Original Research Article

Will Certain Adjuvants Improve the Preemergence Activity of Pendimethalin or *S*-metolachlor?

ABSTRACT

Aims: To determine weed efficacy when using adjuvants such as Grounded or Spectrum in combination with pendimethalin or *S*-metolachlor.
Study design: Randomized complete-block with 3 replications.
Place and Duration of Study: Field studies were conducted during the 2021 growing season near Yoakum (29.2765^{o} N, 97.1238^{o} W) in south-central Texas and near Corpus Christi (27.7817^{o} N, 97.5737^{o} W) along the upper Texas Gulf Coast.
Methodology: Herbicides were applied preemergence either alone or in combination with Grounded at 2.3 L ha^{-1} or Spectrum at 0.6 L ha^{-1} after corn (*Zea mays* L.) or peanut (*Arachis hypogaea* L.) were planted at Yoakum and under a non-crop situation at Corpus Christi.
Results: In corn when evaluated 7 weeks after treatment (WAT), the addition of Grounded to pendimethalin at 1.06 kg ha^{-1} reduced Palmer amaranth control when compared with pendimethalin alone at the same rate or with the addition of Spectrum. Smellmelon control with pendimethalin at 0.53 kg ha^{-1} improved with the addition of Grounded over pendimethalin alone. When evaluated 15 WAT, only Texas millet was present in consistent enough populations to evaluate and no differences in control were noted with/without an adjuvant with either pendimethalin or *S*-metolachlor. In peanut when evaluated 26 and 54 days after treatment (DAT), Texas millet or smellmelon control was not influenced with the use of either Grounded or Spectrum. In the non-cropland study, when evaluated 14 DAT, both Texas millet and Palmer amaranth control was $\geq$ 97% with all combinations of pendimethalin or *S*-metolachlor with/without an adjuvant. At the 42 DAT evaluation, again no differences in weed control were noted between the herbicides without an adjuvant and with the addition of Grounded or Spectrum.
Conclusion: In none of the trials did the addition of either Grounded or Spectrum to either pendimethalin or *S*-metolachlor consistently improve weed efficacy. Also the length of herbicide persistence was not increased with these adjuvants.

Keywords: Palmer amaranth; smellmelon; Texas millet; weed efficacy.

1. INTRODUCTION

The fate of soil-applied herbicides is influenced by several different factors including volatilization, photodecomposition, herbicide movement, plant uptake, and soil absorption [1,2]. Soil type, organic matter, and soil moisture also influence the availability of herbicides in the soil environment [1-4]. The process of adsorption may either directly or indirectly influence all other variables. Therefore, it is a major factor affecting the interactions between herbicides and soil colloids. The process of soil adsorption is influenced most by the chemical and physical properties of the specific herbicide, its formulations, the type and amount of clay, and the organic matter content of the soil [5,6]. Bardsley et al. [7] felt that if the herbicide could be retained in its toxic form by organic matter or clay particles which would tend to prolong its effectiveness, then there may be a gradual desorption of vapors that could biologically affect plant roots and germinating seed.

Leaching is another factor affecting the activity of soil-applied herbicides [8]. Leaching modifies herbicide performance by either moving the herbicide to such a depth that uptake by weed seedlings is reduced or prevented or by moving the herbicide in high concentrations to the zone of uptake by the crop. In addition, degradation of a herbicide to other products which may leach and in some cases possess greater phytotoxicity than the original herbicide affects the consistency of herbicide performance in different soils [9].

Adjuvants should enhance the sorption of herbicides onto soil particles and this can decrease a herbicides availability for microbial degradation and prolong its persistence [10]. A slowing of metazachlor leaching into the deeper soil profile and the half-life has been prolonged for 8 to 16 days with the use of adjuvants [11]. Swarcewicz and Skorska [12] noted a slight increase of the K_d and Koc values for atrazine applied with an adjuvant (containing 80% paraffin oil) over the use of no adjuvant; however, the authors also noted that soil type had more of an influence on those two parameters than was the surfactant. Abu-Zreig et al. [13] noted that the application of an anionic surfactant resulted in a dramatic increase in atrazine sorption while the non-ionic surfactants had less of an effect.

Hollist and Foy [6] found that soil adsorption of the dinitroaniline herbicides was directly related to the amount of organic matter and clay content present in the soil. Due to their low water solubility and high potential for hydrogen bonding, these herbicides are strongly absorbed to soil, in particular to organic, lipophilic, and/or proteinaceous substances [14]. Kennedy and Talbert [15] reported that dinitroaniline herbicides persistence in the soil depended upon the length of time before incorporation and the volatility of the herbicide. Weber [16] reported that pendimethalin was more persistent in the field when the herbicide was incorporated (80% remaining after 20 wks) than when it was surface applied (20% remaining) probably because of less volatilization and photodecomposition of the chemical.

This changes somewhat with the makeup of another formulation of pendimethalin known as Prowl H_20®. This is a water based formulation which maximizes herbicide availability through excellent surface stability and reduced binding to field residue [17]. Also, Jacques and Harvey [18] reported that the persistence of the dinitroaniline herbicides depended on soil temperature and moisture. These herbicides remained biologically active the longest under dry, cool conditions and disappeared most rapidly under warm, moist conditions.

Movement of metolachlor through the soil is controlled by degradation, sorption, and other factors [19]. Persistence of metolachlor in the field varies widely depending on temperature, soil type, soil water, and depth of placement below the soil [19]. Metolachlor is considered to have low to moderate persistence [20-22]. Fifty percent dissipation time $(DT_{50})^3$ in field studies have ranged from 24 to 108 d [20,23-26]. Carryover of significant metolachlor residues into the next cropping season has been observed in various soils [27-30]. Spillner et al. [31] found metolachlor sorption on soils to be linear with respect to concentration of organic matter ranging from 3.8 to 8.2%. Obrigawitch et al [32], working with three low organic matter soils (0.5 to 0.9%), reported that the metolachlor sorption coefficient $(K_d)^3$ decreased with increasing metolachlor concentration and was not fully reversible.

Several adjuvants (Grounded® and Spectrum®) now on the market claim to improve the activity of soil applied herbicides. Grounded spray adjuvant is a specialized blend of surfactants and aliphatic hydrocarbons designed to enhance the deposition and absorption of both ground and aerial spray applications [33]. Spectrum is a nonionic spray adjuvant containing methylated seed oils and a two phase organosiloxane based surfactant/emulsifier system [34]. Spectrum is reported to provide penetration properties superior to a crop oil concentrate with the coverage of a nonionic surfactant. The label states that Spectrum improves preemergence herbicide activity by improving soil penetration, coverage, and retention [35].

Little information is available concerning the effects of adjuvants on soil-applied herbicides. The movement of diuron through a soil column was markedly influenced by different adjuvants [36]. The influence of several adjuvants on metribuzin leaching has been investigated, but none had a significant influence [37,38].

Table 1. Variables associated with this study at each location.

	Location		
Variables	**Yoakum 1**	**Yoakum 2**	**Corpus Christi**
	Corn	**Peanut**	**Non crop**
Soil name	Denhawken	Tremona	Victoria clay
Soil type	Sandy clay loam	Loamy fine sand	Sandy clay
Sand (%)	71	81	46
Silt (%)	15	9	15
Clay (%)	14	10	39
pH	7.4	7.6	8.4
OM (%)	< 1.0	< 1.0	1.3
CEC	34	26	36
Planting date	April 8	June 14	-
Herbicide application	April 12	June 16	Mar 30
CO_2 backpack sprayer			
Operating pressure (kPa)	207	207	207
Spray volume (L ha^{-1})	190	190	190
Spray nozzles	DG 11002	DG 11002	TTI 11002
Rainfall			
1-7 day	0	0.68	0
8-14 day	0.67	0.89	0

The objective of this research was to determine the efficacy of pendimethalin and *S*-metolachlor alone and in combination with either Grounded or Spectrum for control of annual grasses and broadleaf weeds commonly found in corn (*Zea mays* L.), peanut (*Arachis hypogaea* L.) and under fallow production in the south Texas growing area.

2. MATERIALS AND METHOD

2.1 Research Sites. Field studies were conducted during the 2021 growing season at two sites in south-central Texas near Yoakum (29.2765° N, 97.1238° W) with corn (designated as Yoakum 1) and peanut (designated as Yoakum 2) and along the upper Texas Gulf Coast near Corpus Christi (27.7817° N, 97.5737° W) under fallow conditions. Soil characteristics and other variables for this study are shown in Table 1.

2.2 Plot Design and Treatments. A randomized complete-block experimental design was used and treatments were replicated three times. Herbicide treatments included pendimethalin at 0.53 and 1.065 kg ha^{-1} and *S*-metolachlor at 0.72 and 1.42 kg ha^{-1} applied either alone or in combination with Grounded at 2.3 L ha^{-1} or Spectrum at 0.6 L ha^{-1}. Treatments were applied preemergence (PRE) after corn and peanut were planted under rainfed conditions at the Yoakum locations or under a non-cropland situation at Corpus Christi. A non-treated control was included for comparison at all locations. Plot size in both Yoakum 1 and Yoakum 2 were two rows (96.5 cm apart) by 9.1 m long. At the Corpus Christi location, plots were 3.86 m wide by 10.7 m long.

2.3 Weed Populations and Populations. At all locations plots were infested with naturally occurring weed populations. At Yoakum 1, plots were infested with populations of Texas millet [*Urochloa texana* (Buckl.)] at 6 to 8 plants/m^2, smellmelon (*Cucumis melo* L.) at 3 to 5 plants/m^2, and Palmer amaranth (*Amaranthus palmeri* S. Wats.) at 2 to 4 plants/ m^2. At the late-season evaluation Texas millet was the predominate weed species and had completely taken over all the plots so only this weed was evaluated. At Yoakum 2 Texas millet was present at 8 to 10 plants/m^2 and smellmelon was present at 4 to 6 plants/m^2. At the Corpus Christi location Texas millet was present at 6 to 8 plants/m^2 while Palmer amaranth was present at 4 to 6 plants/m^2.

Weed control was estimated visually on a scale of 0 to 100 (0 indicating no control or plant death and 100 indicating complete control or plant death) relative to the untreated check [39]. At Yoakum 1 dry conditions existed early in the growing season resulting in erratic weed populations and slow growth so the initial evaluation was delayed to seven weeks after herbicide treatment (WAT) with the final evaluation 15 WAT. At Yoakum 2 evaluations were taken 26 and 54 days after treatment (DAT) while at Corpus Christi evaluations were taken 14 and 42 DAT.

2.4 Data Analysis. An analysis of variance was performed using the PROC ANOVA procedure for SAS [40] to evaluate the significance of herbicide treatments on weed control. Fisher's Protected LSD at the 0.05 level of probability was used for separation of mean differences.

3. Results and Discussion

3.1 Corn study.

<u>3.1.1 Texas millet control</u>. When evaluated 7 WAT Texas millet control with pendimethalin, regardless of adjuvant used, was ≤ 68%. *S*-metolachlor at 0.72 kg ha^{-1} controlled this weed 47 to 64% while *S*-metolachlor at 1.42 kg ha^{-1} provided at least 90% control (Table 2). The use of an adjuvant with either herbicide had no effect on Texas millet control. At the 15 WAT evaluation, pendimethalin provided ≤ 35% control. *S*-metolachlor at 0.72 kg ha^{-1} provided 10 to 40% control while *S*-metolachlor at 1.42 kg ha^{-1} controlled Texas millet 45 to 58%. Using Grounded with *S*-metolachlor at 0.72 kg ha^{-1} resulted in the least amount of control of all *S*-metolachlor combinations (Table 2).

Table 2. Weed control in corn when adding an adjuvant to either pendimethalin or *S*-metolachlor.

			Weed control			
			7 WAT[b]			15 WAT
Herbicide	**Rate**	**Adjuvant[a]**	**UROTE[c]**	**AMAPA**	**CUMME**	**UROTE**
	Kg ha^{-1}				%	
Untreated	-	-	0	0	0	0
Pendimethalin	0.53	-	42	47	37	0
		Grounded	51	57	80	22
		Spectrum	55	65	65	10
Pendimethalin	1.06	-	68	76	92	20
		Grounded	53	40	63	23
		Spectrum	68	75	80	35
S-metolachlor	0.72	-	57	72	83	33
		Grounded	47	65	82	10
		Spectrum	64	94	96	40
S-metolachlor	1.42	-	97	98	98	58
		Grounded	98	99	98	45
		Spectrum	90	100	100	58
LSD (0.05)			42	33	32	38

[a]Adjuvant rate: Grounded, 2.3 L ha^{-1}; Spectrum, 0.6 L ha^{-1}.
[b]Abbreviations: WAT, weeks after herbicide application.
[c]Bayer Code for Weeds: UROTE, *Urochloa texana* (Buckl.); AMAPA, *Amaranthus palmeri* S. Wats; CUMME, *Cucumis melo* L.

<u>3.1.2 Palmer amaranth control.</u> At the 7 WAT evaluation, pendimethalin at 0.53 kg ha^{-1} without an adjuvant provided 47% control while pendimethalin plus Grounded controlled Palmer amaranth 57% and pendimethalin plus Spectrum controlled 65% (Table 2). Using Grounded with pendimethalin at 1.06 kg ha^{-1} resulted in 40% Palmer amaranth control while pendimethalin alone or with Spectrum provided 76 and 75% control, respectively. Using Spectrum with *S*-metolachlor at 0.72 kg ha^{-1} resulted in 94% Palmer amaranth control while the use of Grounded resulted in 65% control. When using metolachlor at 1.42 kg ha^{-1} regardless of the use of an adjuvant or no adjuvant Palmer amaranth control was ≥ 98%.

<u>3.1.3 Smellmelon control</u>. When evaluated 7 WAT, the use of Grounded plus pendimethalin at 0.53 kg ha^{-1} greatly improved smellmelon control over the use of no adjuvant (Table 2). When the pendimethalin rate was increased the opposite was true. The use of pendimethalin at 1.06 kg ha^{-1} without an adjuvant resulted in 92% smellmelon control while the use of either Grounded or Spectrum resulted in 63 and 80% control, respectively. *S*-metolachlor at 0.72 kg ha^{-1} with Spectrum provided a numerical increase over the use of no adjuvant or Grounded; however, when the rate of *S*-metolachlor was increased no differences were noted (Table 2).

3.2 Peanut study.

<u>3.2.1 Texas millet control</u>. When evaluated 26 DAT, pendimethalin at 0.53 with the use of Grounded provided 91% control while pendimethalin plus Spectrum provided 80% control (Table 3). When the rate of pendimethalin increased, no differences in control were noted (87 to 93%). The efficacy of *S*-metolachlor was not influenced with the use of an adjuvant.

Table 3. Weed control in peanut when adding an adjuvant to either pendimethalin or *S*-metolachlor.

			Weed control			
			26 DAT[b]		54 DAT	
Herbicide	**Rate**	**Adjuvant[a]**	**UROTE[c]**	**CUMME**	**UROTE**	**CUMME**
	Kg ha^{-1}			%		
Untreated	-	-	0	0	0	0
Pendimethalin	0.53	-	85	92	23	47
		Grounded	91	89	27	50
		Spectrum	80	96	30	52
Pendimethalin	1.06	-	87	91	37	63
		Grounded	93	94	48	78
		Spectrum	89	95	42	57
S-metolachlor	0.72	-	80	87	30	53
		Grounded	79	98	40	80
		Spectrum	87	79	45	57
S-metolachlor	1.42	-	87	99	38	57
		Grounded	84	96	38	53
		Spectrum	93	90	40	50
LSD (0.05)			11	23	17	29

[a]Adjuvant rate: Grounded, 2.3 L ha^{-1}; Spectrum, 0.6 L ha^{-1}.
[b]Abbreviations: DAT, days after herbicide treatment.
[c]Bayer Code for Weeds: UROTE, *Urochloa texana* (Buckl.); CUMME, *Cucumis melo* L.

At the 54 DAT evaluation Texas millet control with pendimethalin ranged from 23 to 48% while control with *S*-metolachlor ranged from 30 to 45%. The use of an adjuvant had no effect on Texas millet control.

<u>3.2.2 Smellmelon control</u>. At the 26 DAT evaluation, pendimethalin controlled smellmelon 89 to 96% while *S*-metolachlor provided 79 to 99% control (Table 3). More consistent smellmelon control with *S*-metolachlor was noted as the rate increased. The use of an adjuvant had not effect on smellmelon control with either herbicide. When evaluated 54 DAT, smellmelon control was best when using Grounded with either pendimethalin at 1.06 kg ha^{-1} or *S*-metolachlor at 0.72 kg ha^{-1}. Pendimethalin at 0.53 kg ha^{-1} controlled smellmelon 47 to 52% while *S*-metolachlor at 1.42 kg ha^{-1} controlled smellmelon 50 to 57% with or without an adjuvant.

3.3 Non-cropland study.

<u>3.3.1 Texas millet control</u>. When evaluated 14 DAT both pendimethalin and *S*- metolachlor with or without the use of an adjuvant controlled this weed 97 to 100% (Table 4). At the 42 DAT evaluation, no response was seen when using Grounded or Spectrum with pendimethalin at 0.53 kg ha^{-1}; however, when using pendimethalin at 1.06 kg ha^{-1}, the use of Grounded did improve Texas millet control over pendimethalin without an adjuvant. *S*-metolachlor at 0.72 kg ha^{-1} controlled Texas millet 61 to 66% while *S*-metolachlor at 1.42 kg ha^{-1} resulted in slightly better (71 to 75%) control (Table 4).

3.3.2 Palmer amaranth control. At the 14 DAT evaluation, all pendimethalin and *S*-metolachlor treatments provided 99 to 100% control while at the 42 DAT pendimethalin

Table 4. Weed control under non-cropland when adding an adjuvant to either pendimethalin or *S*-metolachlor.

			Weed control			
			14 DAT[b]		42 DAT	
Herbicide	**Rate**	**Adjuvant[a]**	**UROTE[c]**	**AMAPA**	**UROTE**	**AMAPA**
	Kg ha^{-1}				%	
Untreated	-	-	0	0	0	0
Pendimethalin	0.53	-	99	100	50	26
		Grounded	98	100	52	28
		Spectrum	99	100	53	27
Pendimethalin	1.06	-	99	100	79	48
		Grounded	100	99	85	47
		Spectrum	100	100	84	47
S-metolachlor	0.72	-	97	100	61	90
		Grounded	99	99	64	92
		Spectrum	98	100	66	97
S-metolachlor	1.42	-	100	100	75	98
		Grounded	98	100	71	100
		Spectrum	100	100	71	97
LSD (0.05)			3	1	6	16

[a]Adjuvant rate: Grounded, 2.3 L ha^{-1}; Spectrum, 0.6 L ha^{-1}.
[b]Abbreviations: DAT, days after herbicide treatment.
[c]Bayer Code for Weeds: UROTE, *Urochloa texana* (Buckl.); AMAPA, *Amaranthus palmeri* S. Wats.

controlled this weed $\leq$ 48% (Table 4). However, an increase in control was noted as the pendimethalin rate increased but no effect was seen with the use of an adjuvant. *S*-metolachlor provided 90 to 100% control of this weed regardless of rate or the use of an adjuvant.

4.0 Conclusions. In this study the addition of either Grounded or Spectrum to pendimethalin or *S*-metolachlor had little to no effect on weed control compared to either of those herbicides without an adjuvant regardless of soil type or field conditions (Table 1). Abu-Zreig et al. [13] reported an increase of atrazine sorption due to an addition of three different surfactants. In this case, the characteristics of a given surfactant were more important than was the soil texture class. Also, Kocarek et al. [10] reported the presence of non-ionic and anionic surfactants did not modify insecticide (diazinon, dimethoate, malathion, and methidathion) sorption by the soils and this was not correlated with soil properties.

The lack of response to the use of Grounded or Spectrum may also be partially attributed to the amount of herbicide remaining in the soil. Kocarek et al [10] found the effects of irrigation and adjuvant were not statistically significant for either pendimethalin or dimethenamid-P (another chloroacetamide herbicide) in terms of their total amounts occurring in tested soil layers (5-15 cm). In another study, Andr et al. [41] reported that the use of silicon or paraffin oil adjuvants had no effect on the distribution of flurochloridone, linuron, and oxyfluorfen in soil layers 0-5 and 5-10 cm.

Also, Kocarek et al. [10] reported that there was a greater potential for leaching of the chloroacetamide herbicides than the dinitroaniline herbicides. In addition to the dinitroaniline herbicides being less water soluble [6,10,15], they partially attributed the potential for leaching to the amount of herbicides applied onto the soil surface. In their study, the doses of pendimethalin were 1.6 times greater than the doses of dimethenamid-P and thus larger amounts of pendimethalin were distributed in the top soil layer immediately after application. In our study the doses of S-metolachlor were approximately 1.35 times greater than that of pendimethalin; therefore, there was a greater potential for leaching of the chloroacetamide herbicide in addition to the fact that the dinitroaniline herbicide is less water soluble.

Another factor is the herbicide half-life. Kocarek found that the half-life of pendimethalin in irrigated or non-irrigated soil without Grounded was 43.1 and 44.1 days, respectively. No effect of either irrigation or adjuvant was found in the pendimethalin half-life as the half-life of pendimethalin ranged between 43 and 44.6 days. The half-life of dimethanamid-P ranged from 8.8 days for the irrigated soil without Grounded to 12.9 days for non-irrigated soil with Grounded [10]. Also the half-life of dimethenamid-P was longer under non-irrigated conditions and also in treatments with Grounded. We did not see any of these effects with either pendimethalin or S-metolachlor in any of our studies with regard to weed control or length of control.

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COMPETING INTERESTS

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly used products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any ligation but for the advancement of knowledge.

AUTHORS' CONTRIBUTIONS

Both authors designed the studies and performed the statistical analysis. W. J. Grichar wrote the first draft of the manuscript while Joshua A. McGinty reviewed the manuscript. Both authors read and approved the final manuscript.

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