broken into turbulent eddies by passage through the outer canopy, causing the leaves to flutter, exposing both surfaces to spray. The worst inconsistencies occurred with coverage of fruit by the ground sprayers which the paper targets permitted us to observe in 1994. Again, outside surfaces closest to the fan outlets received the majority of spray. However, coverage of inward-facing fruit surfaces was better at greater distance from the source of air, low in the canopy for the helicopter and high in the canopy for the air blast sprayers.

One explanation for apparently more uniform coverage of fruit at greater distance from the sprayer, may be that spray material approached from a more vertical angle, giving greater exposure to the paper target placed on the back surface. In this case, the observation is largely an artifact of target placement and half of the fruit would still have been shaded from spray. However, it is possible that coverage of fruit really improved with distance from the sprayer where air speed would be lower but turbulence greater so that more spray material was carried to the sheltered side of the fruit. Air speed is highest close to the fans where air movement would be largely unidirectional. As energy dissipates further from the fan, turbulence should increase so that air movement would be more multi-directional. Since the Curtec's tower placed all parts of the outer canopy close to the fans, inside surfaces of all fruit were deprived of spray. At the other extreme, the helicopter blades which drive the air carrier are a considerable distance from the tree so turbulence may have been greater at all tree locations.

Turbulence is clearly desirable to move spray material in different directions and also to flutter leaves and move fruit to expose otherwise sheltered surfaces. Slowing the fans is probably not a good means to this end because the air carrier must be accelerated sufficiently to move spray material effectively through the entire canopy. However, it might be possible to introduce additional sources of turbulence with some device that produced a rapid pulsation of the air stream to increase movement of fruit and leaves, thereby improving coverage over otherwise sheltered surfaces.

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MANAGEMENT OF GLYPHOSATE-RELATED CITRUS FRUIT DROP

CLAIR G. ERICKSON
Monsanto Company
P.O. Box 7, Tangerine, FL 32777-0007

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Abstract. **Citrus fruit drop resulting from glyphosate applications has become more of a concern over the last several years. The objective of this research was to understand the mechanisms behind glyphosate related fruit drop and determine how to reduce these effects in standard grove practices. Specific amounts of glyphosate were applied to individual 'Hamlin' oranges at various stages of maturity and percentage of drop determined. The data indicate 'Hamlin' orange sensitivity in the fall at 0.1 µl per fruit. This rate roughly corresponds to 4 spray droplets of a 2 quart/acre glyphosate application at 20 gallons/acre. Field experiments were conducted comparing herbicide effects from various boom designs and nozzle configurations. The experiments were designed to determine levels of naturally occurring fruit drop, drop occurring from shielded booms without herbicide, as well as herbicide effects. Natural fruit drop ranged from 15 to 33 fruit per tree, mechanically induced fruit drop ranged from 1 to 6 fruit per tree, glyphosate induced fruit drop ranged from 0 to 26 fruit per tree in these experiments. Fully enclosed booms with heavy back covers and plugged off center nozzles had significantly less fruit drop than open booms with no back cover and open off center nozzles.**

Grower concern over glyphosate-related citrus fruit drop has increased over the past several years (Hest, 1996). Glyphosate-related fruit drop seems most likely to occur from late summer and fall glyphosate applications and is observed most frequently on early season oranges and grapefruit. Tucker (1977) reported that 6 week old fruit sprayed in May, showed no external damage and no abnormal drop. However, 5 month old fruit sprayed in September, resulted in peel burn on the exposed surfaces where most of the spray contact occurred and that extensive drop followed, suggesting that fruit is more susceptible to glyphosate as it nears maturity. Glyphosate has been shown to enhance ethylene production in plant tissues (Abu-Irmaileh, et al., 1979, Grossbard and Atkinson, 1985), and since ethylene is known to enhance leaf and fruit abscission and color development, especially in maturing citrus, (Ismail, 1969, 1971, Wardowski and McCornack, 1973), glyphosate contact with maturing citrus fruit could result in increased ethylene concentrations and result in pre-mature fruit drop. Rouse (Hest, 1996) suggested that only fruit directly contacted by glyphosate spray during susceptible periods was subject to glyphosate-related fruit drop. As fruit develops, especially on younger trees, heavy fruit bearing branches are more likely to come in contact with herbicide sprays resulting in contact with the fruit. The objective of this research was to determine the sensitivity of citrus fruit to glyphosate, determine if a correlation exists between fruit maturity and glyphosate applications and evaluate several application techniques for glyphosate-related fruit drop.

Materials and Methods

Experiment 1: Rates of 0.001, 0.01, 0.1, 1, 10 ml of the commercial formulation of the isopropylamine salt of glyphosate were applied from stock solutions of 0.004, 0.04, 0.4, 4 and 40% in five, 5 ml droplets to individual 'Hamlin' oranges using a handheld micropipette. Treatments were replicated 3 times and each plot consisted of 5 fruit. Individual fruit were marked to insure future identification. Applications were made on approximately 2 week intervals beginning on 14 Aug. 1995, and ending 11 Oct. 1995. Fruit drop counts were made at about 2 week intervals following treatment. Fruit samples were analyzed for brix, acid, juice content, size and percent color break on each application date. Fruit drop data were correlated with maturity factors using regression analysis.

Experiment 2 : The application and data collection methods previously described were also used for this experiment, with rates of 0.1, 1, 5, 10, 50 and 100 ml of 100% commercial glyphosate in 1-4 droplets applied either on individual 'Hamlin' fruit or leaves immediately next to untreated fruit. Treatments were applied 19 Sep. 1995. This experiment was established as a 2×6 factorial design with glyphosate droplet location and glyphosate rate as the factors. Data were analyzed and means separated using Duncan's multiple range test.

Experiment 3: Rates of 0.01, 0.1 and 1 ml of commercial glyphosate were applied from stock solutions as described in experiment 1 to individual 'Hamlin', 'Navel', 'Pineapple' and 'Valencia' oranges, 'Ruby Red' and 'Marsh' grapefruit and 'Murcott' tangerines on 10 Oct. 1995. This experiment was established as a 3×7 factorial design with glyphosate rate and citrus variety as the factors. Data were taken as previously described. Data was analyzed as a factorial and means separated by Duncan's multiple range test. All trees used in the pipette experiments were being grown under normal production practices for the northern ridge production area.

Experiment 4: Similar experiments were conducted in 1992, 1993, and 1995 on 'Hamlin' oranges at Indiantown, Fl, in 1992 and 1993, and Felda, Fl, in 1995. The isopropylamine salt of glyphosate was applied at 2.25 lb ae/acre in 1992, and 1993, and 1.5 lb ae/acre in 1995, using commercial shielded sprayer equipment with six 11002 flat fan nozzles and one size 4 off center (OC) nozzle at 20-25 gpa, 20-28 psi, and 3 mph. Treatments included a fully open boom with no back covering and an operational OC nozzle, a fully closed boom with a heavy back cover and the OC nozzle plugged, the boom with no herbicide application, and an untreated check. Plots included 10 or 15 trees and 3 or 4 replications. Fruit drop counts were made at 18-21 and 40-45 days after treatment, and reported as number of fruit dropped per tree. Data were analyzed as previously mentioned.

Results and Discussion

Fruit drop data 4 weeks after treatment indicated that the 0.001 and 0.01 µl glyphosate rates resulted in little or no fruit drop and the 1 or 10 µl rates resulted in essentially complete fruit drop. The 0.1 µl rate resulted in progressively more fruit drop from the late treatments than from the earlier applications (see table 1). The maturity factors also increased at each application timing from 14 Aug. 1995, to 11 Oct. 1995. A moderate positive correlation of the fruit drop data with the brix/acid ratio were indicated. However, since the correlation is only moderately positive, it suggests that the correlation with glyphosate-related fruit drop may be secondary to the natural ripening of the fruit.

Glyphosate rate comparisons and all factorial interactions were not statistically significant in experiment 2, but a significant difference in glyphosate droplet placement was observed. Fruit applied glyphosate resulted in all 5 treated fruit per plot to drop, while leaf applied glyphosate resulted in only 0.17 dropped fruit per plot.

The factorial comparison of citrus variety sensitivity to glyphosate resulted in statistical significance for glyphosate rates, variety response, and the interaction between rate and varieties (Table 2). The data from the 0.1 µl glyphosate fall application indicate a reduced sensitivity to glyphosate in mid- and late season varieties, specifically 'Pineapple' and 'Valencia' oranges and 'Murcott' tangerines. However, it should be considered that if maturity, other than size and proximity to the spray boom, has a primary role in glyphosate-related fruit drop, then the later maturing varieties may become more susceptible as they get closer to harvest. Of the early maturing varieties, 'Hamlin' is the most susceptible, followed by 'Navel'. The red and white grapefruit are less responsive to glyphosate applications at the low 0.01 µl rate.

The micropipette experimental data can be related to commercial applications. Since a spray droplet from a standard glyphosate 1.5 lb/acre application at 20 gpa would have a 2.5% v/v herbicide concentration, and since a standard 20 gpa application using flatfan 11002 nozzles is 250 microns in diameter and contains 1 µl of spray solution (Erickson, 1981), the 0.1 and 1 µl rate of glyphosate applied through the micropipette is roughly equivalent to 4 and 40 standard spray droplets, respectively. The micropipette data suggest that the sensitivity of a 'Hamlin' orange in the fall is between 4 and 40 standard spray droplets per fruit and that glyphosate must contact the fruit directly. It also suggests that other varieties, though not as sensitive, may also be at risk from fall applied glyphosate unless it is adequately shielded from spray contact.

Data from experiments in 1992, 1993, and 1995, indicate that properly adjusted spray booms can be used during sensitive periods if they are fully enclosed using a heavy material for a back cover behind the spray nozzles and if the off center nozzle is closed (Table 3). It should be noted that natural fruit drop shifts significantly from year to year, and location to location. In a commercial grove the naturally occurring fruit drop might inappropriately be attributed to glyphosate-associated fruit drop. Mechanical movement of the boom through the grove also results in some fruit drop, but this drop is usually minimal, and like natural fruit drop, does not show the symptomology described by Tucker (1977). In 1992, or 1995, glyphosate applied through a closed spray boom with the OC nozzle closed did not result in an increase in fruit drop when compared with the natural background fruit drop levels. In 1993, a statistically significant increase in drop was documented, but that increase was minimal, as all treatments had less than 50 and 33% of the drop observed in 1992 and 1995, respectively. The open boom application with the OC nozzle operating resulted in significant increases of fruit drop in all three years, showing that standard glyphosate appli-

Table 1. Glyphosate-related fruit drop, 4 weeks after treatment, at various brix/acid ratios.

	Date of Application				
	8/14/95	8/30/95	9/13/95	9/27/95	10/11/95
Fruit drop[y]	0	1	0.67	2.33	3.33
Brix/acid ratio[z]	4.09	5.24	6.33	8.15	8.49

[y]Average number of fruit dropped from 0.1 ul of glyphosate.
[z]Brix/acid ratio at the time of glyphosate application.
Y = 0.65X + 2.74, r 2 = 0.5

Table 2. Fruit sensitivity to glyphosate by variety.

Glyphosate rate (ul)	Number of dropped fruit (4 weeks after treatment)[z]						
	Hamlin	Navel	Ruby Red	Marsh	Pineapple	Valencia	Murcott
0	0.5cd	0.5cd	0d	0d	0d	0d	0d
0.01	1.5c	0.5cd	0d	0d	0d	0d	0d
0.1	3.5b	4ab	4ab	3.5b	1cd	0d	1cd
1	5a	5a	5a	4.5ab	5a	5a	4ab

Mean separation by Duncan's multiple range test. There was a significant interaction between rate and variety, therefore each mean in each column can be compared with each mean in every other column.
[z]Treatments applied October 10, 1995.

Table 3. Comparison of natural, mechanical and glyphosate-related fruit drop.

	Number of fruit dropped 18-21 days after treatment		
	1992	1993	1995
natural	15.73b	6.35c	33.07b
mechanical	21.71b	6.23c	34.37b
closed, no oc[z]	21.28b	10.19b	34.9b
open, with oc[z]	44.23a	14.14a	60.03a

[z]Glyphosate rate 1.5-2.25 lb ae/a in fall applications. Closed indicates a solid back cover with off-center nozzle plugged. Open indicates no back cover with the off-center nozzle open.
Mean separation by Duncan's multiple range test.

cations, without concern for keeping the spray off the fruit, can result in unacceptable fruit drop. Growers should check the condition of their herbicide sprayers regularly, especially in the fall, and insure that booms are covered, that OC nozzles are plugged and plan their herbicide applications away from sensitive fruit drop periods when possible.

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