FL) was

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Fig. 1. A spray boom designed to spray upward inside the canopy to minimize spray or drift on adjacent, non-HLB trees.

designed to spray up into the canopy of target trees (Fig. 1). A test on full size and young bearing 'Valencia' trees affected by HLB about 5 miles north of Lake Placid, FL was conducted on 25 Mar. 2008 using this boom and the Landmaster and Remedy products at a concentration of 0.125% (v/v) product with 0.25% (v/v) diesel in water sprayed at 0.5 gal/tree.

Four tests were conducted near Ft. Basinger, FL on mature 'Valencia' orange trees from 8 Sept. 2008 to 15 Apr. 2009. The trunks of the trees were cut 10 times with a hand hatchet, three cuts on each side of the trunk facing the row middle and two on each side in the tree row (Fig. 2). Each cut was 0.3 to 0.6 inch deep, and 0.33 oz (8 to 10 mL) of herbicide solution was sprayed into the 10 cuts. In test one, Remedy with diesel, Landmaster and Arsenal (imazapyr) were applied at 1:1 dilution. In test two (14 d later), the products were sprayed without dilution since little effect was observed from the applications made in test one by this time. In tests three and four, Arsenal and ClearStand (imazapyr plus metsulfuron methyl) were sprayed in cold weather and during the spring, respectively, using 1:1, 1:4, and 1:10 dilutions.

Tests of Midas (iodomethane) soil fumigant were conducted at three sites (two in Lake Placid and one in Lake Wales, FL). Rates of 0.2 to 0.5 lb product per tree were applied in one to four soil probes to 18-inch depth using a stainless steel tube filled with another tube of non-absorbing plastic. Generally, rates and number of probes were increased as tree size increased with details provided with the data. In the last test, one treatment included wetting the soil surface immediately after injection.

Results

In the full canopy spray tests, only Remedy with diesel killed the citrus trees, but even so only 14 of 24 total treated trees were completely killed by the various combinations of Remedy with diesel. Landmaster did not completely kill any trees and additions of urea or phosphorous acid to the spray mixes did not increase the apparent damage or killing of the treated trees (data not shown). Adjacent trees always had some foliage damage as it was not possible to avoid some overspray to these trees in hedgerows when using a hand gun to spray the trees (Fig. 3A). Even when some space occurred between trees, there was usually some damage

Fig. 2. Hatchet cuts and a small hand sprayer were used to apply herbicides to trunks of trees.

Fig. 3. Herbicide damage to adjacent trees in a (**A**) tight hedgerow and even when (**B**) trees had some space between them.

to the non-target trees (Fig. 3B). The last test examined spraying only the inside of the trees to avoid this overspray problem, and Remedy worked as well by this method as when the whole canopy was sprayed (6 of 12 killed compared to 8 of 12 for full canopy sprays).

When the upward spray boom was tested, Remedy with diesel killed many of the trees but Landmaster II, even with

Table 1. Effect of various herbicides on percentage tree death after inside canopy sprays with a upward spraying U-shaped boom (Fig.1). Evaluations were 1 and 2 months after application.

Treatment on 25 Mar. 2008	% Tree death 25 Apr. 2008	% Tree death 25 May 2008
Landmaster + diesel	30 A[z]	48 A
Remedy + diesel	80 B	75 B
Landmaster II + Remedy + diesel	30 A	58 A

[z]Numbers in columns with different letters are significantly different at the 1% level.

diesel, did not (Table 1). The overall effect of these sprays was usually evident in 30 d with little change by 60 d. Smaller trees were usually killed, but larger trees with limbs growing into row middles were not affected very much due to poor spray coverage of these outward growing limbs (Fig. 4). A better spray boom design with additional nozzles directed to cover these outside limbs was needed.

When applied to mature 'Valencia' trees east of Sebring, the trunk cut and spray method worked well with imazapyr products, but Remedy, Landmaster II, or Arsenal with 2,4-D were not as effective (Table 2; Fig. 5). Remedy with only water dilution appeared to be less effective than with diesel, but neither completely killed trees. Adding 2,4-D to Arsenal decreased the effectiveness of Arsenal. The 1:1 dilution of Arsenal was nearly as effective as using the undiluted product. Only one tree had less than total kill (95%), probably due to poor location of the cuts. Symptoms started as disappearance of new flush in 7 to 10 d, followed by fruit drop and then leaves. Twig dieback and complete leaf loss took 30 d or longer. No new growth or root sprouting was observed.

Arsenal and a similar product, Clearstand (imazapyr + metsulfuron methyl), were tested in one of the coldest weeks in 2008 to see if there was sufficient vascular transport for the products to be effective (Table 3). Results were as good as in earlier trials using this method. On the other hand, a similar test in the spring resulted in lower percent tree kill, particularly at the more dilute spray concentration (Table 4). Whether this was due to movement of too much of the chemicals into the extensive new spring growth or other factors needs more study. Additional tests are needed to determine the highest dilution that consistently results in 100% tree kill, but in general, this method was very effective and used very little of the best chemicals, about 0.33 oz of a 1:3 or 1:10 dilution. From a practical point of view, a front-end attachment on a four-wheeler utility vehicle that will cut the trunk and apply the herbicide is needed.

An alternative method of tree killing using a soil fumigant was tested with promising results. Midas (iodomethane) was applied using one to four probes/tree in a preliminary test near Lake Placid. Small trees, <5-inch diameter, were usually killed with one probe of 0.3.lb product applied about 1 ft from the trunk. Large trees, >15-inch diameter, often were not affected when 0.5–0.6 lb Midas was applied with three to four probes per tree (0.125–0.165 lb/probe). Placing the probe under the trunk or more than 2 ft from the trunk appeared to be less effective than near the trunk. Results on intermediate size trees varied, but usually a large part of the canopy was killed (data not shown). From these preliminary tests it was obvious that more studies about rate and probe placement were needed.

In a subsequent test near Alcoma, FL (Tables 5 and 6), small and large mature trees were tested with different numbers of probes,

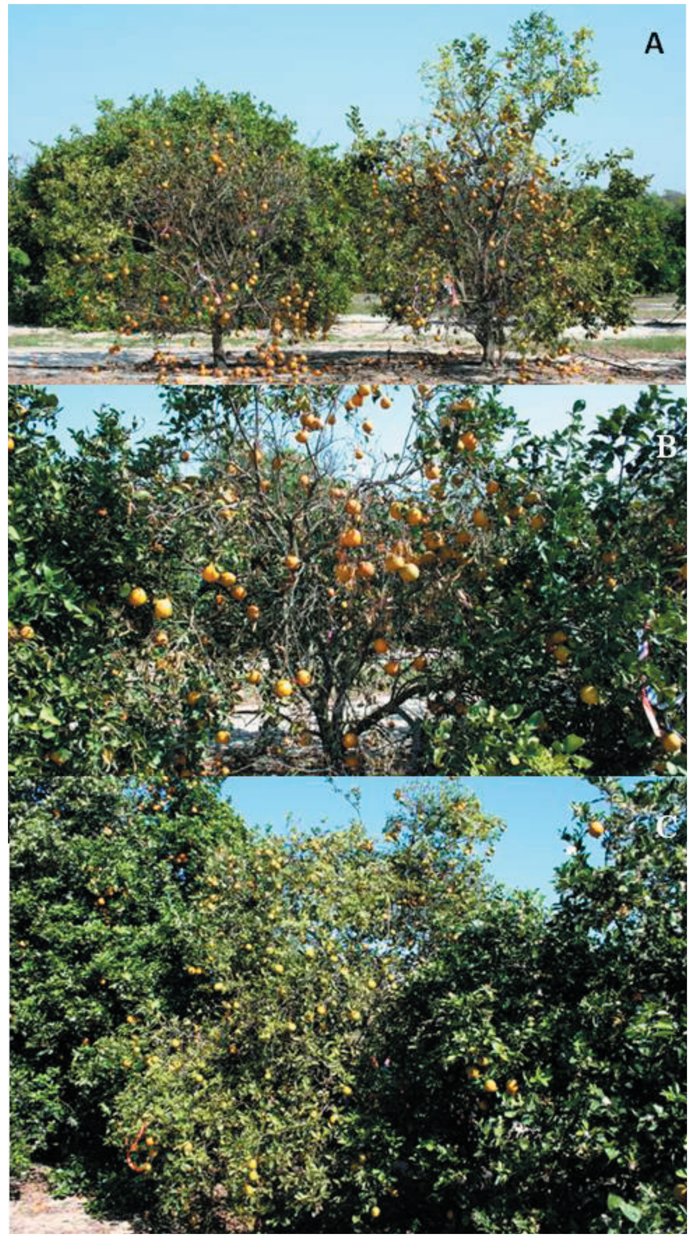

Fig. 4. Most of larger trees killed by Remedy with diesel sprayed with under-tree boom (**A**), and no adjacent tree damage even in tight row (**B**), but weak coverage of large limbs growing into row middles often happened due to the lack of an outward spray pattern in boom design (**C**).

Table 2. Preliminary tests with undiluted and 1:1 diluted sprays of several herbicides done on mature 'Valencia' trees in two separate tests about 2 weeks apart.

Treatment	Concentrated product % tree kill	Diluted 1 to 1 % tree kill
Arsenal	100 B[z]	99 C
Arsenal + 2, 4-D (80 % active)	59 A	ND
Remedy + diesel	65 A	60 B
Remedy + water	ND	40 A
Landmaster II	ND	35 A

[z]Numbers in columns with different letters are significantly different at the 1% level; ND = no data.

Fig. 5. Example of poor tree kill using Remedy with the trunk cut and spray method (**A**), but imazapyr products gave better results (**B**).

Table 3. Tree killing from trunk cut application of imazapyr products on 14 Jan. 2009, with maximum air temperature of 66 °F and maximum temperatures of 53 to 73 °F during the following week.

Product concn:	50%	25%	10%
	% tree kill	% tree kill	% tree kill
Clearstand	96 B[z]	96 B	75 A
Arsenal	100 B	90 AB	83 A

[z]Numbers with different letters are significantly different at the 1% level.

Table 4. Tree killing from trunk cut application of imazapyr products on 15 Apr. 2009, when trees had spring flush and maximum air temperatures were 79 to 85 °F.

Product concn:	50%	25%	10%
	% tree kill	% tree kill	% tree kill
Clearstand	100 c[z]	95 c	66 b
Arsenal	85 c	45 b	11 a

[z]Numbers with different letters are significantly different at the 5% level; ND = no data.

amount of fumigant, and distance from the trunk. Two probes placed 1 ft from the trunk on opposite sides of the tree gave the most consistent results (70% kill or higher), when compared to one probe placed 2 ft from or under the trunk for smaller trees (Table 5). For trees with >10-inch diameter, two probes and three probes at 1 ft from the trunk (80% to 100% kill) gave better results than under the trunk or 2 ft from the trunk and were slightly better than four probes 2.5 ft from the trunk (Table 6).

Table 5. Test of Midas soil fumigant on smaller trees, trunk diameters of 4.7–10 inches using 0.3 lb product per tree.

No. probes/ distance FT[z]	Lb/probe	Lb/tree	% Kill	% Kill range
1 / UT	0.3	0.3	68 B[y]	33–100
1 – 1 ft	0.3	0.3	57 B	35–100
1 – 2 ft	0.3	0.3	13 A	0–70
2 – 1 ft	0.15	0.3	87 C	70–100
2 – 2 ft	0.15	0.3	72 B	40–100

[z]Distance FT = distance from trunk, UT = under trunk.
[y]Numbers in columns with different letters are significantly different at the 5% level.

Table 6. Test of Midas soil fumigant on larger trees with diameters of 10–30 inches using 0.5 lb product per tree.

No. probes/ distance FT[z]	Lb/probe	Lb/tree	% Kill	% Kill range
1 / UT	0.5	0.5	42 a[y]	5–95
1 – 2 ft	0.5	0.5	63 a	10–100
2 – 1 ft	0.25	0.5	92 b	80–100
2 – 2 ft	0.25	0.5	56 a	15–100
3 – 1 ft	0.165	0.495	96 b	80–100
3 – 2 ft	0.165	0.495	53 a	10–90
4 – 2.5 ft	0.125	0.5	96 b	75–100

[z]Distance FT = distance from trunk, UT = under trunk.
[y]Numbers in columns with different letters are significantly different at the 5% level.

Table 7. Test applying Midas soil fumigant to various sized trees using 0.3, 0.4, or 0.5 lb product and different numbers of probes as tree diameter increased.

Trunk diameter	No. probes[z]	Lb/probe	Lb/tree	% Kill	% Kill range
3.5–5 inches	1	0.3	0.3	60[y]	50–100
3.5–5 inches	2	0.15	0.3	92	50–100
3.5–5 inches	3	0.10	0.3	87	15–100
5–9 inches	2	0.2	0.4	90	50–100
5–9 inches	3	0.13	0.39	98	85–100
10–19 inches	2	0.25	0.5	53	10–100
10–19 inches	3	0.165	0.495	87	70–100
10–19 inches	4	0.125	0.5	82	40–100

[z]All probes placed 1 ft from trunk
[y]There were no significant treatment differences.

In a third trial on bearing 'Valencia' orange trees with HLB near Lake Placid, we tested product amount and probe number, all placed 1 ft from the trunk. Trees were divided into small (<5-inch diameter) receiving 0.3 lb Midas, medium (>5- to 10-inch diameter) receiving 0.4 lb Midas, and large (>10-inch diameter) receiving 0.5 lb Midas per tree (Table 7). For small trees, one or two probes worked better (50% to 100% kill) than three (15% to 100% kill), perhaps because at the low dosage per probe with three probes some root areas were not adequately killed. For medium size trees, dividing 0.4 lb Midas in three probes was more consistent (85% to 100% kill) than two probes (50% to 100% kill). The three probes placed just off root flares evenly spaced around the trunk left fewer canopy areas without an associated root flare. For larger trees, the most consistent results

Fig. 6. Soil fumigation with Midas killed most smaller mature trees (**A**), but results were inconsistent on larger trees (**B**).

were with dividing 0.5 lb of Midas into three probes (70% to 100% kill), while two and four probes had trees with as little as 10% and 40% kill, respectively. An attempt to improve total tree kill on larger trees by irrigating to wet the soil immediately after injection to hold the fumigant longer did not improve the results (data not shown). A recent study (Guo and Gao, 2009) indicated that moderate soil moisture did not influence methyl iodide degradation compared to dry soil but higher temperature did increase rate of degradation.

Observations from these tests indicated that probe placement about 1 ft from the trunk was better than 2 or more ft away or directly under the trunk. Often, poor results were obtained if the probe alignment was not directly out from the root flares. Although the data were limited, it did appear that 0.1 lb or less Midas per probe was not very effective. On the other hand, 0.4 lb or more per probe did not appear to increase tree kill. Fumigant needed to kill a tree did appear to increase with tree size, but even large amounts did not consistently kill large trees, some of which were hardly affected. Perhaps the thicker bark around the lower trunk and root flares of larger trees inhibited uptake of the fumigant. Overall, the percent kill was too variable and further work is needed to provide more consistent results, hopefully, with lower amounts of fumigant.

Among the herbicide application methods tried in these trials, the best method was trunk application of imazapyr products sprayed into shallow hatchet cuts. As little as 0.33 oz of a 1:3 or 1:10 diluted product was effective. This treatment showed evidence of young flush removal in about 10 d but it took more than 30 d for significant dieback to develop. No new flush or root sprouting was evident. Clearance and labeling would be required for this use as there is no label for imazapyr products on citrus.

The soil fumigation tests with Midas (iodomethane) worked quickly, causing tree death in as little as 10 to 14 d but results were not consistent, particularly on larger trees. Again clearance and a label for this use would be needed. Further work on probe placement, product/probe, effects of soil moisture on efficacy, and other factors are needed. Both trunk herbicide and soil fumigation would require machinery to apply the treatments quickly and safely.

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