Carfentrazone Plus Pyroxasulfone Combinations for Weed Control in Peanut (*Arachis hypogaea* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. Author WJG designed the studies, performed the statistical analysis, and wrote the first draft of the manuscript while authors PAD and TB reviewed the manuscript. All authors read and approved the final manuscript.

ABSTRACT

**Aims:** To determine peanut response and weed control following the use of carfentrazone plus pyroxasulfone (C + P).

**Study Design:** Randomized complete block design with 3-4 reps depending on location.

**Place and Duration of Study:** Studies were conducted during the 2015 and 2016 growing seasons in south Texas near Yoakum (29.276° N, 97.123° W), the High Plains of Texas near Lamesa (32.769° N, 101.977° W) or Brownfield (33.104° N, 102.161° W), and southwestern Oklahoma near Ft. Cobb (35.091° N, 98.275° W).

**Methodology:** Plots were infested with naturally occurring weed populations. Pendimethalin was applied either preplant incorporated (PPI) or preemergence (PRE). Early postemergence (EPOST) applications varied according to weather conditions and peanut growth at each location. Postemergence (POST) treatments were applied 26 to 58 days after planting. Weed control and peanut stunting were visually estimated on a scale of 0 to 100 (0 indicating no control or plant death and 100 indicating complete control or plant death).

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Results: Peanut stunting with C + P was only noted at the High Plains and Oklahoma locations in 2015 but not 2016. *Urochloa texana* (Buckl.) control with C + P (PRE) varied from 75 to 93%. POST applications provided inconsistent control. *Amaranthus palmeri* S. Wats. control with C + P (PRE) was at least 78% season-long while POST applications were inconsistent (24 to 100%). Pendimethalin plus C + P controlled *Cucumis melo* L. var. *Dudaim* Naud. at least 80% late-season. *Ipomoea hederacea* Jacq. control was excellent season-long (≥ 80%) in 2015 but poor (< 60%) in 2016. Reduced peanut yields were noted with C + P in Oklahoma in 2015 due to excessive season-long injury.

Conclusion: The premix of C + P has potential for use in peanut especially for control of many small-seeded annual broadleaf weeds that continue to plague many peanut growers across the southwest. For effective broad-spectrum annual weed control season-long, the addition of pendimethalin to PRE applications will be required.

Keywords: Preemergence; preplant incorporated; early postemergence; broadleaf weeds; annual grasses.

1. INTRODUCTION

Success of weed management practices can be influenced by the ability of peanut (*Arachis hypogaea* L.) to compete with weeds, cultural practices that minimize the soil seed bank and weed infestation, mechanical practices such as primary tillage prior to planting, cultivation during the growing season, and through the application of herbicides. The slow prostrate growth habit of peanut contributes to its vulnerability to interference by weeds. Weeds interfere with peanut through direct competition for light, soil water, nutrients, essential gases, and space [1,2]. The requirement to dig pods and invert vines prior to mechanical harvest further underscores the need for effective season-long weed control. Annual and perennial grasses exacerbate pod loss during the digging process [1,2]. The tight fibrous root system of broadleaf weeds such as *Amaranthus* spp. and annual grasses such as *Texas millet* (*Urochloa* texana (Buckl.) R. Webster) becomes intertwined with the peanut plant, causing peanut pods to be stripped from the vine during digging and also can slow down the drying process. Peanuts that become detached from the plant remain unharvested in or on the soil [1]. Also, peanut fields are often treated with multiple fungicides to control stem rot disease (caused by *Sclerotium rolfsii* Sacc.) and early and late leaf spot disease (caused by *Cercospora arachidicola* Hori) and *Cercosporidium personatum* (Berk. & M.A. Curtis) Deighton, respectively, and weeds can interfere with uniform deposition of fungicides and subsequent pathogen control [3].

Pyroxasulfone is a new herbicide in the class called isoxazolines [4]. Isoxazolines are Weed Science Society of America (WSSA) site of action Group 15 herbicides along with several chloroacetamide herbicides including acetochlor (Warrant®), S-metolachlor (Dual Magnum®) and dimethenamid (Outlook®). These herbicides are root and shoot growth inhibitors and control susceptible germinating seedlings before or soon after they emerge from the soil. They act by reducing the biosynthesis of very-long-chain fatty acids, which causes a buildup of fatty acid precursors [4-6]. Pyroxasulfone is registered in the U. S. for either preplant (PP), preplant incorporated (PPI), preemergence (PRE), or early postemergence (EPOST) use in corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), peanut, soybean (*Glycine max* L.), and wheat (*Triticum aestivum* L.) and application timing is crop specific [5,7-9]. It controls *Amaranthus* spp., *Lolium* spp, *Urochloa* spp., goosegrass (*Eleusine indica* L.), crowfootgrass (*Dactyloctenium aegyptium* L.), and *Digitaria* spp. [4,10-14]. Although pyroxasulfone has a similar weed control spectrum as S-metolachlor and dimethenamid-P, it has a higher specific activity allowing for use rates approximately eight times lower than dimethenamid-P [6]. Pyroxasulfone inhibits very-long-chain fatty acid synthesis similar to chloroacetamide, oxycacetamide, and tetrazolinone herbicides [4].

Previous research in the southeast determined that pyroxasulfone has good peanut crop tolerance and provides control of problem weeds [15]. Pyroxasulfone applied PRE to peanut has been documented to cause early-season stunting but no yield loss [15]. Grichar et al. [16] reported smellmelon (*Cucumis melo* L.) and Texas millet control with pyro sulfone applied PPI or PRE was inconsistent when used alone; however, when used in a systems approach with either pendimethalin, S-metolachlor, or dimethenamid,
control was greater than 90%. Palmer amaranth control was greater than 90% with pyroxasulfone combinations while ivyleaf morningglory \([Ipomoea hederacea (L.) Jacq.]\) control was less than 50% unless imazapic or imazethapyr was used postemergence (POST), which increased control to at least 80%. Russian-thistle \((Salsola tragus L.)\) control was at least 80% with pyroxasulfone combinations. Some peanut stunting was noted with pyroxasulfone; however, all herbicide systems improved peanut yield over the untreated weedy check.

Carfentrazone (Weed Science Society of America site of action Group 14) is an aryl triazolinone herbicide [17] and the mode of action is the inhibition of protoporphyrinogen oxidase \((\text{Protox})\) [18,19] in the chlorophyll biosynthesis pathway, which results in the accumulation of protoporphyrin IX \((\text{PPIX})\) in the cytosol [20,21]. PPIX is phototoxic and involved in the light-dependent formation of singlet oxygen, which is responsible for plant death via membrane oxidation [22]. It is a rapid-acting contact herbicide with little or no soil residual activity [23] and susceptible weeds begin to desiccate within hours of treatment, followed by necrosis and plant death within days.

The premix of carfentrazone + pyrosulfone \((\text{C + P})\) has recently been labelled in the U. S. for use on peanut as Anthem Flex® by the FMC Corporation [24]. In peanut, \(\text{C + P}\) is labelled for EPOST or POST use only. The EPOST peanut stage is often referred to as peanut cracking or when the plant begins to emerge from the ground or until the plant is almost saucer size (10 to 15 cm wide). Since no research information could be found on the use of this premix on peanut production in the southwest peanut production region, research was undertaken in the Texas and Oklahoma peanut growing areas to determine crop response and weed control efficacy with \(\text{C + P}\) when applied PRE, EPOST (ground cracking), or late POST (LPOST).

2. MATERIAL AND METHODS

2.1 Field Studies

These studies were conducted during the 2015 and 2016 growing seasons to determine peanut response and weed efficacy of the \(\text{C + P}\) premix in the southwestern U. S. peanut growing areas. Locations included the Texas A&M AgriLife Research Site near Yoakum \((29.276^\circ \text{N}, 97.123^\circ \text{W})\) in south-central Texas, Lamesa \((32.769^\circ \text{N}, 101.944^\circ \text{W})\) in 2015 and Brownfield \((33.104^\circ \text{N}, 102.161^\circ \text{W})\) in 2016 both in the Texas High Plains, and at the Oklahoma State University Caddo Research Station near Ft. Cobb \((35.091^\circ \text{N}, 98.275^\circ \text{W})\) in southwestern Oklahoma. The test locations at Yoakum and Ft. Cobb were in the same general areas but different parts of the field over years. Other details of the test locations, peanut variety, and spray information are given in Table 1. The experimental design was a randomized complete block with three to four replications depending on location. An untreated check was included each year at all locations.

2.2 Plot Size and Weed Populations

Each plot at Yoakum consisted of two rows spaced 97 cm apart and 7.6 m long, plots at Lamesa and Brownfield were four rows wide spaced 102 cm apart and 9.5 m long, while plots at Ft. Cobb were four rows wide spaced 91 cm apart and 9.1 m long. At all locations plots were infested with naturally occurring weed populations. At the south Texas location, field plots were infested with populations of Texas millet \((Urochloa texana \text{ (Buckl)})\), smellmelon \((Cucumis melo L.)\), and Palmer amaranth \((Amaranthus palmeri S. Wats)\) populations (6 to 8 plants/ m\(^2\)). At the Lamesa and Brownfield locations, Palmer amaranth populations were moderate (4 to 5 plants/m\(^2\)) and this was the only weed present at these locations. At the Oklahoma locations, Palmer amaranth and Texas millet populations were severe (9 to 45 plant/m\(^2\)) while ivyleaf morningglory \((Ipomoea hederacea L.)\) populations were low to moderate (3 to 6 plants/m\(^2\)).

2.3 Herbicide Treatments and Application

Herbicide treatments varied across years but were the same across locations for each respective year. In 2015, pendimethalin at 1.06 kg ha\(^{-1}\) was applied preplant incorporated \((\text{PPI})\) at Yoakum and Lamesa while at Ft. Cobb pendimethalin was applied preemergence \((\text{PRE})\) to all herbicide plots with the exception of the untreated check. The PPI treatments at Yoakum were applied just prior to planting and incorporated 3 to 5 cm deep with a tractor-driven power tiller while at Lamesa these treatments were applied before planting to flat ground and incorporated 4 to 5 cm deep one time using a tandem disk. The EPOST herbicide applications varied according to weather conditions and peanut growth at each location. In 2015, this was 18 days after planting \((\text{DAP})\) at Yoakum and Ft. Cobb and 28 DAP at the High Plains location. In 2016, the Herbicide standards varied between
Table 1. Variables associated with the study at each location

<table>
<thead>
<tr>
<th>Variables</th>
<th>Location</th>
<th></th>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Yoakum</td>
<td>Ft Cobb</td>
<td>Lamesa</td>
<td>Brownfield</td>
<td>Amarillo</td>
</tr>
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<td>Binger</td>
<td>Binger</td>
<td>Brownfield</td>
<td>Amarillo</td>
</tr>
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<td>65</td>
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<td>50</td>
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<td>6</td>
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<td>25</td>
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<td>July 5</td>
<td>June 1</td>
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<td>May 18</td>
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<td>Application</td>
<td>PPI</td>
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<td>EPOST</td>
<td>POST</td>
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<td></td>
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<td>June 29</td>
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<tr>
<td>Weed height (cm) at EPOST</td>
<td>AMAPA</td>
<td>2.5-8</td>
<td>0-2.5</td>
<td>10-20</td>
<td>1.25-2.5</td>
<td>2.5</td>
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<td>CUMME</td>
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<td>-</td>
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<td>CYPES</td>
<td>-</td>
<td>-</td>
<td>10-30</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>IPOHE</td>
<td>-</td>
<td>-</td>
<td>1.25-15</td>
<td>1.25-3.7</td>
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<tr>
<td></td>
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<td>2.5-8</td>
<td>0-2.5</td>
<td>5-15</td>
<td>1.25-7.5</td>
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<tr>
<td>Weed height (cm) at POST</td>
<td>AMAPA</td>
<td>38-76</td>
<td>25-38</td>
<td>35-30</td>
<td>-</td>
<td>5-10</td>
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<td>25-38</td>
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<td>IPOHE</td>
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<td>1.25-15</td>
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<td>25-38</td>
<td>25-38</td>
<td>15-30</td>
<td>1.25-20</td>
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<td>Weather conditions at PRE application</td>
<td>Temperature (°C)</td>
<td>23.9</td>
<td>26.7</td>
<td>30</td>
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<td>Relative humidity (%)</td>
<td>94</td>
<td>95</td>
<td>62</td>
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<td></td>
<td>Soil moisture</td>
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<td>Good</td>
<td>Good</td>
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<tr>
<td></td>
<td>Sprayer</td>
<td>CO₂ backpack</td>
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<td>Operating pressure (kPa)</td>
<td>207</td>
<td>207</td>
<td>124</td>
<td>161</td>
<td>165</td>
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<td>Spray volume (L ha⁻¹)</td>
<td>187</td>
<td>187</td>
<td>94</td>
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<td>94</td>
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<td></td>
<td>Spray nozzles</td>
<td>DG 11002</td>
<td>DG 11002</td>
<td>TT 110015</td>
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<td>TT110015</td>
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<td>Peanut variety</td>
<td>Georgia 09B</td>
<td>Webb</td>
<td>Florida Fancy</td>
<td>Florida Fancy</td>
<td>Georgia 09B</td>
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<tr>
<td></td>
<td>Coordinates</td>
<td>29.27° N</td>
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<td>35.06° N</td>
<td>35.06° N</td>
<td>32.76° N</td>
</tr>
<tr>
<td></td>
<td></td>
<td>97.12° W</td>
<td>97.12° W</td>
<td>98.27° W</td>
<td>98.27° W</td>
<td>101.94° W</td>
</tr>
</tbody>
</table>

EPOST treatments were applied 8 DAP at Yoakum, 15 DAP at Ft. Cobb, and 14 DAP at Lamesa. Postemergence (POST) treatments were applied 26 to 40 DAP at Yoakum, 34 to 58 DAP at Ft. Cobb, and 41 DAP at Lamesa in 2015 and 44 DAP at Brownfield in 2016. All EPOST and POST treatments included a crop oil concentrate (Agridex®) at 1.25% v/v or a non-ionic surfactant (Induce®) at 0.25% v/v. Herbicide standards varied between locations and years. In 2015 at both the Yoakum and Ft. Cobb locations, flumioxazin at 0.11 kg ai ha⁻¹ applied
PRE followed by either S-metolachlor at 1.42 kg ai ha\(^{-1}\) applied EPOST or lactofen at 0.22 kg ai ha\(^{-1}\) plus 2,4-DB at 0.28 kg ai ha\(^{-1}\) applied POST were the standard comparison treatments. At Lamesa, flumioxazin at 0.11 kg ai ha\(^{-1}\) followed by S-metolachlor at 1.07 kg ha\(^{-1}\) applied POST was the standard. In 2016, at Yoakum, pendimethalin at 1.06 kg ai ha\(^{-1}\) plus S-metolachlor at 1.47 kg ha\(^{-1}\) applied PRE was the standard while at the Brownfield location, flumioxazin at 0.11 kg ai ha\(^{-1}\) applied PRE plus S-metolachlor at 1.47 kg ha\(^{-1}\) applied either EPOST or POST was the standard. At the Ft. Cobb location, pendimethalin at 1.06 kg ai ha\(^{-1}\) plus flumioxazin at 0.07 kg ai ha\(^{-1}\) applied PRE followed by paraquat at 0.28 kg ai ha\(^{-1}\) plus diethenamid-P at 0.63 kg ai ha\(^{-1}\) applied EPOST followed by imazapic at 0.07 kg ai ha\(^{-1}\) applied POST was the standard.

2.4 Irrigation, Weed Control, Peanut Injury, and Peanut Harvest

Sprinkler irrigation was applied on a 2- to 3-week schedule throughout the growing season as needed at all locations. Weed control and peanut injury was visually estimated 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 control [25]. Peanut yields were obtained in 2015 at Lamesa and Ft. Cobb, but not Yoakum by digging each plot separately, air-drying in the field for 4 to 7 d, and harvesting peanut pods from each plot with a combine. Weights were recorded after soil and trash were removed from plot samples. Plots were not dug for yield at any location in 2016 due to the difficulty of digging plots with high weed populations.

2.5 Data Analysis

Weed control and peanut injury data were arcsine transformed prior to analysis of variance; however, because the transformation did not alter treatment means original data are presented. Means were compared with Fisher’s Protected LSD test at the 5% probability level. The untreated control was not included in weed control or peanut injury analysis but was included in the yield analysis.

3. RESULTS AND DISCUSSION

Palmer amaranth data in 2015 were combined over the three locations because of a lack of treatment by location interaction. However, all other weed control data are presented separately by weed species and location because there was a treatment by location interaction or herbicide treatments were different at some locations.

3.1 Weed Control

3.1.1 Palmer amaranth

3.1.1.1 2015

When combined over locations, all herbicide systems controlled this weed at least 97% at the 11 to 16 weeks after planting (WAP) evaluation (Table 2). Systems that included the premix of C + P applied PRE controlled Palmer amaranth 97 to 100% while systems that included the premix of C + P applied either EPOST or POST controlled this weed 99 to 100%.

3.1.1.2 2016

Since herbicide treatments varied by location no attempt was made to combine data over locations. At Yoakum when evaluated 12 weeks after planting (WAP), all herbicide systems that included the premix of C + P applied alone, with the exception of carfentrazone at 0.035 kg ha\(^{-1}\) plus pyroxasulfone at 0.05 kg ha\(^{-1}\) applied POST, provided at least 90% Palmer amaranth control while herbicide systems that included pendimethalin controlled Palmer amaranth 97 to 99% (Table 3). At the Brownfield location all herbicide systems that included the premix of C + P applied alone, with the exception of carfentrazone at 0.035 kg ha\(^{-1}\) plus pyroxasulfone at 0.05 kg ha\(^{-1}\) applied PRE, provided at least 93% Palmer amaranth control 6 WAP. Herbicide systems that included flumioxazin controlled this weed 93 to 95%. At Ft. Cobb when evaluated 13 WAP, only the premix combinations of C + P applied PRE controlled Palmer amaranth 78 to 92% while C + P combinations applied either EPOST or POST provided no better than 70% control (Table 3). The standard, which included pendimethalin plus flumioxazin applied PRE, controlled Palmer amaranth 98%.

Dotray et al. [26] reported on the Texas High Plains that pyroxasulfone applied either PRE or EPOST provided at least 95% Palmer amaranth control in peanut and this was as good as all other herbicide treatments evaluated. In corn, Steele et al. [5] reported that pyroxasulfone at 0.125 to 0.5 kg ha\(^{-1}\) provided comparable control.
Table 2. Weed control with carfentrazone plus pyroxasulfone (C + P) during the 2015 growing season in Texas and Oklahoma

<table>
<thead>
<tr>
<th>Treatments(^{a,b,c,d})</th>
<th>Rate Kg ai ha(^{-1})</th>
<th>Application Timing</th>
<th>Yoakum 11-16WAP</th>
<th>Ft. Cobb 11WAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>-</td>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Flumioxazin</td>
<td>0.11</td>
<td>PRE</td>
<td>100</td>
<td>93</td>
</tr>
<tr>
<td>S-metolachlor</td>
<td>1.42</td>
<td>EPOST</td>
<td>85</td>
<td>80</td>
</tr>
<tr>
<td>(C + P)</td>
<td>0.007 + 0.1</td>
<td>POST</td>
<td>100</td>
<td>95</td>
</tr>
<tr>
<td>Flumioxazin + (C + P)</td>
<td>0.11 + 0.007 + 0.1</td>
<td>PRE</td>
<td>100</td>
<td>94</td>
</tr>
<tr>
<td>Flumioxazin + (C + P)</td>
<td>0.007 + 0.1</td>
<td>POST</td>
<td>97</td>
<td>83</td>
</tr>
<tr>
<td>Imazapic/imazethapyr + S-metolachlor</td>
<td>0.07 + 1.07</td>
<td>POST</td>
<td>100</td>
<td>97</td>
</tr>
<tr>
<td>Imazapic/imazethapyr + (C + P)</td>
<td>0.007 + 0.1</td>
<td>PRE</td>
<td>99</td>
<td>98</td>
</tr>
<tr>
<td>(C + P)</td>
<td>0.07 + 0.1</td>
<td>POST</td>
<td>99</td>
<td>99</td>
</tr>
<tr>
<td>Lactofen + 2,4-DB + (C + P)</td>
<td>0.22 + 0.28 + 0.009 + 0.12</td>
<td>POST</td>
<td>100</td>
<td>99</td>
</tr>
<tr>
<td>Lactofen + 2,4-DB + (C + P)</td>
<td>0.22 + 0.28 + 0.009 + 0.12</td>
<td>PRE</td>
<td>100</td>
<td>99</td>
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<tr>
<td>Lactofen + 2,4-DB + (C + P)</td>
<td>0.22 + 0.28 + 0.009 + 0.12</td>
<td>POST</td>
<td>100</td>
<td>99</td>
</tr>
<tr>
<td>Lactofen + 2,4-DB + (C + P)</td>
<td>0.22 + 0.28 + 0.009 + 0.12</td>
<td>PRE</td>
<td>100</td>
<td>99</td>
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<tr>
<td>Lactofen + 2,4-DB + (C + P)</td>
<td>0.22 + 0.28 + 0.009 + 0.12</td>
<td>POST</td>
<td>100</td>
<td>99</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>3</td>
<td>9</td>
<td>19</td>
<td>10</td>
</tr>
</tbody>
</table>

\(^{a}\)With the exception of the untreated check, pendimethalin at 1.06 kg ha\(^{-1}\) was applied preplant incorporated at the south Texas and Texas High Plains locations and preemergence at Ft. Cobb to all plots. \(^{b}\) EPOST and POST treatments included Agridex at 0.25% v/v. \(^{c}\) Imazapic used at the south Texas location while imazethapyr used at the Texas High Plains and Oklahoma locations. \(^{d}\) Abbreviations: (C + P), premix of carfentrazone + pyroxasulfone; EPOST, early postemergence; POST, postemergence; PRE, preemergence; WAP, weeks after planting. \(^{e}\) Bayer code for weeds: AMAPA, Amaranthus palmeri S. Wats.; CUMME, Cucumis melo L. var. Dudaim Naud; IPOHE, Ipomoea hederacea (L.) Jacq; UROTE, Urochloa texana (Buckl.). \(^{f}\) Combined over the three locations Lamesa (Texas High Plains), Yoakum (south Texas), and Ft. Cobb (Oklahoma). Evaluations taken 11 to 16 wks after planting.
Table 3. Early to late season weed control with carfentrazone + pyroxasulfone (C + P) in 2016.

<table>
<thead>
<tr>
<th>Treatments a,b</th>
<th>Rate</th>
<th>Appl timing</th>
<th>Yoakum AMAPA c</th>
<th>Yoakum UROTE</th>
<th>Yoakum CUMME</th>
<th>Brownfield AMAPA c</th>
<th>Brownfield UROTE</th>
<th>Brownfield IPOHE</th>
<th>Ft. Cobb AMAPA c</th>
<th>Ft. Cobb UROTE</th>
<th>Ft. Cobb IPOHE</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Kg ai ha⁻¹</td>
<td>12 %</td>
<td>6 %</td>
<td>13 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Untreated</td>
<td>-</td>
<td>0</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(C + P)</td>
<td>0.0035 + 0.05</td>
<td>PRE</td>
<td>90</td>
<td>47</td>
<td>98</td>
<td>82</td>
<td>82</td>
<td>93</td>
<td>46</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(C + P)</td>
<td>0.005 + 0.07</td>
<td>PRE</td>
<td>94</td>
<td>66</td>
<td>92</td>
<td>98</td>
<td>78</td>
<td>89</td>
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</tr>
<tr>
<td>(C + P)</td>
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<td>75</td>
<td>99</td>
<td>100</td>
<td>92</td>
<td>93</td>
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</tr>
<tr>
<td>(C + P)</td>
<td>0.0035 + 0.05</td>
<td>EPOST</td>
<td>96</td>
<td>61</td>
<td>95</td>
<td>94</td>
<td>24</td>
<td>84</td>
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<tr>
<td>(C + P)</td>
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<td>EPOST</td>
<td>95</td>
<td>46</td>
<td>97</td>
<td>100</td>
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<td>(C + P)</td>
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<td>EPOST</td>
<td>99</td>
<td>68</td>
<td>98</td>
<td>93</td>
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<td>89</td>
<td>33</td>
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<td></td>
</tr>
<tr>
<td>(C + P)</td>
<td>0.0035 + 0.05</td>
<td>POST</td>
<td>82</td>
<td>48</td>
<td>98</td>
<td>-</td>
<td>41</td>
<td>75</td>
<td>33</td>
<td></td>
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<tr>
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<td>POST</td>
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<td>80</td>
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<td>-</td>
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<td>76</td>
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</tr>
<tr>
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<td>POST</td>
<td>100</td>
<td>60</td>
<td>88</td>
<td>-</td>
<td>68</td>
<td>83</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pendimethalin</td>
<td>1.06</td>
<td>PRE</td>
<td>99</td>
<td>61</td>
<td>99</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ (C + P)</td>
<td>+ 0.007 + 0.1</td>
<td></td>
<td></td>
<td></td>
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<td>PRE</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(C + P)</td>
<td>0.007 + 0.1</td>
<td>EPOST</td>
<td>99</td>
<td>85</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td></td>
</tr>
<tr>
<td>+ 1.47</td>
<td>S-metolachlor</td>
<td>PRE</td>
<td>97</td>
<td>66</td>
<td>89</td>
<td>-</td>
<td>-</td>
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<td>-</td>
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</tr>
<tr>
<td>Flumioxazin</td>
<td>0.11</td>
<td>EPOST</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>95</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
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<tr>
<td>S-metolachlor</td>
<td>1.47</td>
<td>PRE</td>
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<td>-</td>
<td>-</td>
<td>93</td>
<td>-</td>
<td>-</td>
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<td></td>
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<tr>
<td>Flumioxazin</td>
<td>0.11</td>
<td>POST</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>S-metolachlor</td>
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<td>PRE</td>
<td>-</td>
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<td>-</td>
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<tr>
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<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
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<td></td>
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<tr>
<td>Paraquat +</td>
<td>0.28 +</td>
<td>POST</td>
<td>98</td>
<td>91</td>
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<td>Dimethenamid-P</td>
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</tr>
<tr>
<td>Imazapic</td>
<td>0.07</td>
<td>POST</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

a All EPOST and POST treatments included Agridex at 0.25% v/v.

b Abbreviations: (C + P), premix of carfentrazone + pyroxasulfone; EPOST, early postemergence; PRE, preemergence; POST, postemergence.

c Bayer code for weeds: AMAPA, Amaranthus palmeri S. Wats.; CUMME, Cucumis melo L. var. Dudaim Naud; CYPES, Cyperus esculentus L.; IPOHE, Ipomoea hederacea (L.) Jacq.; UROTE, Urochloa texana (Buckl.).
of Palmer amaranth as S-metolachlor at rates of 1.1 to 4.3 kg ha\(^{-1}\). Knezevic et al. [14] found that pyroxasulfone at 0.16 kg ha\(^{-1}\) provided 90% control of tall waterhemp \((\textit{Amaranthus tuberculatus} \text{ (Moq.)})\) 28 DAT and that a higher rate was required to obtain the same control at 45 (0.2 kg ha\(^{-1}\)) and 65 DAT (0.27 kg ha\(^{-1}\)). Jha et al. [27] reported that the addition of pendimethalin to pyroxasulfone improved control of several weeds including common lambsquarters \((\textit{Chenopodium album} \text{ L.})\), kochia \([\textit{Kochia scoparia} \text{ (L.) Scharf}]\), and wild buckwheat \((\textit{Polygonum convolvulus} \text{ L.})\) over pyroxasulfone alone.

In soybean \((\textit{Glycine max} \text{ L.})\), Mahoney et al. [28] found that, under conventional tillage, flumioxazin/pyroxasulfone combinations provided 100% control of redroot \((\textit{Amaranthus retroflexus} \text{ L.})\) and smooth pigweed \((\textit{Amaranthus hybridus} \text{ L.})\) while under no-till control ranged from 53 to 100%. They noted that the differences in the weed efficacy with flumioxazin/pyroxasulfone combinations under conventional and no-till systems could not be attributed to environment alone but was related to differences in weed populations between the two systems.

### 3.1.2 Texas millet

#### 3.1.2.1 2015

At Yoakum, herbicide treatments which included imazapic provided 98% control of Texas millet while treatments that included pendimethalin plus the premix of C + P applied PRE without imazapic applied POST provided 87 to 96% control (Table 2). The herbicide systems that included the premix of C + P applied PRE and POST provided comparable control to those systems that included a POST application of imazapic.

At the Ft. Cobb location, the herbicide systems which included pendimethalin + flumioxazin plus the premix of C + P applied PRE provided 95 to 100% control and this was as good as or better than systems that included imazethapyr (Table 2). The herbicide standard system of flumioxazin applied PRE + lactofen + 2,4-DB applied POST, without either the premix of C + P applied PRE and POST or imazethapyr applied POST, provided 89% control.

#### 3.1.2.2. 2016

At Yoakum when evaluated 12 WAP, Texas millet control was no better than 85% with any herbicide system (Table 3). The C + P premix alone applied PRE controlled this weed 47 to 75%, EPOST applications provided 46 to 68% control and POST applications provided 48 to 80% control. Adding pendimethalin to C + P applied PRE resulted in 61% Texas millet control. The herbicide standard of pendimethalin plus S-metolachlor provided 66% control.

At the Ft. Cobb location, Texas millet control with the premix of C + P was 89 to 93% PRE, 84 to 89% EPOST, and 75 to 83% POST. This compares to 91% control with the standard treatment of flumioxazin + pendimethalin applied PRE followed by paraquat + dimethenamid-P applied EPOST and imazapic applied POST (Table 3).

In previous studies, Texas millet control with pyrosulfone applied PPI or PRE was inconsistent when used alone; however, when used in a systems approach with either pendimethalin, S-metolachlor, or dimethenamid control was greater than 90% [16,29].

### 3.1.3 Smellmelon

#### 3.1.3.1 2015

Smellmelon was only present at the Yoakum location. Pendimethalin plus the premix of C + P applied PRE followed by imazapic plus C + P applied POST controlled smellmelon 100% (Table 2). Pendimethalin plus the premix applied PRE followed by imazapic plus S-metolachlor applied POST failed to control smellmelon (63%). Herbicide systems that included lactofen plus 2,4-DB applied POST also provided inconsistent control ranging from 41 to 99%. Flumioxazin applied PRE followed by S-metolachlor applied EPOST controlled smellmelon 53%. In earlier work in south Texas, Grichar [30] reported that imazapic provided consistent control of smellmelon (> 85%).

#### 3.1.3.2 2016

All herbicide systems provided excellent smellmelon control. Pendimethalin applied PRE followed by carfentrazone plus pyroxasulfone applied EPOST provided perfect control (Table 3).

### 3.1.4 Yellow nutsedge

#### 3.1.4.1 2015

Yellow nutsedge was only present in 2015 at Ft. Cobb. No herbicide treatments provided better
than 59% control (Table 2). Herbicide systems that included imazethapyr only controlled this weed 56 to 59%. Control of yellow nutsedge with imazethapyr has been variable [31-34]. Grichar et al. [31] noted that imazethapyr PPI provided more consistent control than PRE or POST applications. They speculated that environmental factors may account for the relatively poor control (less than 80%) following PRE applications of imazethapyr. Exposure to sunlight has been shown to degrade or alter the structure of imidazolinone herbicides [35] and rainfall soon after application is essential for imazethapyr activation. Imazethapyr control of nutsedge is obtained primarily through root absorption [31].

3.1.5 Ivyleaf morningglory

3.1.5.1 2015

Ivyleaf morningglory was present only at the Ft. Cobb location. Herbicide systems that included lactofen plus 2,4-DB provided 99 to 100% control of ivyleaf morningglory while systems that included imazethapyr provided 83 to 95% control of this weed (Table 2). Systems that included the premix of C + P applied PRE controlled ivyleaf morningglory 83 to 100% while the standard of flumioxazin plus S-metolachlor provided 80% control.

Table 4. Peanut stunting and yield when using carfentrazone plus pyroxasulfone (C + P) during the 2015 growing season in Texas and Oklahoma

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Rate</th>
<th>Appl timing</th>
<th>Weeks after last appl</th>
<th>Lamesa</th>
<th>Ft. Cobb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>-</td>
<td>-</td>
<td>0 0 0 0</td>
<td>1671</td>
<td>4089</td>
</tr>
<tr>
<td>Flumioxazin</td>
<td>0.11</td>
<td>PRE</td>
<td>2 0 0 0</td>
<td>1504</td>
<td>5679</td>
</tr>
<tr>
<td>S-metolachlor</td>
<td>1.42</td>
<td>PRE</td>
<td>18 17 0 0</td>
<td>1226</td>
<td>5941</td>
</tr>
<tr>
<td>Flumioxazin</td>
<td>0.11</td>
<td>PRE</td>
<td>22 12 30 0</td>
<td>1281</td>
<td>3689</td>
</tr>
<tr>
<td>(C + P)</td>
<td>0.07</td>
<td>EPOST PRE</td>
<td>13 15 11 0</td>
<td>1300</td>
<td>4151</td>
</tr>
<tr>
<td>Lactofen + 2,4-DB</td>
<td>0.22</td>
<td>POST PRE</td>
<td>17 2 0 0</td>
<td>1690</td>
<td>5432</td>
</tr>
<tr>
<td>(C + P)</td>
<td>0.07</td>
<td>POST PRE</td>
<td>17 2 0 0</td>
<td>1690</td>
<td>5432</td>
</tr>
<tr>
<td>Lactofen + 2,4-DB</td>
<td>0.22</td>
<td>POST PRE</td>
<td>17 2 0 0</td>
<td>1690</td>
<td>5432</td>
</tr>
<tr>
<td>(C + P)</td>
<td>0.07</td>
<td>POST PRE</td>
<td>17 2 0 0</td>
<td>1690</td>
<td>5432</td>
</tr>
</tbody>
</table>

LSD (0.05)

5 8 8 NS 869

a All treatments, with the exception of the untreated check, included pendimethalin applied preplant incorporated at 1.06 kg ai ha⁻¹ at the south Texas and Texas High Plains locations and preemergence at the Ft. Cobb location. b All EPOST and POST treatments included Agridex at 0.25% v/v. c Imazapic used at the south Texas location while imazethapyr used in Lamesa and Ft. Cobb. d (C + P), premix of carfentrazone + pyroxasulfone. e Abbreviations: EPOST, early postemergence; POST, postemergence; PRE, preemergence. f Late season peanut stunting was not visible at Ft. Cobb. g Weeks after the last application (POST) of carfentrazone plus pyroxasulfone.
3.1.5.2 2016

Only flumioxazin plus pendimethalin applied PRE followed by paraquat + dimethenamid-P applied EPOST followed by imazapic applied POST provided excellent control of ivyleaf morningglory (Table 3). All systems that included C + P alone applied PRE provided 30 to 46% control, C + P alone applied EPOST provided 29 to 43% control, and C + P alone applied POST controlled this weed 30 to 40%. Application timing of C + P did not affect ivyleaf morningglory control.

Pyroxasulfone is not considered an outstanding herbicide for *Ipomoea* spp. control [7,28]; however, Hardwick [36] reported in corn that pyroxasulfone at 0.15 kg ha⁻¹ applied PRE controlled *I. hederacea* at least 89% and *Ipomoea lacunose* (L.) no better than 70% throughout the growing season.

3.2 Peanut Injury

Peanut injury soon after the application of C + P consisted of peanut leaf burn and was evident at all locations (data not shown). This leaf burn can be attributed to carfentrazone (C) in the premix and is typically transient, lasting 7 to 10 d, and the new peanut growth does not show any type of leaf burn [15,16,26,29]. Peanut stunting four weeks after herbicide application was visible in 2015 at Lamesa and Ft. Cobb (Table 4) but was not evident in 2016 at either Brownfield or Ft. Cobb (data not shown). The increased stunting seen at Ft. Cobb in 2015 can be attributed to the excessive rainfall (> 100 mm) received the first 2 wks after planting.

3.2.1 Yoakum

When evaluated 4 and 9 weeks after the last C + P application, no stunting was noted with any C + P treatment (data not shown).

3.2.2 Lamesa

Peanut stunting 4 weeks after the last C + P application was evident with all C + P treatments regardless of application timing and this injury ranged from 16 to 23% (Table 4). Systems that included S-metolachlor applied PRE resulted in ≤ 2% stunt. When evaluated 9 weeks after application all C + P systems still resulted in at least 10% stunting with the exception of lactofen + 2,4-DB + ( C at 0.007 kg ha⁻¹ + P at 0.1 kg ha⁻¹) applied POST which resulted in only 2% stunting.

3.2.3 Ft. Cobb

Flumioxazin at 0.11 kg ha⁻¹ plus C + P (0.007 kg ai ha⁻¹ + 0.1 kg ai ha⁻¹) applied PRE followed by the same rate of C + P applied EPOST resulted in 30% peanut stunting while systems that included flumioxazin applied PRE without C + P resulted in no stunting (Table 4).

3.3 Peanut Yield

3.3.1 Lamesa

No difference in peanut yield from the untreated check were noted with any herbicide systems although there were trends to lower yields with systems that caused 12 to 17% peanut injury (Table 4).

3.3.2 Ft. Cobb

Several herbicide systems improved peanut yield over the untreated check (Table 4). Flumioxazin plus S-metolachlor applied PRE, flumioxazin applied PRE followed by C + P (0.007 kg ha⁻¹ + 0.1 kg ha⁻¹) applied EPOST, C + P (0.009 kg ha⁻¹ + 0.12 kg ha⁻¹) followed by lactofen plus 2,4-DB applied POST, flumioxazin applied PRE followed by lactofen plus 2,4-DB applied POST, and flumioxazin applied PRE followed by lactofen plus 2,4-DB plus the premix of C + P applied POST resulted in yield increases of 33 to 45% over that of the untreated check (Table 4). These systems that resulted in the greatest yields showed no injury when evaluated 4 weeks after the last C + P application (Table 4).

4. CONCLUSION

The premix of C + P has provided excellent season-long control of Palmer amaranth and smellsmelon, which are broadleaf weeds that can cause Texas peanut growers considerable problems and are hard-to-control with current herbicides. This premix will control ALS- (WSSA Group 2 herbicides) and glyphosate- (WSSA Group 9 herbicides) resistant Palmer amaranth, which is becoming more widespread across southwestern peanut producing areas. Control of annual grasses such as Texas millet is limited and full–season control of this annual grass in peanut will require the postemergence use of clethodim® (WSSA Group 1 herbicide) or other graminicides.
ACKNOWLEDGEMENTS

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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