Chapter

Influence of Adjuvants on Efficacy of Postemergence Herbicides Commonly Used in Peanut (*Arachis hypogaea* L.)

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Abstract

Field studies were conducted for 2 years in the High Plains of Texas (34.1826° N, 101.9505° W) and in South Texas (29.1634° N, 97.0725° W) to evaluate weed control when using different adjuvants with commonly used peanut herbicides. In the High Plains, *Amaranthus palmeri* L. control with acifluorfen, imazapic, lactofen, and 2,4-DB at the 1X dose improved with the use of an adjuvant over no adjuvant. *A. palmeri* control with imazethapyr was similar to that seen with imazapic and lactofen with the exception of the 1/2X rate of imazethapyr, which showed improved control with Agridex over the use of no adjuvant or Induce in 1 year, while Induce was better than no adjuvant or Agridex in the other year. In 1 year in South Texas, *A. palmeri* control with imazapic at the 1X dose was ≥73% with/without an adjuvant. In another year, the 1X dose of imazapic controlled *A. palmeri* 64% without an adjuvant, while the addition of Cide Kick II resulted in 83% control. An adjuvant did not improve *A. palmeri* control with lactofen or *Cucumis melo* L. control with either imazapic or lactofen. *Urochloa texana* (Buckl.) control with clethodim at the 1X dose was not improved by the addition of an adjuvant in either year. *U. texana* control was not improved when using the 1X dose of fluazifop-P with any adjuvant.

Keywords: herbicides, Palmer amaranth, smell melon, Texas millet, weed control

1. Introduction

An adjuvant is described as any compound that lowers the surface tension of a liquid, thereby increasing the contact between the liquid and another substance [1]. The efficacy of postemergence (POST) herbicides is influenced by several factors including weed species [2], weed size [2, 3], environmental conditions at the time of application [4, 5], application rate [2], interactions with other agrichemicals [6, 7], and the interaction with adjuvants [3, 7–10].

Adjuvants enhance herbicide efficacy primarily through increasing herbicide absorption [9–12]. Some adjuvants alter the formulation of a herbicide so that the herbicide more completely and evenly covers the plant surfaces, thereby keeping the herbicide in contact with plant tissue rather than beading up and rolling off [13, 14]. This is accomplished by the adjuvant reducing the surface tension and contact angle of herbicide solution, thereby improving the coverage of the solution and improving the chance for the herbicide to penetrate the plant surface [15–17].

Foy and Smith [18] studied the effect of adjuvants on surface tension and herbicide efficacy and found that minimum surface tension and contact angle occurred at concentrations of 0.1–0.5% for all adjuvants tested. However, maximum herbicidal activity was observed at 1% concentration, which indicated that there were other factors increasing herbicide activity besides surface tension and contact angle. They concluded that specific interactions of herbicide-adjuvant-plant surface were a part of the total adjuvant action.

Other adjuvants increase the herbicides' penetration through the cuticular wax, cell walls, and/or stomatal openings [13, 14, 19, 20]. Crop oil concentrates and vegetable oils fall into the category of penetrants [20]. This type of adjuvant improves cuticular penetration by softening, plasticizing, or dissolving cuticular waxes and allowing herbicide movement to the more hydrophilic regions underneath [20]. Although volatile herbicides easily penetrate stomata, stomatal penetration by an aqueous solution is not possible unless the surface tension of the spray solution is reduced significantly [20]. Most adjuvants are incapable of reducing surface tension enough to allow stomatal penetration. Prior to the development of the organosilicone surfactants, stomatal infiltration of herbicides into the leaf was considered to be of minor importance [20]. In contrast to other wetting agents, the organosilicone surfactants can reduce surface tension to levels low enough to allow stomatal infiltration of aqueous spray solutions [21–23]. When stomatal penetrations occur, it is greatest in the morning when stomates are more likely to be open.

The objectives of this research were (1) to compare efficacy of several grass and broadleaf herbicides commonly used in peanut (*Arachis hypogaea* L.) when applied with different adjuvants and (2) compare the different spray adjuvants when labeled and sublethal herbicide doses are used with acifluorfen, clethodim, fluazifop-P-butyl, imazapic, imazethapyr, lactofen, and 2,4-DB on four major weeds found in Texas peanut.

2. Materials and methods

2.1 Field studies

These studies were conducted during the 2011 and 2012 peanut growing seasons in the Texas High Plains near Halfway (34.1826° N, 101.9505° W) and during the 2012 and 2013 growing seasons in the south-central Texas peanut growing region near Yoakum (29.276° N, 97.123° W). Soil type at the High Plains location was a Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll) with less than 1% organic matter and pH 7.7, while at the South Texas location, the soil type was a Denhawken sandy loam (fine-silty, carbonitic, hyperthermic Fluventic Ustochrepts) with less than 1.0% organic matter and pH 7.6. Studies were conducted in the same field but moved from year-to-year to different areas within those fields. Irrigation was applied as needed to maintain soil moisture and plant growth.

2.2 Herbicides, doses, and application

Postemergence herbicide treatments at the High Plains location included acifluorfen {5-[2-chloro-4-(trifluoromethyl) phenoxy]-2-nitrobenzoic acid} at 0.28 (1/2X) and 0.56 kg ai/ha (1X), imazapic {(+)-2-[4,5-dihydro-4-methyl-4-4(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-methyl-3-pyridinecarboxylic acid} at 0.035 (1/2X) and 0.07 kg ai/ha (1X), imazethapyr {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid}

Adjuvant	Adjuvant composition	Dose (%, v/v)	Manufacturer
Agridex	Paraffin-based petroleum oil (83%) and surfactant blend (17%)	1.0	Helena Chem. Co.
Cide-Kick II	100% d'limonene and related isomers plus selected emulsifiers	1.0	Brewer International
ETA	Paraffinic petroleum oil (60%) and ethoxylated nonionic surfactant (40%); unsulfonated oil residue (UR) value, 90% minimum	1.0	Aurora Cooperative
Induce	Alkylarylpolyoxylkane ether, free fatty acids isopropyl (90%) and water and formulation aids (10%)	0.25	Helena Chem. Co.
90–10	Alkyl, polyethoxy ethers, ethoxylated and soybean derivatives, and antifome 90–10	1.0	Precision Laboratories

Table 1.
Adjuvants, composition, dose, and manufacturer.

at 0.035 (1/2X) and 0.07 kg ai/ha (1X), lactofen {2-ethoxyl-1-methyl-2-oxoethyl 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzene} at 0.11 (1/2X) and 0.22 (1X) kg ai/ha, and 2,4-DB [4-(2,4-dichlorophenoxy) butanoic acid] at 0.14 (1/2X) and 0.28 (1X) kg ai/ha. An untreated check was included for comparison.

In South Texas, herbicides in the broadleaf weed study included imazapic and lactofen at the previously mentioned rates, while in the annual grass study, the herbicides included clethodim {(E)-2-[1-[[(3-chloro-2-propenyl) oxy]imino]propyl]5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one} at 0.05 (1/2X) and 0.1 (1X) kg ai/ha and fluazifop-P-butyl {(butyl)(R)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoate} at 0.1 (1/2X) and 0.2 (1X) kg ai/ha. Adjuvants in both studies include Agridex®, Cide-Kick II®, ETA®, Induce®, and 90–10® (**Table 1**). An untreated check was included for comparison in each study.

Herbicides were applied in water using a CO_2 pressurized backpack sprayer with TeeJet® 11002 DG (Spraying Systems Company, P.O. Box 7900, North Avenue, Wheaton, IL 60188) nozzles calibrated to deliver 190 L/ha at 180 kPa at the South Texas location and TurboTee® 110015 nozzles calibrated to deliver 94 L/ha at 207 kPa at the High Plains location. Herbicides were applied POST when *Amaranthus palmeri* L. was up to 43 cm tall, while *Cucumis melo* L. var. Dudaim Naud. vines were vining up to 38 cm in length. *Urochloa texana* (Buckl.) R. Webster was up to 46 cm in height at the time of herbicide application (**Table 2**).

2.3 Experimental design, weeds, and densities

The experimental design was a randomized complete block with three replications at both locations. *A. palmeri* was evaluated at the High Plains location in a 5-(herbicide)-by-2-(dose)-by-3 (adjuvant) factorial arrangement of treatments.

At the South Texas location, two separate studies were completed. In the first study, *A. palmeri* and *C. melo* were evaluated using imazapic and lactofen, while in another study, *U. texana* was evaluated using clethodim and fluazifop-P butyl for control. Both studies in South Texas were a 2-(herbicide)-by-2-(dose)-by-6-(adjuvant) factorial arrangement of treatments.

Individual plots at the High Plains location were four rows 9.5 m long spaced 101 cm apart, and the middle two rows of each plot were sprayed, while at the South Texas location, plots were two rows 7.9 m long spaced 97 cm apart. Natural

Date	Time of day	Herbicide appl.	Dew	RH (%)	AT (°C)	ST (°C)	SM[a]	WS[a, b] (cm)
High Plains								
6/30/2011	10:30 am	All	No	35	32	26	G	10–36
6/02/2012	2:30 pm	All	No	51	29	31	D	25–43
South Texas								
7/19/2012	7:45 am	Imazapic lactofen	Yes	90	31	27	E	15–36(A) 15–38(C)
7/23/2012	8:00 am	Clethodim fluazifop	Yes	98	25	27	E	20–46(U)
7/13/2013	6:30 am	Imazapic	Yes	90	24	27	G	15–25(A) 15–30(C)
7/14/2013	6:30 am	Lactofen	Yes	94	24	27	G	15–25(A) 15–30(C)
7/23/2013	7:00 am	Clethodim	Yes	96	26	26	E	20–46(U)
7/24/2013	7:00 am	Fluazifop	Yes	96	24	26	E	20–46(U)

[a]*A, A. palmeri; AT, air temperature; C, C. melo; D, dry; E, excellent; G, good; RH, relative humidity; ST, soil temperature; SM, soil moisture; U, U. texana; and WS, weed size.*
[b]*Only A. palmeri was present at Halfway.*

Table 2.
Environmental conditions at time of herbicide application at each location.

infestations of *A. palmeri* at the High Plains location were present at a population range of 6–8 plants/m^2. *A. palmeri*, *C. melo*, and *U. texana* were present in South Texas at a population density of 6–10 plants/m^2 in both years.

2.4 Peanuts and planting

At the High Plains location, OLin [24] was planted in both years at the rate of 100 kg/ha. Planting date in 2011 was April 27, while in 2012, the planting date was May 1. Tamrun OL07 [25] and Georgia 09B [26] peanut were planted at the rate of 110 kg/ha in South Texas on June 14, 2012 and June 6, 2013, respectively. At neither location was peanut harvested for yield.

2.5 Weed efficacy ratings and data analysis

Weed control or peanut injury was estimated visually using a scale of 0 (no weed control or peanut injury) to 100 (complete weed control or plant death) relative to the untreated control [27]. Weed control ratings and peanut injury consisting of chlorosis and/or stunting (where applicable) were taken 2 and 4 weeks after herbicide application.

Data from the High Plains were analyzed using a five by a two-by-three factorial analysis (POST herbicide by dose by adjuvant), while the data from South Texas were analyzed using a two-by-two-by-six factorial analysis (POST herbicides by dose by adjuvant). Significant differences among treatments were determined using analysis of variance and means were separated by protected Fisher's LSD test at $P < 0.05$ [28]. Visual estimates of weed control and peanut injury were transformed to the arcsine square root prior to analysis of variance, but are expressed in their original form for clarity because the transformation did not alter interpretation. The untreated check was not included in the weed control or peanut injury analysis.

3. Results and discussion

3.1 *Amaranthus palmeri* control

3.1.1 High Plains of Texas

No attempt was made to consolidate data over years since there was a treatment by year interaction and environmental conditions (relative humidity, soil temperature, and soil moisture) at time of herbicide application varied between years (**Table 2**). Also, extremely hot, dry weather conditions were observed in 2011 (data not shown). Although the test area was irrigated, the record high temperatures and low rainfall [29] made it difficult to maintain adequate soil moisture for plant growth.

In 2011, only the high dose of acifluorfen and 2,4-DB showed no response to the addition of an adjuvant, while the addition of either Agridex or Induce to the low dose of acifluorfen and 2,4-DB improved *A. palmeri* control over those herbicides with no adjuvant (**Table 3**). The addition of Induce to either imazapic or imazethapyr at 0.035 kg/ha or lactofen at 0.11 kg/ha improved control over those herbicides without any adjuvant, while the addition of Agridex to the high dose of these herbicides improved control over Induce or the use of the herbicide with no adjuvant. Other research has reported that herbicide rates can be reduced up to 75% with the use of adjuvants, usually when applications are made during early growth stages [30–32]. However, successful control using reduced herbicide rates depends on weed growth stage sensitivity [33, 34] and current environmental conditions [35, 36].

In 2012, the low dose of either imazapic or lactofen showed no response to *A. palmeri* control with the addition of an adjuvant, while acifluorfen, imazapic, imazethapyr, or lactofen at the high dose and 2,4-DB at both doses resulted in greater control with the addition of either Agridex or Induce over the use of no adjuvant (**Table 3**). *A. palmeri* control with acifluorfen, imazapic, or lactofen herbicides was similar with either adjuvant. Imazethapyr, at either dose, provided better control with the addition of Agridex than the addition of Induce. Since soil moisture was low in 2011 and weed size at time of herbicide application was greater in 2012 than 2011 (**Table 2**), the use of an adjuvant proved beneficial. Adjuvants have been reported to increase absorption of bentazon in *Abutilon theophrasti* Medic. [37] although plants were water-stressed [38]. Bellinder et al. [39] reported that there was no benefit in using a crop oil concentrate (COC) with either bentazon or fomesafen at the 0–2 or 2–4-leaf stage of *A. theophrasti*; however, control was inconsistent at the 4–6-leaf stage even when a COC was used.

3.1.2 South Texas

In 2012, only the addition of ETA to imazapic at the low dose improved *A. palmeri* control over the use of either imazapic or lactofen without an adjuvant (**Table 4**). In 2013, the addition of either Induce or Cide-Kick II to the low dose of imazapic or Cide-Kick II and 90–10 to the high dose of imazapic improved control over both doses of imazapic without an adjuvant. No other adjuvants improved *A. palmeri* control over either dose of imazapic or lactofen without an adjuvant.

In both years, *A. palmeri* amaranth control when using lactofen with or without an adjuvant was at least 88% with the exception of the addition of ETA to the high dose of lactofen in 2012, which resulted in 78% control. Grichar and Dotray [40] reported that lactofen control of *A. palmeri* was greater when applied to 2–5 cm tall compared with either 15–20 or 25–30 cm tall plants.

Mayo et al. [41] concluded that *A. palmeri* control generally decreased as application timing was delayed for acifluorfen, imazethapyr, and lactofen.

Herbicide/dose	Adjuvant[a]	Peanut injury[b,c] (%)	A. palmeri (%)	
		2012	2011	2012
Acifluorfen/0.28 kg/ha	None	3	7	22
	Agridex	7	30	30
	Induce	5	30	25
Acifluorfen/0.56 kg/ha	None	5	27	32
	Agridex	6	43	47
	Induce	6	43	47
Imazapic /0.035 kg/ha	None	0	33	70
	Agridex	0	22	67
	Induce	0	53	70
Imazapic /0.07 kg/ha	None	0	58	78
	Agridex	0	80	93
	Induce	0	58	93
Imazethapyr/0.035 kg/ha	None	0	27	10
	Agridex	0	27	27
	Induce	0	50	12
Imazethapyr/0.07 kg/ha	None	0	42	47
	Agridex	0	65	82
	Induce	0	27	67
Lactofen/0.11 kg/ha	None	4	8	15
	Agridex	4	18	22
	Induce	4	33	20
Lactofen/0.22 kg/ha	None	6	40	22
	Agridex	5	73	35
	Induce	6	38	37
2,4-DB/0.23 kg/ha	None	2	12	37
	Agridex	3	52	63
	Induce	3	65	60
2,4-DB/0.46 kg/ha	None	5	68	73
	Agridex	5	77	87
	Induce	5	78	83
LSD (0.05)		2	18	8

[a]*Adjuvant doses: Agridex, 1.0% v/v; Induce, 0.25% v/v.*
[b]*No injury was noted in 2011.*
[c]*Acifluorfen and lactofen leaf injury consisted of leaf burn, interveinal chlorosis, and marginal necrosis while 2,4-DB injury consisted of leaf curling and irregular leaf growth.*

Table 3.
Peanut injury and Amaranthus palmeri *control in the High Plains 1 month after herbicide application when using different adjuvants.*

Herbicide/dose	Adjuvant[a,b]	Peanut injury[c]		A. palmeri		C. melo	
		2012 (%)	2013 (%)	2012 (%)	2013 (%)	2012 (%)	2013 (%)
Imazapic/0.035 kg/ha	None	0	0	66	70	82	97
	Agridex	0	0	82	75	89	89
	Induce	0	0	72	86	91	82
	C-K II	0	0	66	82	85	93
	90–10	0	0	53	66	91	90
	ETA	0	0	88	80	94	97
Imazapic /0.07 kg/ha	None	0	0	75	64	99	95
	Agridex	0	0	73	71	97	91
	Induce	0	0	83	66	97	97
	C-K II	0	0	80	83	95	98
	90–10	0	0	88	79	99	99
	ETA	0	0	83	57	98	99
Lactofen/0.11 kg/ha	None	23	2	94	96	82	97
	Agridex	38	18	99	97	89	99
	Induce	27	4	91	92	91	95
	C-K II	33	18	99	100	85	94
	90–10	18	10	88	98	91	89
	ETA	33	19	93	96	94	99
Lactofen/0.22 kg/ha	None	22	6	97	98	99	100
	Agridex	38	20	97	89	97	100
	Induce	19	7	91	99	97	100
	C-K II	33	17	99	92	95	99
	90–10	23	10	99	95	99	99
	ETA	38	22	78	97	98	100
LSD (0.05)		11	5	22	12	14	9

[a] *Adjuvant dose: Agridex, 1.0% v/v; Induce, 0.25% v/v; Cide-Kick II, 1.0% v/v; 90–10, 1.0% v/v; and ETA, 1.0% v/v.*
[b] *C-K II, Cide-Kick II.*
[c] *Peanut injury ratings taken 4 days after herbicide application in 2012 and 7 days after herbicide application in 2013.*

Table 4.
Peanut injury, Amaranthus palmeri, *and* Cucumis melo *control in South Texas 1 month after imazapic and lactofen application when using different adjuvants.*

3.2 *Cucumis melo* L. control

In neither 2012 nor 2013 did the use of any adjuvant with either dose of imazapic or lactofen improve *C. melo* control over the use of no adjuvant (**Table 4**). In 2013, using Induce with the low dose of imazapic did reduce *C. melo* control compared to the use of no adjuvant or ETA. Imazapic at 0.04–0.07 kg/ha controlled greater than 90% *C. melo* in corn (*Zea mays* L.) regardless whether applied either preemergence, early POST or late POST [42], while Grichar [43] has seen similar results in peanut with imazapic POST applications.

The high humidities at application timing may have been a factor in the excellent control [44]. Wichert et al. [44] reported that relative humidity appeared to be a more important environmental factor than temperature on the activity of lactofen and other diphenylether herbicides on *Sida spinosa* L. Control of *Xanthium strumarium* L. and *Ambrosia artemisiifolia* L. with acifluorfen at 85% relative humidity was 10–30% greater than control with treatments applied at 50% relative humidity [45].

3.3 *Urochloa texana* control

The use of an adjuvant with either dose of clethodim did not improve *U. texana* control over clethodim alone at either evaluation timing or in either year (**Table 5**). Trends in 2013, when evaluated 2 weeks after herbicide application, did indicate that the addition of either Agridex or Cide-Kick II hastened the kill of *U. texana*. Jordan et al. [46] reported that the most consistent grass control with clethodim was obtained when applied with adjuvants containing a crop oil constituent or with the adjuvant Dash. They stated that although clethodim applied with a conventional non-ionic adjuvant or silicone-based adjuvant controlled grasses in some instances, especially when applied at the higher dose of 0.14 kg/ha, control was inconsistent. They concluded that differences in efficacy among experiments could not be explained by differences in visible plant stress or extremes in temperature or relative humidity.

As seen with clethodim, the addition of an adjuvant to fluazifop-P-butyl did not improve *U. texana* control over the use of fluazifop alone at either dose (**Table 5**). At the time of herbicide application, relative humidity was at least 96% and soil moisture was excellent in both years (**Table 2**). These conditions can greatly influence herbicide activity [47, 48]. The effect of one climatic factor, such as humidity, will be greatest when other factors such as temperature or soil moisture are optimal [48].

3.4 Peanut injury

No injury was noted at the High Plains location in 2011 (data not shown). In some instances, imazapic can cause a yellowing of peanut plant for approximately 7–10 days after application; however, no injury was noted when rated 1 month after herbicide application (**Table 3**) in the High Plains or 4–7 days after application in South Texas (**Table 4**). Acifluorfen did cause a leaf burn, which was still noticeable 1 month after herbicide application (**Table 3**). The use of either Agridex or Induce with the lower dose of acifluorfen resulted in greater leaf burn than acifluorfen alone; however, this was not seen with the higher dose as there was no difference in leaf burn with/without the use of an adjuvant. The use of 2,4-DB did result in leaf curling and some irregular leaf growth, but no differences were noted with or without adjuvant with either dose (**Table 3**). Lactofen can also result in peanut leaf burn. Peanut injury ratings with lactofen were less in the High Plains (**Table 3**) than South Texas (**Table 4**), and this was due in part to the time interval between herbicide application ratings. In South Texas, ratings were taken 7 days or less after herbicide application, while in the High Plains, ratings were taken 30 days after application. Also, delaying the rating in 2013 by 3 days resulted in less injury than the 4 days evaluation (**Table 4**). At the High Plains location, no differences in leaf burn were noted with any adjuvant with either dose of lactofen (**Table 3**). At the South Texas location in 2012, leaf burn was greatest with Agridex when using the lower dose of lactofen (**Table 5**). At the higher dose of lactofen, Agridex, Cide-Kick II, and ETA resulted in greater injury than lactofen alone or lactofen plus Induce. In 2013, leaf burn with lactofen was greater when Agridex, Cide-Kick II, or ETA was used with either dose of lactofen. The addition of Induce or 90–10 resulted in 10% or less injury when added to either dose of lactofen (**Table 4**).

Herbicide/dose	Adjuvant[a,b]	*U. texana*			
		2 weeks after		4 weeks after	
		2012 (%)	2013 (%)	2012 (%)	2013 (%)
Clethodim/0.05 kg/ha	None	73	74	98	80
	Agridex	68	92	89	87
	Induce	75	77	97	88
	C-K II	60	82	84	83
	90–10	65	77	98	91
	ETA	77	81	98	70
Clethodim/0.1 kg/ha	None	84	90	98	95
	Agridex	91	90	99	94
	Induce	81	64	97	95
	C-K II	77	81	85	97
	90–10	76	77	93	94
	ETA	77	87	95	96
Fluazifop-P/0.11 kg/ha	None	65	81	92	96
	Agridex	62	85	65	93
	Induce	63	81	87	88
	C-K II	62	72	73	88
	90–10	63	95	78	97
	ETA	65	86	85	90
Fluazifop-P/0.22 kg/ha	None	67	88	92	95
	Agridex	58	62	91	93
	Induce	65	79	94	93
	C-K II	57	99	83	93
	90–10	62	96	95	97
	ETA	63	90	84	96
LSD (0.05)		15	24	19	15

[a]*C-K II, Cide-Kick II.*
[b]*Adjuvant dose: Agridex, 1.0% v/v; Induce, 0.25% v/v; C-K II, 1.0% v/v; 90–10, 1.0% v/v; and ETA, 1.0% v/v.*

Table 5.
U. texana *control with clethodim and fluazifop-P when using different adjuvants.*

4. Conclusion

The use of an adjuvant in South Texas did not always improve weed efficacy, while in the High Plains of Texas, the use of an adjuvant did improve weed efficacy in most instances. The herbicide-adjuvant-plant interaction is a complex system. An adjuvant can impose its impact at several stages of the herbicide application including tank mixing, deposition and retention on the plants, absorption by the plants, and translocation from the applied area to the site of action [15, 18, 20, 23]. Understanding the different roles of adjuvants in enhancing herbicide efficacy is essential for the optimum use of adjuvants in herbicide application. Reducing the herbicide rate proved to be effective in South Texas but not so in the High Plains due to several factors including a higher relative humidity, the time of herbicide application in the early morning hours, and excellent moisture conditions at time of herbicide application in South Texas. Postemergence herbicide efficacy may be affected by environmental factors including light duration and intensity, air temperature, relative humidity, and dew or precipitation [47–51]. These environmental conditions may influence processes such as herbicide absorption, translocation, or plant metabolism, which influence herbicide efficacy [52]. Air temperature in South Texas varied from 25 to 31°C, while air temperature varied from 29 to 32°C in the High Plains region (**Table 2**). As temperature increased, glyphosate efficacy on *Avena fatua* L., *Urochloa panicoides* Beauv. [53], and *Echinochloa colona* (L.) Link [54] increased. Temperature also influenced ^{14}C-glyphosate absorption by cultured velvetleaf cells [55]. Nearly twice as much glyphosate was absorbed at 28°C than at 4 or 16°C. Similar temperature effects were observed with *Cynodon dactylon* (L.) Pers. [56] and *Sorghum halepense* L. [57]. Herbicide activity or absorption increased with increasing relative humidity for *Elytrigia repens* (L.) Nevski [58], *C. dactylon* [56], *U. panicoides* [53], *E. colona* [54], and *S. halepense* [57]. Generally, high relative humidity and high temperatures, as well as low light intensity before treatment, increased plant susceptibility to POST herbicides [49]. Plant stress may also reduce systemic herbicide activity and account for relatively poor performance. Buhler and Burnside [58] noted that glyphosate was less effective on drought-stressed annual grass species than actively growing plants. Contact herbicides such as lactofen are not as dependent on translocation for activity, and their activity is not as adversely affected by drought-stressed plants. The above-mentioned factors all contributed to the lack of difference of the postemergence herbicides alone or with an adjuvant as well as the effectiveness of the 1/2X herbicide doses specifically in the South Texas studies. Many field applications of herbicides in South Texas start early in the morning to avoid windy conditions that may develop late in the day when coastal sea breezes may start up. Under the early morning conditions, with high humidity, dew can be found on weeds as well as on the crop at the time of application. Dew, defined as the presence of free water on plant foliage [59], could affect the foliar uptake and therefore efficacy of foliar-applied herbicides, mainly those of high water solubility. The presence of dew at application is believed to increase or decrease foliar herbicide efficacy [60]. Herbicide runoff and herbicide dilution could explain the negative effect of dew [61]. By contrast, dew can increase the total area of herbicide interception and reduce the impact of large drops on foliage surfaces, avoiding their loss from the leaves [62]. At the same time, the presence of dew results in hydration of the cuticle and may play an important role favoring foliar uptake [59]. The effect of dew on herbicide activity is not thoroughly understood, due to limited research where dew has not been quantified [63]. Another factor which may explain the lack of a response to a surfactant in South Texas may be the effects of higher spray volumes used in South Texas (190 L/ha) compared to the High Plains (94 L/ha). In order to obtain acceptable control with lactofen, a contact herbicide, a large portion of the leaf, must receive a spray solution [64] and with higher spray volumes in South Texas more of the leaflet received spray coverage. The drift guard (DG) nozzles used in South Texas contained larger droplets [65]. A larger droplet size causes localized injury to the weed leaf resulting in better control with contact herbicides such as acifluorfen and lactofen. Several researchers have investigated the effects of carrier volumes on the efficacy of herbicides [66–69] and results have been variable. At a constant spray droplet size, glyphosate [66, 67] and paraquat efficacy increased as application volume decreased. However, clopyralid activity decreased as application volume decreased [68]. Results from these trials suggest that not all adjuvants perform the same for individual herbicides. It is critical that a quality adjuvant be used when the label suggests that one is needed for maximum herbicidal activity. Since adjuvants may also increase herbicidal toxicity to crops, it is also critical to omit the surfactant if the label suggests to do so for individual herbicides.

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Conflict of interest

The authors have declared that no competing interests exist.

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