Effects of Glyphosate on Apple Tree Health

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The herbicide glyphosate (Roundup and generics) has been used in fruit plantings for many years and is critically important for controlling weeds such as Canada thistle, poison ivy, sumac, brambles, and other woody perennials that are difficult to control with other herbicides. However, over the past decade, we gradually became aware that glyphosate might be a contributing factor for some apple tree diseases and postharvest storage problems.

> **"Our research has shown that although glyphosate can exacerbate internal browning of Empire fruit in some orchards and some years, the overall impacts of glyphosate exposure in apple trees are inconsistent and less significant than we initially feared."**

Glyphosate kills plants by blocking a critical enzyme pathway known as the shikimic acid pathway. The blocked enzyme is essential for respiration in plants, so plants that receive a full dose of glyphosate cannot survive unless they are engineered to be glyphosate-resistant or have developed field resistance. At lower concentrations, however, glyphosate can adversely affect plants without producing any immediately visible effects. Glyphosate has been shown to enhance disease development in some crops by interfering with host defense mechanisms, plant rhizosphere microorganisms, and mineral uptake and translocation within exposed plants (Johal and Huber, 2009). Researchers in Ohio reported that glyphosate applied to trunks of container-grown ornamental trees, including crab apple trees, reduced winter hardiness, and the elevated levels of shikimic acid caused by the glyphosate exposure could be detected in the leaves of glyphosate-exposed trees for at least two years (Daniel et al., 2009). They also noted that trunks of trees exposed to glyphosate frequently developed vertical cracks in the bark.

Our own field observations suggested that lower scaffolds on apple trees that had been exposed to glyphosate drift could be "winter killed" in a single year whereas the tops of those trees still appeared healthy (Figure 1). In most of those cases, a few leaves could be found that showed the typical narrowed, strap-leaf pattern on foliage that is typical of glyphosate injury, but the majority of the surviving foliage showed none of the classic glyphosate toxicity symptoms.

Starting about 2003, we began seeing trees with basal trunk cankers that appeared where herbicide applied via boom sprayers was hitting the lower portions of the trunks. The damage was especially severe on Macoun trees, although other cultivars were also affected. Observations in numerous orchards led to the hypothesis that glyphosate exposure predisposed the trunks to infection by

Figure 1. Lower limbs of a Jonamac tree (left) showing dieback from winter injury that occurred after these limbs were exposed to sublethal drift from glyphosate applied the previous season (Photo by Mike Fargione).

Botryosphaeria dothidea, a canker fungus that could girdle the trunks (Rosenberger & Fargione, 2004). Since that time, growers in the northeast have lost thousands of Macoun trees to the basal trunk cankers that were described in 2004. However, the link between glyphosate and basal cankers on apple trees has never been verified in controlled trials.

Because the shikimic acid pathway is important in development of plant defense mechanisms and in fruit ripening processes, we initiated studies to determine if sublethal exposure of apple trees to glyphosate as may occur via drift or uptake through root suckers or green bark would impact (i) the incidence/severity of internal browning in Empire apples during long-term storage, or (ii) susceptibility of exposed trees to spread of fire blight during summer.

Impact of Glyphosate Exposure on Internal Browning

Our initial work with glyphosate and internal browning indicated that fruit from trees exposed to glyphosate during late summer developed more internal browning during controlled atmosphere storage than fruit from control trees (Rosenberger *et al.*, 2010). Similar trials were conducted again in 2010 and 2011 on several different farms. Only farm FO was used in all three years, and on that farm different trees were used each year to avoid any carry-over effect from the previous year's treatments. After 2009, simulated glyphosate drift was applied to both leaves and fruit on a lower limb of each tree and we omitted any further attempts to expose only terminal leaves without contacting fruit on that limb. For treatments applied in 2011, we included trees where glyphosate was applied only in June or only in early August, and in August some trees were treated with glyphosate solution that contained 3 ml/gal of Roundup PowerMax® as compared to the lower rate of 1 ml/gal that was used in 2009 and 2010. Even at the higher rate of 3 ml/gal, the concentration of glyphosate used to simulate drift was only about 7.5% of the concentration that would commonly be used to control weeds in August applications.

In another trial initiated in summer of 2011, effects of treatments on internal browning were assessed using fruit from small Empire trees on Bud.9 rootstock that had been planted at the Hudson Valley Lab in 2008. Seven treatments were replicated 10 times in 2011 and 9 times in 2012 using single-tree plots, and the same treatments were applied to the same trees each year. In addition to the untreated control, glyphosate (Touchdown Total) was applied to either leaves and fruit on a lower limb or to root suckers at various times during the summer. Fruit were harvested on 27 September 2011 and 20 September 2012. The September glyphosate treatments would be commercially impractical due to conflicts with harvest but were included here to determine if applications shortly before harvest would induce more browning than earlier applications.

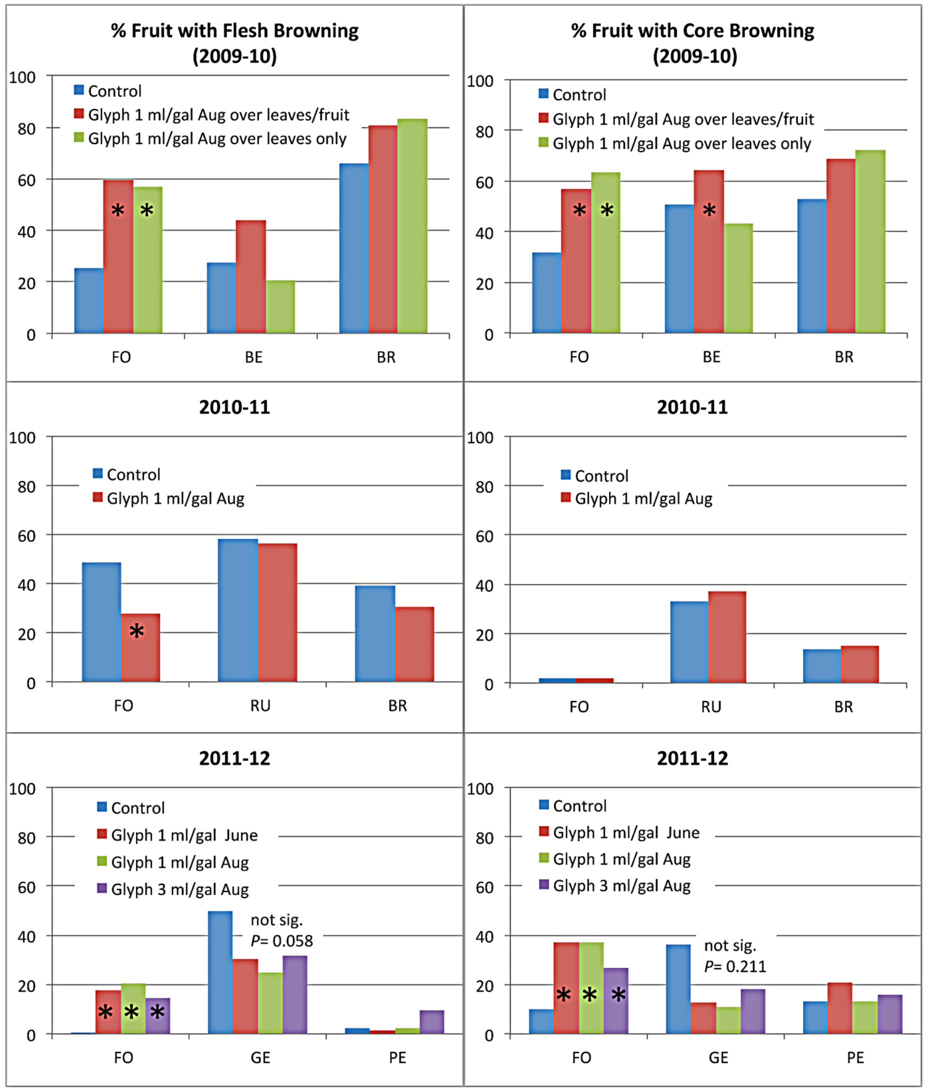

Figure 2. Effects of glyphosate exposure on the incidence of flesh browning and core browning detected in Empire fruit after 8.5 months of CA storage. Results are shown for treatments applied to three farms in each of three successive years. Except for farm FO, the same farms were not used every year. Asterisks indicate treatments that were significantly different (P ≤ 0.05) from the control for that farm.

In 2011, all treatments at the Hudson Valley Lab were applied by lightly misting the targeted foliage with a hand-held sprayer containing 3 ml of Touchdown Total per gallon. A section of insulation board was placed behind the targeted leaves to prevent drift to other leaves on adjacent trees or limbs. The low rate of glyphosate used in treatments 2 through 4 was intended to simulate glyphosate drift that might occur when small droplets are blown onto lower leaves during commercial applications of glyphosate. Root suckers were treated with a solution containing 31.5 ml of Touchdown Total per gallon, which is equivalent to a rate of 1 qt/A in a sprayer that was calibrated to deliver 30 gal of spray solution per acre. The higher rate was used for root suckers because suckers at the base of trees are generally exposed to the full rate that is being applied. The root suckers that were sprayed in June were generally 6-12 inches long whereas the root suckers sprayed in August and September were 18-24 inches long.

In 2012, the treatments at the Hudson Valley Lab were applied with a micropipette to allow accurate measurement of the dose applied to each tree. The same concentration of Touchdown Total (62.4 ml/gal, which is equal to 2 qt/A in 30 gal of water) was used for both limbs and root suckers. Treatments were applied with a micropipette by placing a 5-µl droplet on each of 50 different leaves around the lower tree canopy for limb treatments and by placing 50 of the 5-µl droplets on the available leaves on two root suckers per tree for trees receiving root sucker treatments. The same treatments (limbs vs. root suckers) were applied to the same trees in each year so as to increase the potential for detecting cumulative effects of treatments.

In all of the field trials, 25 fruit per tree were harvested at maturity and were immediately transported to Ithaca where they were held in controlled-atmosphere storage (2% O_2, 2.5% CO_2) for 8.5 months. None of the fruit were treated with 1-MCP prior to storage.

Glyphosate treatments applied to trees in the summer of 2009 resulted in increased incidence and severity of both flesh browning and core browning for farm FO and of core browning for one of the two glyphosate treatments at farm BE with similar trends on farm BR (Figure 2; Rosenberger *et al*., 2010). Results from the next two years were less consistent. Fruit from the 2010 field treatments showed either no effect from glyphosate exposure or, in the case of farm FO, the opposite effect from what was observed in the 2009-10 trial (Figure 2, center). In the 2011-12 trials, farm FO had results similar to those noted in the first year of these trials (Figure 2, bottom), but Farm GE showed less internal browning where glyphosate had been applied ($P = 0.058$). Differences in treatment timing and glyphosate dose had no effect on development of browning in the 2011-12 trials in western New York.

In the orchard at the Hudson Valley Lab, fruit from three treatments involving glyphosate applications to lower limbs had a higher incidence of flesh browning in 2010 than fruit from trees with treated root suckers when combined treatments in each category were compared ($P = 0.02$; Figure 3A). However, analysis of the seven individual treatments showed that none of the treatments differed from the controls. Furthermore, differences between root sucker exposure and canopy exposure detected in 2010 were absent in fruit harvested in 2011. Even though the same trees received the same treatments in two successive years at the Hudson Valley Lab, tree-by-tree comparisons showed no correlation from one year to the next in the percentages of fruit with browning ($P=0.098$, $R^2=0.047$ for core browning; $P= 0.424$, $R^2=0.011$ for flesh browning). Timing of glyphosate exposure had no significant impact on the incidence of browning although there was a trend toward more core browning in 2011-12 with applications that were made closer to harvest (Figure 3B).

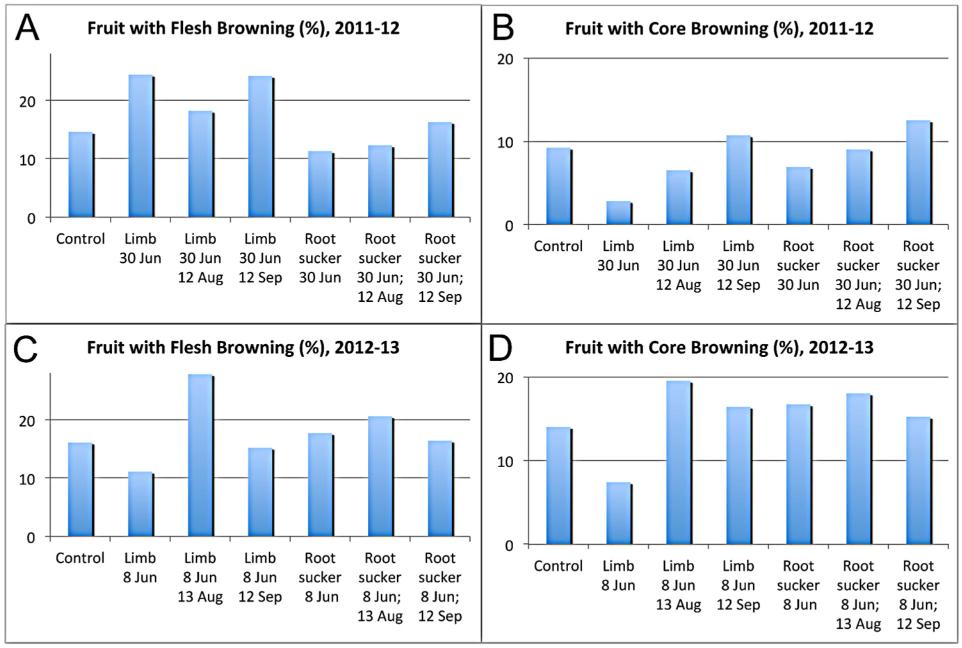

Figure 3. Effects of glyphosate applied to either lower limbs (as a simulation of drift) or to root suckers at various times of year on the incidence of flesh and core browning that developed on Empire apples grown at the Hudson Valley Lab in Highland, NY and stored in controlled atmosphere for 8.5 months. The same trees were used for the same treatments in both years. Analysis of variance showed that there were no significant treatment effects, with P-values of 0.337, 0.340, 0.482, and 0.441 for comparisons shown in A, B, C, and D, respectively.

After evaluating fruit from 11 different field trials between 2009 and 2013, the relationship between glyphosate exposure and the incidence and severity of internal browning in Empire apples during CA storage remains unclear. In three of 11 trials we detected glyphosate-related increases in flesh browning and/or core browning, but the reverse effect was noted on one trial and approached the level of significance in another trial. The time of glyphosate exposure (June vs. late summer) did not affect the incidence of browning in our trials.

The varying response to glyphosate (or lack thereof) in our trials is presumably attributable to differences in the role shikimic acid synthesis was playing in fruit maturation at the time the glyphosate was applied. Other sources of variation may have included the dose that reached the fruit and other environmental factors (weather, soil moisture, crop load, etc.) that would be expected to vary from site to site and year to year.

Impact of Glyphosate Exposure on Spread of Fire Blight

To determine if sublethal exposure to glyphosate would affect susceptibility of trees to fire blight, trials were conducted in a tightly spaced meadow orchard of the cultivar Lady Apple propagated on MM.111 rootstocks and planted in 2007. Trees were pruned back severely each year to encourage an abundance of vigorous vegetative shoots. In both 2011 and 2012, treatments that included a control and several doses of glyphosate were replicated four times in 6-tree plots. Two shoots on each tree were inoculated with the fire blight pathogen, *Erwinia amylovora,* in early June by introducing inoculum into wounds on a single unfolding leaf on each of the two shoots. Trees were exposed to known doses of glyphosate by applying micro-droplets from a pipette to lower leaves on each tree either several days before or after the trees were inoculated. Plots were monitored several times weekly, and all new blight infections (other than those on inoculated shoots) were removed as soon as they appeared. The length of the cankers on inoculated shoots was measured at the end of each growing season.

At the end of the 2011 season, we initially thought that trees exposed to the highest dose of glyphosate had 76% more fire blight strikes during the 28 days following inoculation than either control trees or trees exposed to the two lower doses of glyphosate. However, we later realized that some of the shoots that we had counted as fire blight infections in 2011 probably were dying from the glyphosate treatment itself rather than from fire blight. Therefore, in 2012 we did not count any dying shoots on the lower portions of trees as fire blight infections unless we could actually see bacterial ooze on the shoots. Infections in the upper parts of the tree were also carefully assessed to be certain that we were not confusing shoot blight with glyphosate injury. The dying shoots in the lower part of the tree canopy where glyphosate had been applied were counted separately and removed as they appeared so that we could quantify the number of glyphosate-killed shoots resulting from the various treatments. Most of these glyphosate-killed shoots were short secondary or tertiary branches that were two to 12 inches long, so removing them had no effect on tree structure.

In 2012, glyphosate treatments had no impact on the percent of inoculated shoots with symptoms of blight infection on 27 June or with visible cankers on 20 July (Table 1). The high dose of glyphosate applied six days before inoculation resulted in significantly less length of killed shoot above the inoculation point than did the non-glyphosate controls, suggesting that the growing shoot above the inoculation point was killed more quickly where the high dose of glyphosate was applied (Table 1).

Secondary spread of fire blight to non-inoculated shoots was also unaffected by glyphosate treatment (Table 2). The fact that we continued to find new strikes throughout the summer indicates that trees remained somewhat susceptible to spread of fire blight even thought the total number of new blight strikes was less than one per tree when results for the entire season were added together. Thus, we should have been able to detect any effect of glyphosate exposure if any had occurred.

The concentration of glyphosate used in both our 2011 and 2012 fire blight trials was higher than would occur from drift, but it was chosen because we wanted to use the maximum conceivable dose that trees could tolerate to ensure that the rates in our trials would encompass even the worst-case exposure scenarios for commercial orchards. The dose applied was high enough to cause die-back of some treated shoots on all of the exposed trees (Table 2). However, even these very high doses of glyphosate failed to make trees more susceptible to fire blight. Thus, glyphosate exposure did not increase either canker extension in inoculated shoots or the spread of blight to new shoots in either of the two years of this trial and we conclude that it is unlikely to play any role in the spread of fire blight in commercial orchards.

Table 1. Effects of 2012 glyphosate exposures on the incidence of fire blight symptoms on inoculated shoots.

Glyphosate treatment		% of inoculated shoots with			Canker length on as measured 20 July 2012		
Glyphosate dose[z]	timing as compared to inoculation date[y]	Dying shoot tips on 27 June	Any symptoms of blight on 27 June[x]	Fire blight cankers 20 July	Canker length below inoculation point (cm)	Killed shoot length above inoculation point (cm)	Total length of killed shoot and canker (cm)
Low	21 d. before	14.6	70.9	77.1	19.4	20.4 ab[w]	39.7 ab
High	21 d. before	16.7	77.1	83.3	20.0	17.6 a	37.5 ab
Low	6 d. before	20.9	70.8	83.4	21.5	18.4 a	39.8 ab
High	6 d. before	17.1	86.7	84.2	18.2	17.1 a	35.3 a
Low	6 d. after	13.3	78.4	78.8	20.4	25.0 bc	45.4 bc
High	6 d. after	19.6	76.7	84.6	20.6	18.0 a	38.6 ab
No glyphosate (control)		8.4	79.2	77.1	22.2	27.0 c	49.2 c
P-values		0.409	0.459	0.929	0.901	0.026	0.037

[z] Glyphosate treatments consisted of 10 µl of glyphosate solution applied to either 25 leaves/tree (low dose) or 50 leaves/tree (high dose). The treatment solution contained 68 ml of Touchdown Total in 1 liter of water.
[y] Treatments were applied to leaves either on 17 May (21 days before inoculation), 1 June (6 days before inoculation), or 14 June (7 days after inoculation). Trees were inoculated on 7 June.
[x] Symptoms included inoculated leaves with blackened veins or bacterial ooze, yellowed leaves on the inoculated shoot, or curling and necrosis of the shoot tip.
[w] Simple means within columns followed by the same lower-case letter are not significantly different as determined by applying Fisher's Protected LSD (P≤0.05).

Table 2. Effects of 2012 glyphosate treatments on the incidence of shoot blight in non-inoculated shoots and on the incidence of lower shoots killed or damaged by the glyphosate treatment.

		Mean number shoots/tree removed	
	Glyphosate	18 Jun to 17 Aug due to:	
Glyphosate dose	treatment timing	fire blight strikes	killed/damaged by glyphosate
Low	21 d. before	0.75 a	9.37 d
High	21 d. before	0.46 a	17.12 e
Low	6 d. before	0.63 a	2.08 b
High	6 d. before	0.29 a	4.76 c
Low	6 d. after	0.35 a	4.30 c
High	6 d. after	0.50 a	8.46 d
None (control)		0.71 a	0.00 a
P-values		0.432	<0.001

For treatment details, see footnotes for Table 1.

Conclusions and Recommendations

Subjective observations in commercial orchards suggest that repeated exposure of tree trunks to glyphosate can lead to development of basal trunk cankers and drift to foliage can make trees more susceptible to winter injury. However, glyphosate did not affect susceptibility to fire blight in two years of replicated trials, and it increased the incidence/severity of internal browning in Empire apples in only three of 11 trials. Thus, our research has shown that, although glyphosate can exacerbate internal browning of Empire fruit in some orchards and some years, the over-all impacts of glyphosate exposure are inconsistent and less significant than we initially feared. We can probably continue to use glyphosate in apple orchards if it is applied carefully.

Following are guidelines that should help to minimize glyphosate damage to apple trees.

1. Whenever glyphosate is applied, a drift-inhibitor should be included in the spray mixture to minimize the number of small droplets that are produced because the very small droplets are likely to drift upward onto apple foliage.
2. Where possible, a hooded boom sprayer should be used to apply glyphosate in orchards so as to minimize the bounce-back from bare soil that sometimes allows a haze of small droplets to drift upward into the trees.
3. The pressure on herbicide sprayers should be kept as low as possible (e.g. 20-30 psi) to minimize generation of small droplets, or air-induction nozzles should be used to further reduce the production of small droplets.
4. Cheaper formulations of glyphosate may be safer than the more expensive "fully loaded" formulations because the cheaper formulations usually do not contain the surfactants that were added to the more advanced formulations after the Roundup patent expired. High concentrations of surfactants may increase uptake through tree bark, so cheaper products with less surfactant should be safer around trees.
5. Avoid using glyphosate for sucker control on apples because doing so may reduce winter hardiness, especially if applications are made in August. Glyphosate should not be applied immediately after suckers are cut because it is readily absorbed by freshly cut stems.
6. Never apply glyphosate with controlled-droplet applicators that disperse concentrated glyphosate from a spinning disk. The fine droplets produced by these CDAs can remain airborne for a long time and will almost certainly drift onto trees.
7. Never apply glyphosate to Macoun trees. This variety seems uniquely susceptible to damage if glyphosate hits the tree trunks near the soil line.
8. Some growers and consultants believe that protecting trunks with white latex after planting can reduce the potential for herbicide injury, but this claim needs verification in replicated trials.
9. The risk of injury may be lower if glyphosate is applied in more

dilute solutions (e.g., by mixing glyphosate in 50 gal of water sprayed per acre rather than in 30 gal).

In summary, glyphosate can be a valuable tool for managing weed problems in orchards. However, when misapplied, glyphosate can also cause extensive damage to trees. Therefore, it should be used only when necessary and then with special precautions aimed at minimizing glyphosate contact with tree foliage, root suckers, and trunks.

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Literature Cited

Daniel, K., Mathers, H. M., and Case, L. T. 2009. Effect of postemergent herbicide on sucker removal / injury of field tree liners. [Abstract]. HortScience. Vol. 44(4): 2158.

Johal, G.S. and Huber, D.M. 2009. Glyphosate effects on diseases of plants. European J. Agron. 31:144-152.

Mathers, H. 2010. Current knowledge of causes and influences of bark cracking. Proc. 2010 Great Lakes Fruit, Vegetable and Farm Market Expo, Grand Rapids, MI. On-line at http://www.glexpo.com/summaries/2010summaries/TreeFruit.pdf.

Rosenberger, D., and Fargione, M. 2004. Apple tree deaths attributable to herbicides? Scaffolds 13(13):3-5. On-line at: http://www.nysaes.cornell.edu/ent/scaffolds/2004/040615.html#disease.

Rosenberger, D. Watkins, C., Miranda Sazo, M., Kahlke, C., and Nock J. 2010. Glyphosate exposure contributes to internal browning of apples during long-term storage. N.Y. Fruit Quarterly 18(3):15-18. On-line at: http://www.nyshs.org/fq.php.

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