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Impact of Ten Spray Adjuvants on Leaf Gas Exchange of Pecan, Blueberry, Photinia, and Azalea

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Abstract. **Three separate factorial experiments were designed to evaluate the effect of 10 adjuvants on net CO_2 assimilation rate (A), leaf conductance to water vapor (g_l), and transpiration rate (E) of pecan [*Carya illinoensis* (Wagenh.) C. Koch] 'Elliott', blueberry (*Vaccinium ashei* Reade) 'Chaucer', red top photinia (*Photinia* x *Fraseri* Dress), and azalea (*Rhododendron* x 'Pink Ruffles'). Single applications of Bond, Leaf Act 80A, Nu-Film-17, Ortho X-77, Penetrator 3, Plyac, Sorba Spray ZNP, Sun Spray 7E, Triton CS-7, or Triton B-1956 at recommended rates did not affect A, g_l, or E compared to a water spray. The main effect of plant species was highly significant in all three studies without adjuvant–species interactions. A significant adjuvant effect on A occurred with a second application of Nu-Film-17, Plyac, and Triton B-1956. The only significant effect, when treatments were analyzed separately by species, was that A of Plyac-treated blueberry was less than the control.**

Adjuvants are a diverse group of compounds added to pesticide sprays that are imprecisely classified according to their purported effect (i.e., spreader, wetting agent, surfactant, emulsifier, sticker-extender, activator, compatability agent, acidifying agent, etc.) (13, 15).

Certain pesticides applied to apple (*Malus domestica* Borkh) (3, 5, 6), sour cherry (*Prunus cerasus* L.) (9), orange (*Citrus sinensis* L.) (15), peach (*Prunus persica* L. Batsch) (2), pecan (17, 18), lettuce (*Lactuca sativa* L.) (13), strawberry (*Fragaria ananassa* Duch.) (8), and chrysanthemum (*Chrysanthemum morifolium* Ramot) (7) have been reported to affect photosynthesis and/or transpiration. Yield reductions have occurred with the following crop/pesticide combinations: apple, benomyl and oil (11); lettuce, methyl parathion (13); grapes (*Vitis labruscana* L.), Bordeaux mixture (12); grapefruit (*Citrus paradisi* Macf.), various oil sprays (4); and strawberry, formetanate hydrochloride and propargite (8). However, the effects of the components of a pesticide mixture on plant physiology rarely have been isolated.

Although oil and emulsifiable concentrate formulations have been reported to depress photosynthesis more than wettable powder formulation of a given pesticide (3, 5, 17), few studies have assessed the effects of adjuvants alone on photosynthesis (5).

The objective of this study was to compare the effect of 10 adjuvants on leaf gas exchange of pecan, blueberry, photinia, and azalea.

The following container-grown plant material was used in all experiments: 'Elliott' pecan, 'Chaucer' blueberry, 'Fraiser' photinia, and 'Pink Ruffles' azalea. The plants were obtained from local nurseries and were subjected to standard culture and management practices. All plants were in an active state of growth, except pecan, which had ceased growth in mid-summer. Plants were placed on plastic mulch in direct sun and were irrigated with 1.5 cm of water daily.

Ten adjuvants were applied at recommended rates (Table 1) in three separate experiments during September and October Abaxial and adaxial leaf surfaces were sprayed to runoff with a Solo backpack sprayer between 8:00 and 10:00 AM. Nu-Film-17, Plyac, Triton B-1956, and water were sprayed in the first study on 11 Sept. and again on 23 Sept. 1986. Bond, Ortho X-77, Triton CS-7, and water were applied in the second study on 23 Sept. 1986. Leaf Act 80A, Penetrator 3, Sorba-Spray ZNP, Sunspray 7E, and water were applied in the third study on 7 Oct. 1986.

Leaf CO_2 and H_2O vapor exchange were measured on abaxial leaf surfaces on one or two mature fully expanded leaves per plant between 10:00 AM and 2:00 PM, as described previously (2). New CO_2 assimilation rate (A) was measured with a portable open-system LCA-2 Analytical Development Corporation (ADC Hoddesdon, U.K.) infrared gas analyzer. Leaf conductance to water vapor (g_l), transpiration rate (E), leaf temperature, air temperature, relative humidity, and photosynthetic photon flux were determined with a LI-COR 1600M steady-state diffusion porometer on the same leaf immediately after CO_2 exchange measurements. Preliminary experiments have shown that CO_2 exchange measurements did not significantly affect subsequent determinations of H_2O vapor exchange.

Each adjuvant/species combination was replicated four times, with one replication represented in each of four blocks. Leaf gas exchange was measured on one or two leaves of each plant. Data were analyzed as a 4 × 4 factorial (studies 1 and 2) or 5 × 4 factorial (study 3) by SAS (Cary, N.C.). When a significant treatment effect occurred, treatment means were compared to the control by Dunnett's *t* test.

Phytotoxicity symptoms did not occur as a result of any adjuvant spray on any species. The first application of Nu-Film-17, Plyac, and Triton B-1956 did not significnatly affect A, g_l, or E of any plant species (Table 2). Species differences in leaf gas exchange were highly significant. Net CO_2 assimilation rate, g_l, and E were highest for pecan, intermediate for photinia, and lowest for blueberry and azalea in this and the two studies to follow. The second application of the same compounds resulted in a significant adjuvant effect ($P < 0.022$) on A when all species were combined. When species were analyzed separately, the only significant effect was that the A of Plyac-treated blueberries was less than the control. No significant

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Table 1. Trade name, chemical name, adjuvant classification, and rates of application of spray adjuvants used in this study.

Trade name	Chemical name [major ingredient(s)]	Adjuvant classification	Concn ($ml \cdot liter^{-1}$)
Bond (Loveland Industries Inc.)	Synthetic latex, primary aliphatic oxyalkylated alcohol	Sticker/extender/ depostion agent	1.88
Leaf Act 80A (Pure-Gro Co.)	Alkyl polyoxyethylene glycols, modified pthalic glycerol, alkyl resins and isopropanol	Spreader/activator	0.78
Nu-Film-17 (Miller Chemical & Fertilizer Co)	Pinolene (di-l-p-menthene)	Spreader/extender (antitranspirant)	0.39
Ortho X-77 (Chevron Chemical Co.)	Alkylarylpolyoxyethylene, glycols, free fatty acids, isopropanol	Spreader/activator/ extender	0.47
Penetrator 3 (Helena Chemical Co.)	Paraffin base petroleum oil, polyol fatty acid esters and polyethoxylated derivative	Penetrant/activator	2.50
Plyac (Hopkins Chemical Co.)	Oxidized polyethylene and octyl phenoxy polyethoxy ethanol	Spreader-sticker	0.23
Sorba Spray ZNP (Leffingwell, Uniroyal Chem, Co)	Alkylbenzenesulfonates, phosphoric acid metallic sulfates and chlorides	Spreader/buffer activator/nutrient	1.88
Sunspray 7B Oil (Sun Oil Co.)		Vegetable oil	2.00
Triton CS-7 (Rohm & Haas)	Alkyl arylpolyethoxylated and sodium salt of alkylsulfonatedalkylate	Spreader-binder	1.88
Triton B-1956 (Rohm & Haas)	Thalestrol (phthalic glycerol alky resin)	Spreader-sticker	0.23

Table 2. Effect of Nu Film-17, Triton B-1956, and water on net CO_2 assimilation rate (A), leaf conductance to water vapor (g_l), and transpiration rate (E) of pecan, blueberry, photinia, and azalea. Measurements were conducted 2 days after first spray and 1 day after second spray. Photosynthetic flux density and leaf temperture were 1543 ± 209 $\mu mol \cdot s^{-1} \cdot m^{-2}$ and 30.3 ± 1.6°C, respectively, during the first measurements and 1678 ± 145 $\mu mol \cdot s^{-1} \cdot m^{-2}$ and 30.4°±1.8°, respectively, during the second measurements.

	A ($\mu mol \cdot s^{-1} \cdot m^{-2}$)				g_l ($mmol \cdot s^{-1} \cdot m^{-2}$)				E ($mmol \cdot s^{-1} \cdot m^{-2}$)			
Adjuvant	Pecan	Blueberry	Photinia	Azalea	Pecan	Blueberry	Photinia	Azalea	Pecan	Blueberry	Photinia	Azalea
First Spray												
Nu-Film-17	11.0	7.8	8.7	6.7	219	105	190	119	3.9	2.2	3.6	2.1
Plyac	13.3	6.7	8.8	6.9	235	124	180	139	4.3	2.7	3.4	2.2
Triton B-1956	11.6	6.3	10.0	6.0	256	116	200	150	4.8	2.7	3.9	2.6
Water	12.8	8.1	9.8	6.0	299	128	206	99	5.0	2.7	3.8	2.0
Main effects[z]												
Adjuvant		NS				NS				NS		
Species		**				**				**		
Interactive effects[z]												
Adjuvant × species		NS				NS				NS		
Second Spray												
Nu-Film-17	12.8	6.0	8.8	7.7	261	130	223	219	3.8	2.4	3.4	3.3
Plyac	13.1	5.1	8.7	7.2	294	79	273	220	4.2	1.5	3.9	3.4
Triton B-1956	12.7	6.3	10.1	6.5	327	119	245	187	4.5	2.2	3.6	2.8
Water	15.5	7.8	11.0	6.4	372	143	248	204	6.0	2.6	3.6	2.9
Dunnett's *t* test (5%)[y]	3.5	2.5	2.5	1.6								
Main effects[z]												
Adjuvant		*				NS				NS		
Species		**				**				**		
Interactive effect[z]												
Adjuvant × species		NS				NS				NS		

[z]Significance based on F values.
[y]Dunnett's *t* test included with significant adjuvant effect.
*, **, NSSignificant at P = 5% or 1% or not significant, respectively.

adjuvant effect occurred when blueberry was omitted from the factorial analysis. Adjuvants did not significantly affect g_l or E on either sampling date.

A single spray of Bond, Ortho X-77, or Triton CS-7 had no significant effect on leaf gas exchange (Table 3). Net CO_2 assimilation rate, g_l, and E were uniform within a species. Similarly, there was no adjuvant effect when Leaf Act 80A, Penetrator 3, Sorba Spray ZNP, Sun Spray 7E, and water were compared in the third study (Table 4).

The adjuvants chosen in this study were manufactured to enhance the effectiveness of insecticides, fungicides, and herbicides by improving pesticide coverage, retention, solubility and/or wettability, and penetration (14, 16). A single application at recommended rates did not affect leaf gas exchange (Tables 2–4). The only significant adjuvant effect occurred for the second application in the first study where A of Nu-Film-17-treated or Plyac-treated pecan, blueberry, and photinia was somewhat less than the control (Table 2). Vapor Gard, an antitranspirant containing the same active ingredient as Nu-Film-17 (pinolene), has been shown to reduce g_l and E of blueberry significantly when sprayed at antitranspirant concentrations [1.5% or 2.5% (v/v)] (1). However, Nu-Film-17, when applied at recommended adjuvant concentrations, did not have an effect on blueberry or the three other plant species (Table 2). We are unable to explain the inhibitory effect of Plyac on blueberry. Given the slight margin of significance, it is indeed possible that a Type II error has occurred, i.e., the null hypothesis may have been rejected erroneously in this case.

There was little suggestion of any effect of the remaining adjuvants on leaf gas exchange. Ferree et al. (5) measured net photosynthesis of apple 7 days posttreatment with Ortho X-77, Nu-Film-17, Triton B-1956, and Triton CS-7, Ortho X-100, Nu-Film-P, and Regulaid. They found that Ortho X-100 reduced and Triton CS-7 increased A, with the other compounds having no significant effect. Our results with materials in common concur with the work on apple (5), except that Triton CS-7 did not have an effect on A

Table 3. Effect of Bond. Ortho x-77, Triton CS-7, and water on net CO_2 assimilation rate (A), leaf conductance to water vapor (g_l), and transpiration rate (E) of pecan, blueberry, photinia, and azalea. Measurements were conducted 3 days after spray application under a photosynthetic photon flux density of 1686 ± 209 $\mu mol \cdot s^{-1} \cdot m^{-2}$ and leaf temperature of 32.0° ± 0.9°C.

	A ($\mu mol \cdot s^{-1} \cdot m^{-2}$)				g_l ($mmol \cdot s^{-1} \cdot m^{-2}$)				E ($mmol \cdot s^{-1} \cdot m^{-2}$)			
Adjuvant	Pecan	Blueberry	Photinia	Azalea	Pecan	Bluberry	Photinia	Azalea	Pecan	Blueberry	Photinia	Azalea
Bond	10.9	6.5	9.4	5.0	297	141	234	159	5.2	3.0	4.5	3.2
Ortho X-77	12.3	6.9	8.6	5.5	300	142	225	136	5.8	3.0	4.3	2.7
Triton CS-7	11.9	7.0	8.9	5.6	343	128	231	153	6.4	2.7	4.5	3.0
Water	12.5	7.1	8.7	5.5	343	160	211	144	6.6	3.4	4.1	2.9
Main effects[z]												
Adjuvant		NS				NS				NS		
Species		**				**				**		
Interactive effect[z]												
Adjuvant × species		NS				NS				NS		

[z]Significance based on F values.
**,nsSignificant at P = 1% or not significant, respectively.

Table 4. Effect of Leaf Act 80, Penetrator 3, Sorba Spray ZNP, Sun Spray 7E, and water on net CO_2 assimilation rate (A), leaf conductance to water vapor (g_1), and transpiration rate (E) of pecan, blueberry, photinia, and azalea. Measurements were conducted 3 days after spray application under a photon flux density of 1697 ± 480 $\mu mol \cdot s^{-1} \cdot m^{-2}$ and leaf temperature of 28.8° ± 1.1°C.

	A ($\mu mol \cdot s^{-1} \cdot m^{-2}$)				g_1 ($mmol \cdot s^{-1} \cdot m^{-2}$)				E ($mmol \cdot s^{-1} \cdot m^{-2}$)			
Adjuvant	Pecan	Blueberry	Photinia	Azalea	Pecan	Blueberry	Photonia	Azalea	Pecan	Blueberry	Photonia	Azalea
Leaf Act 80A	11.0	5.1	7.9	5.9	231	76	147	130	3.9	1.4	2.6	2.4
Penetrator 3	12.9	5.1	8.5	4.7	216	111	206	78	3.6	2.1	3.5	1.5
Sorba Spray ZNP	9.1	4.8	8.5	6.7	215	82	165	131	3.7	1.6	2.8	2.2
Sun Spray 7E	9.5	5.8	7.3	7.3	192	115	144	144	3.5	2.1	2.5	2.7
Water	9.8	6.6	9.8	6.8	199	91	221	116	3.4	1.7	3.7	2.2
Main effects[z]												
Adjuvant		NS				NS				NS		
Species		**				**				**		
Interactive effect[z]												
Adjuvant × species		NS				NS				NS		

[z]Significance based on F values.
**,NSSignificant at P = 1% or not significant, respectively.

of pecan, blueberry, photinia, or azalea. Petroleum oil (70 sec) inhibited A of apple (3, 5), but petroleum-based Penetrator-3 had no effect in the present study. We cannot rule out the possibility that adjuvants may have had a transient effect on leaf gas exchange immediately after application (10), with recovery occurring prior to measurements.

A relatively high proportion of insecticides/fungicides previously tested have had a negative effect on A (3, 6, 8, 13, 17, 18). For instance, a single application of 17 out of 19 insecticides, and fungicides tested significantly reduced A of pecan (17, 18), yet a single application of 10 adjuvants had no effect on leaf gas exchange in this study. Therefore, the active ingredient often may be responsible for pesticide-induced reductions in A, rather than carriers or other additives at recommended concentrations. One exception is petroleum oil, often used as an adjuvant or an insecticide, which has consistently been reported to depress A (2, 5, 15, 18).

Many pesticides and adjuvants are applied repeatedly over a season. Therefore, additional work is required to determine the effect of multiple applications of adjuvants alone and in combination with various pesticides.

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