Chapter 2

Sesame (*Sesamum indicum*) Response to Postemergence-directed Herbicide Applications

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Additional information is available at the end of the chapter

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Abstract

Field studies were conducted from 2006 to 2010 under weed-free conditions in south Texas and in the Texas High Plains to determine sesame tolerance to applied postemergence-directed herbicides. Injury was greatest when herbicides were applied to 15 cm of the main stem compared to herbicide applications made to 5 cm of the main stem height. Glyphosate at 0.84 kg ae/ha and pyrithiobac-sodium at 0.07 kg ai/ha resulted in the greatest sesame stunting (28–90%) when applied up to 15 cm main stem height, while carfentrazone-ethyl, flumioxazin, and imazethapyr caused greatest injury when applied to 5 cm of the main stem. When glyphosate was applied up to 5 cm main stem height, sesame injury was 20% or less. Glyphosate applied up to the 15 cm stem height and pyrithiobac-sodium applied 5 and 15 cm stem height consistently reduced sesame yield when compared with the nontreated control. Acetochlor, diuron, fluometuron, and prometryn did not cause any sesame stunting. Carfentrazone-ethyl, diuron, flumioxazin, imazethapyr, propazine, pyraflufen-ethyl, linuron, and linuron plus diuron reduced sesame yield in at least one year in south Texas.

Keywords: Injury, *Sesamum indicum*, sesame, growth, yield

1. Introduction

Sesame (*Sesamum indicum* L.) is one of the oldest crops known to humans. There are archeological remnants of sesame dating to 5500 BC in the Harappa Valley in the Indian subcontinent [1]. Assyrian tablets from 4300 BC describe how before the gods battled to restore order to the universe, they ate bread and drank sesame wine [2]. Sesame was a major oilseed in the ancient world because of its ease of extraction, great stability, and drought resistance. Sesame production and consumption has been increasing dramatically in the last decade as emerging countries such as China, Korea, and India utilize more sesame based on traditional uses, and thus more is known in these regions about the positive health attributes of this crop. Incidentally, China has changed from being the largest exporter of sesame to the largest importer and India is close to transitioning from the second largest exporter to a net importer. With regard to the health effects, Bedigian [3] has edited a collection of past plus recent research that shows that minor compounds such as lignans "confer outstanding resistance to oxidation and cancer and depress blood pressure and cholesterol levels."

Previous papers [4,5,6,7] have described the problems associated with sesame and weed control as summarized below.

a. Sesame seeds are small and produce a small cotyledon, while many weeds have a larger cotyledon and accelerate their growth faster than sesame.

b. Sesame growth is very slow in the first 4 weeks (wks) after planting (Figure 1), allowing many weeds to grow taller and shade out the sesame as well as use soil moisture and nutrients [8]. Species of *Amaranthus* can be 3 to 4 times taller than sesame in the first 3 wks after planting.

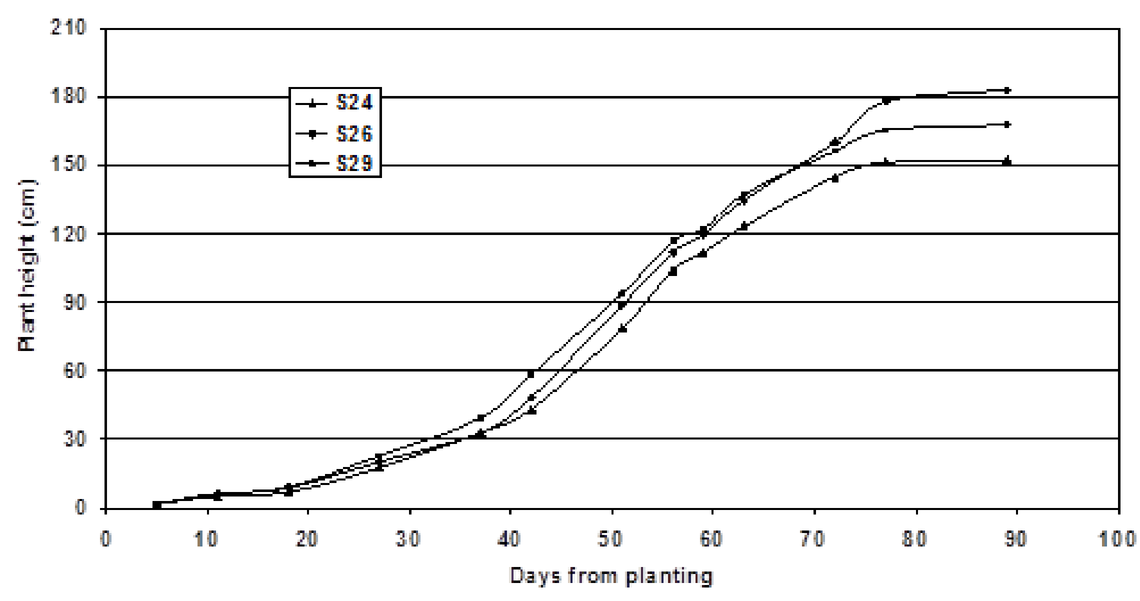

Figure 1. Sesame growth as influenced by days after planting.

c. The presence of weeds can negatively influence sesame yield. Kropff and Spitters [9] reported that the major factor influencing sesame yield loss in a competitive situation between the crop and weed is the ratio between the relative leaf area of the weed and the crop at the time of canopy closure. The effects of weeds on sesame establishment and growth have been well documented. Balyan [10], Gurnah [11], Singh et al. [12], and Upadhyay [13] reported weed-induced reductions of sesame yield up to 100% and a need for a critical weed-free period up to 50 days (d) after planting. Under weedy conditions, Eagleton et al. [14] recorded a weed biomass 6 times that of sesame 48 d after planting and Bennett [15] reported a weed biomass 1.3-fold that of sesame 42 d after planting. Mahgoub et al. [16] compared weedy and weed-free plots of sesame and the effect of weeds on sesame yield over time (Figure 2). The critical period of weed control is the time interval where control is essential to avoid a yield loss and is the interval between the length of weed competition tolerated and the weed-free requirement [17]. In peanut (*Arachis hypogaea* L.), Hill and Santelmann [18] reported that yields were not influenced by weeds removed as late as 3 wks after planting and weed control must persist for at least 6 wks after planting to better reduce weed competition and yield loss. Similarly, in peanut production in India and Ghana, maximum pod yield occurred when weeds were removed within 4 wks after planting [19,20], while Agostinho et al. [21] determined the critical period of weed control in Brazil for five peanut cultivars was from 7 to 65 d after planting. Everman et al. [17] reported that the critical period of interference with mixed broadleaf weed species in peanut was from 2.6 to 8 wks after planting.

Martin et al. [22] stated that weeds could remain in canola (*Brassica napus* L.) up to the four-leaf stage (17–38 d after emergence) even at the 5% yield loss level and even given high levels of weed pressure.

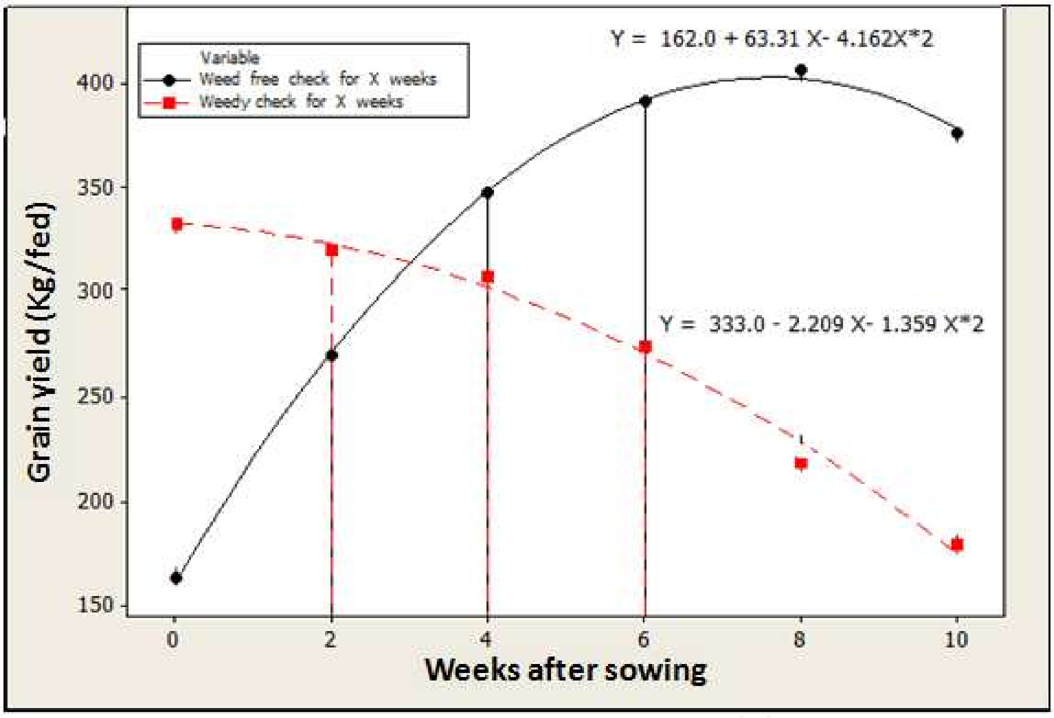

Figure 2. Critical period of weed interference in sesame.

d. Depending on row spacing, the sesame canopy may take as many as 60 d to completely shade the ground. On the other hand, with closer row spacing such as drill-seeded sesames, there is no possibility of being able to use mechanical or manual cultivation to control weeds.

e. Sesame self-defoliates while it is maturing and drying down, thus introducing another period of vulnerability to weeds once the sunlight is again able to reach the soil surface.

f. In manual harvest, the sesame is cut separately from the weeds; therefore, there is little to no weed seed in the harvested grain. In mechanical harvest, weeds are cut at the same time as the sesame. If the weeds are still green, they can introduce moisture into the sample which may lead to heating and ruining of the seed.

g. Many weed seeds have a similar size and/or specific gravity of sesame seeds, making it difficult to separate from the weed seed.

h. It is difficult to evaluate sesame because it has a great ability to compensate for injury, stunting, and stand reduction. In many of the herbicide studies where sesame injury is severe following preemergence (PRE) and postemergence (POST) herbicide treatments, sesame yields are acceptable because the plants can compensate for open space by additional branches with capsules. However, branching can only compensate for gaps of less than 30 cm. Wider gaps not only lead to lower yields, but also let light through the canopy to encourage late-season weed emergence and growth.

The majority of sesame in the world is grown manually – manual planting, manual control of weeds, and manual harvest [23,24]. In countries where there is abundant, cheap manual labor, this methodology will persist. However, in countries such as the USA, the price of sesame will not allow for much manual labor. Planting, cultivating, and harvesting are done mechanically; however, in some cases, manual labor is still required for weed control. The purpose of weed research over the past 23 years conducted by the authors has been to control weeds with the use of herbicides. There have been numerous studies published on preplant [25,26], PRE [27-28], POST [29], postemergence-directed (PDIR) [30], and summaries of various studies [7].

Preplant-incorporated herbicides such as trifluralin, pendimethalin, and ethalfluralin can provide good weed control, but a stand of sesame can be destroyed if precipitation moves the soil particles containing the herbicide into the root zone at an early growth stage [25,26]. Preemergence herbicides such as acetochlor, diuron, linuron, and *S*-metolachlor typically provide favorable control (70–80%) of small seeded grasses and dicots [27,28]. There are numerous studies that have shown that alachlor can be and is used in most of the sesame growing countries around the world [31,32]. The POST graminicides, fluazifop-p-butyl and sethoxydim, provide good grass control at all stages of growth, while clethodim may cause injury when sprayed during the reproductive phase [29]. As for broadleaf weeds, diuron and fluometuron applied POST provide reasonable control but there is risk of injury to sesame [29]. With the exception of glyphosate, which will kill sesame when applied POST, most of these herbicides will moderately to severely damage sesame but will not kill it [7].

In the USA, the use of glyphosate or glufosinate-ammonium tolerant hybrids or varieties in most of the major field crops such as corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), and soybean [*Glycine max* (L.) Merr.] is widespread [33-35] and has led to the evolution of many weeds that are now resistant to these herbicides [36-39]. New cotton and soybean transgenic varieties with traits conferring resistance to the synthetic auxin herbicides, 2,4-D and dicamba (2,4-DR and DR, respectively) have been developed [40-42] and are expected to be quickly adopted by growers who will use these traits to control glyphosate- and glufosinate-ammonium-resistant weed species [43-46]. This type of methodology cannot be used for weed control in sesame because, similar to wheat (*Triticum aestivum* L.), the current markets will not accept a genetically modified sesame.

There is a second issue with the universal use of POST herbicides. When the plants reach a certain height or size, the POST herbicides do not reach below the canopy or on the ground in the seed zone. In the past, many US growers used directed sprays in traditional cropping systems, but much of that equipment has been idle for many years. However, because of weed resistance issues in many areas of the country [33-35], there has been a resurgence in the use of this type of equipment that might be utilized in sesame production. The directed spray equipment covers fewer acres per hour compared to the newer over-the-top sprayers and thus has not been the preferred method of weed control; however, growers have begun to use directed sprayers on sesame.

There has been a federal label in the USA for the use glyphosate as a PDIR spray as long as the glyphosate is applied between the rows and not on the main stem of the sesame [47]. Many commercial fields have used this type of application successfully and it has been particularly effective against viney weeds such as morningglory (*Ipomea* spp.) and smellmelon (*Cucumus melo* L) as long as the vines have grown into the furrows. In some cases, the vines of these weeds start climbing the sesame plant from the ground line and are not covered by the glyphosate application. In addition, there are weeds, such as cutleaf groundcherry (*Physalis angulata* L.), that can grow under poor light conditions found below the crop canopy and eventually grow above the sesame. Also, glyphosate does not provide any soil residual control.

In previous work with the PDIR systems, Grichar et al. [30] used some of the more common cotton herbicides and sprayed those to 5 and 15 cm of the sesame main stem. Sesame injury was greatest when herbicides were applied to 15 cm of the main stem compared to herbicide applications made to 5 cm of the main stem height. Glyphosate at 0.84 kg ae/ha and pyrithiobac-sodium at 0.07 kg ai/ha resulted in the greatest sesame stunting (28–90%) when applied to the 15 cm main stem height. When glyphosate was applied to the 5 cm main stem height, sesame injury was 20% or less. Glyphosate applied to the 15 cm stem height and pyrithiobac applied to the 5 and 15 cm stem height consistently reduced sesame yield when compared with the nontreated control. Glufosinate-ammonium and the premix of linuron plus diuron applied up to the 5 cm stem height caused the least sesame stunting and resulted in no reduction in sesame yield when compared with the nontreated control. It was concluded that up to 5 cm coverage was a safer height because (1) it caused less damage and (2) in a field use setting by growers, the 5 cm height realistically meant the height would be 0–10 cm, whereas setting the height at 15 cm meant the height would be 10–20 cm, a height not commonly utilized by producers and thus introduces more herbicide injury risk to the system.

This study is a continuation of the previous PDIR work [30] and the purpose was to use a wider range of herbicides, with an emphasis on those herbicides that control broadleaf weeds, while eliminating those herbicides that caused too much injury. There are good options for POST treatment of grasses to include fluazifop-p-butyl, sethoxydim, and clethodim [7,29]. Recent work has shown effectiveness with quizalofop [7] and haloxyfop (Hongmei, personal communication). As for POST control of broadleaf weeds, diuron is the only known herbicide that will cause minimal damage to the sesame while controlling many broadleaf weeds [7].

2. Materials and methods

2.1. Research sites

Field studies were conducted during the 2008 through 2010 growing seasons near Uvalde in south Texas and near Lorenzo in the Texas High Plains to evaluate sesame response to herbicides applied PDIR. Fields were selected that had low weed populations so any plant response could be attributed to the herbicide treatment and not weed competition. All plots were manually maintained weed-free and herbicide efficacy was not evaluated. Within 2 d of planting, *S*-metolachor at 1.43 kg ai/ha and glyphosate at 0.4 kg ae/ha were applied to control any existing weeds and provide additional PRE weed control on the nonsprayed areas between the rows. The Uvalde trial was furrow-irrigated, while the Lorenzo field was dryland with no rain after planting in 2009 and 2010. Soil type at Uvalde was a Winterhaven silty clay loam (fine-silty, carbonatic, hyperthermic Fluventic Ustochrepts) with less than 1.0% organic matter and pH 7.8. Soil type at Lorenzo was an Amarillo sandy clay loam (fine-loamy, mixed, thermic Aridic Paleustalf) with 0.8% organic matter and pH 7.8.

2.2. Plot design

A randomized complete-block experimental design was used and treatments were replicated 3 times. Treatments consisted of 12 herbicides applied PDIR no more than 5–10 cm up the main stem of the sesame. A nontreated control was included for comparison. Plot size was five rows (76 cm apart) by 9.1 m in south Texas and four rows (101 cm apart) by 7.3 m in the Texas High Plains. Only the two middle rows were sprayed and the other rows were nontreated and served as buffers. Carfentrazone-ethyl, glufosinate-ammonium, pyraflufen-ethyl, propazine, linuron, and linuron plus diuron were used as standards since they had been tested previously [30]; however, carfentrazone-ethyl, glufosinate-ammonium, and pyraflufen-ethyl were eliminated after 2008 since they provide little or no residual activity [48-50] and; therefore, would not be as beneficial as those herbicides that possessed residual activity. Linuron, the combination of linuron plus diuron, and propazine were used as standards in subsequent years. Acetochlor, as an encapsulated formulation, was released for testing and used only in 2010. The encapsulated formulation of acetochlor was labeled in the USA for use in corn, cotton, milo (*Sorghum bicolor* L. Moench), and soybean in 2011 [51].

2.3. Herbicides and spraying information

Herbicides and doses included in the study are shown in Table 1. At Uvalde, herbicides were applied in water using a CO2-pressurized backpack sprayer calibrated to deliver 190 L/ha at 180 kPa. Spray tips were one Teejet® 8004E nozzle (Teejet Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60188) on each side of the row adjusted to spray a PDIR spray band up to 10 cm

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in height on sesame stem and 10–15 cm band on the soil to simulate the spray of a PDIR spray applicator. At the Lorenzo location, a tractor-mounted compressed-air Redball® sprayer with Teejet® 8002E spray tips (one on each side of row) calibrated to deliver 93 L/ha at 207 kPa was used in 2008, while in 2009 and 2010 a similar setup to the Uvalde location was used. Herbicides were applied when sesame was 38–76 cm in height. All PDIR herbicide sprays with the exception of glufosinate-ammonium included a crop oil concentrate (AgriDex®, a blend of 83% paraffin-based petroleum oil and 17% surfactant, Helena Chemical Company, Suite 500, 6075 Poplar Avenue, Memphis, TN 38137) at 1.0% v/v.

Common name	Trade name	Manufacturer	Dose (kg ai/ha)
Acetochlor	Warrant	Monsanto Company	1.27
Carfentrazone-ethyl	Aim	FMC	0.02
Diuron	Direx	Makhteshim Agan	1.12
Fluometuron	Cotoran	Makhteshim Agan	1.12
Flumioxazin	Valor	Valent, USA	0.07
Glufosinate-ammonium	Liberty	Bayer Crop Science	0.58
Imazethapyr	Pursuit	BASF	0.07
Prometryn	Caparol	Valent USA	1.12
Propazine	Milo-Pro	Albaugh, Inc	0.84
Pyraflufen-ethyl	ET	Nichino America, Inc	0.002
Linuron	Lorox	DuPont Crop Protect.	1.12
Linuron + diuron	Layby Pro	Tessenderlo Kerley, Inc	0.56 + 0.56

Table 1. Herbicides, trade names, manufacturer, and dose used in study.

2.4. Sesame varieties, planting, and harvesting

Sesame variety "Sesaco 32" was planted at all locations. Planting dates at the Uvalde location were late May in all years, while at the Lorenzo location, sesame was planted late June in 2008, 2009, and early June in 2010. Sesaco 32 was seeded approximately 1.0 cm deep at a seeding rate of 3.4 kg/ha at both locations. When the sesame plants in plots were dry enough to harvest, the sesame plants were hand-harvested, dried, threshed with a plot thresher, cleaned, and weighed.

2.5. Data analysis

An analysis of variance was performed using the ANOVA procedure for SAS [52] to evaluate the significance of herbicides on sesame response and yield. Fishers Protected LSD at the 0.05 level of probability was used for separation of mean differences.

3. Results

Since not all herbicides were included in each year of this study, no attempt was made to combine data over years or locations; therefore, each year is presented separately.

3.1. South Texas (Uvalde)

3.1.1. Sesame stunt

In 2008, when rated early season (21 d after herbicide application), imazethapyr caused the greatest stunting (97%), while carfentrazone-ethyl and linuron alone caused at least 50% sesame stunting (Table 2). Sesame in the linuron plots recovered substantially (17%) by 70 d after herbicide application. Flumioxazin, glufosinate-ammonium, and propazine caused 27–37% sesame stunting, while diuron, prometryn, and the combination of diuron plus linuron resulted in 8% or less stunting (Table 2). When rated later in the growing season (70 d after herbicide application), sesame stunting with carfentrazone-ethyl and imazethapyr was still greater than 60%, while flumioxazin, propazine, pyraflufen-ethyl, and linuron caused 17–48% sesame stunting. Diuron, glufosinate-ammonium, prometryn, and the combination of diuron plus linuron caused 10% or less stunting (Table 2).

In 2009, when rated 26 d after herbicide application, flumioxazin, propazine, and the combination of diuron plus linuron caused significant sesame stunting (>30%), while in 2010, only flumioxazin caused stunting that was greater than the nontreated control (Table 2).

3.1.2. Sesame yield

In 2008, all PDIR herbicide treatments with the exception of diuron, glufosinate-ammonium, and prometryn reduced sesame yield when compared with the nontreated control (Table 2). In 2009, all of the PDIR treatments except acetochlor, fluometuron, and prometryn reduced the sesame yield when compared to the nontreated control. In 2010, only flumioxazin reduced yield when compared with the nontreated check.

		Stunt (%)[b]				Yield		
		2008				(Kg/ha)		
Treatment[a]	Dose (Kg/ha)	Early	Late	2009	2010	2008	2009	2010
Nontreated	-	0	0	0	0	1233	1309	1230
Acetochlor	1.27	-	-	3	0	-	1334	1159
Carfentrazone-ethyl	0.02	63	62	-	-	336	-	-
Diuron	1.12	8	1	8	0	1159	1061	1344
Fluometuron	1.12	-	-	11	2	-	1183	1282

Flumioxazin	0.07	37	48	78	30	717	446	724
Glufosinate-ammonium	0.58	30	10	-	-	1054	-	-
Imazethapyr	0.07	97	65	-	-	583	-	-
Prometryn	1.12	3	4	8	0	1168	1122	1294
Propazine	0.84	27	22	53	5	968	536	1180
Pyraflufen-ethyl	0.002	15	25	-	-	975	-	-
Linuron	1.12	50	17	14	0	986	1033	1234
Diuron + Linuron	0.56 + 0.56	3	3	30	3	901	919	1272
LSD (0.05)		24	15	27	8	213	235	327

[a] All PDIR herbicides, except glufosinate-ammonium, included a crop oil concentrate at 1.0 % v/v.

[b] Stunt ratings taken 21 and 70 d after herbicide application in 2008 and 26 and 13 d after herbicide application in 2009 and in 2010, respectively.

Table 2. Sesame stunt and yield in south Texas as influenced by postemergence-directed herbicide sprays.

3.2. High Plains (Lorenzo)

3.2.1. Sesame stunt

In 2008, all herbicides applied PDIR, with the exception of pyraflufen-ethyl, caused stunting that was greater than the nontreated control (Table 3). Greater than 10% stunting was observed when using flumioxazin or propazine. In 2009, prometryn, diuron, or linuron caused 4–7% sesame stunting when compared with the nontreated control; however, flumioxazin caused severe stunting (43%). Fluometuron and propazine caused stunting (1%) that was not different from the nontreated control. In 2010, all herbicides, with the exception of fluometuron (2%), caused minor stunting (4–5%), while flumioxazin again caused severe stunting (23%).

3.2.2. Sesame yield

Sesame was not harvested in 2009 at Lorenzo due to dry growing conditions during the growing season and yields which were extremely low (<100 kg/ha). Sesame yields were extremely low in 2010 also due to the extreme drought and high temperatures [53]. In neither year (2008 or 2010) was sesame yields reduced from the nontreated control with any herbicide treatment (Table 3). However, in 2010, yields from sesame treated with propazine or the combination of diuron plus linuron resulted in a yield increase over the nontreated control. The lack of yield differences from the nontreated control may be due to the fact that although sesame stunting, with the exception of flumioxazin, was greater than the nontreated control in many instances, injury was less than 10%. Sesame does have the ability to compensate for reduced populations and early season injury due to herbicides [5]. In numerous yield analyses, Langham [8] found little difference in yield from sesame populations of 10–26 plants per meter. Many sesame cultivars can adjust to the population; that is, produce more branches (and therefore more capsules) under low populations. However, branching can only compensate for gaps of about 30 cm. Wider gaps not only lead to lower yields but also let light through the canopy to encourage weed emergence and growth [7].

		Stunt (%)[b]			Yield (Kg/ha)	
Treatment[a]	**Dose (Kg/ha)**	**2008**	**2009**	**2010**	**2008**	**2010**
Nontreated	-	0	0	0	818	302
Acetochlor	1.27	-	-	0	-	330
Carfentrazone-ethyl	0.02	7	-	-	859	-
Diuron	1.12	5	6	4	751	333
Fluometuron	1.12	-	1	2	-	314
Flumioxazin	0.07	12	43	23	650	351
Glufosinate-ammonium	0.58	5	-	-	789	-
Prometryn	1.12	7	7	5	706	313
Propazine	0.84	13	1	4	706	430
Pyraflufen-ethyl	0.002	3	-	-	859	-
Linuron	1.12	5	4	5	664	367
Diuron + Linuron	0.56 + 0.56	5	-	4	661	430
LSD (0.05)		3	4	3	200	87

[a] All PDIR herbicides, except glufosinate, included a crop oil concentrate at 1.0 % v/v.

[b] Stunt ratings taken 28–30 d after herbicide application.

Table 3. Sesame stunt and yield in the High Plains of Texas as influenced by postemergence-directed herbicides sprays.

3.3. Combined data over PDIR studies

3.3.1. Yields

Yield data from Grichar et al. [30] and this study were combined and averages were compiled with the treatment yield average compared to the nontreated control and expressed as a percent increase or decrease from the nontreated (Table 4). As mentioned earlier, yields from Lorenzo in 2009 were not taken due to the extremely dry conditions, while yields at Uvalde were consistent due to the use of furrow irrigation to supplement rainfall. All PDIR herbicide treatments, with the exception of acetochlor, glyphosate plus prometryn, paraquat, and pyraflufen-ethyl, resulted in yield reductions when compared with the nontreated control (Figure 3). In 2010, Monsanto launched an encapsulated formulation of acetochlor (Warrant®) [51]. This encapsulated formulation of acetochlor provides greater crop safety in several crops, including soybean, and was designed to give

PRE control of weeds as well as assist in POST weed control in acetolactate synthase (ALS) and glyphosate-resistant weeds [54,55]. The encapsulated formulation requires limited moisture for activation, helps minimize a negative crop response, and also can extend weed control for up to 40 d [54,55]. Glyphosate, paraquat, and pyraflufen-ethyl all have resulted in sesame injury and yield reductions in several studies [7,29]. Glyphosate is cleared in the USA for use in sesame as a burndown, with wiper applicators, and/or hooded sprayers in row middles [6,7,47]. For burndown use, glyphosate should be applied before, during, or just after planting but before the sesame seedlings emerge [47]. Glyphosate applied POST to sesame will result in plant death or yellowing of the sesame and a lack of capsule formation for 1–3 wks after application. When capsule formation does somewhat recover, the capsules will be smaller and will have less seeds and seed weight [6,7].

4. Discussion

4.1. Ideal herbicide and those that have shown the most promise

The ideal PDIR herbicide is one that will kill existing weeds and also provide residual PRE soil activity. The killing of the weeds with POST herbicides can be broken down into 2 categories: those herbicides that are systemic and kill the whole plant and those herbicides that just kill the plant tissue that comes in contact with the herbicide. In the latter category, if there is enough dead tissue, the weed may die.

There are nine herbicides that are selective to sesame: acetochlor, diuron, fluometuron, glufosinate-ammonium, linuron, linuron plus diuron, paraquat, prometryn, and pyraflufen-ethyl (Table 5). Acetochlor can be eliminated because it has residual control but will not kill existing weeds. Glufosinate-ammonium, paraquat, and pyraflufen-ethyl can be eliminated because they will kill existing weeds but do not have a residual effect.

The following are the most promising for use as a PDIR spray application:

1. Diuron, a systemic urea herbicide that inhibits photosynthesis and has been used to control various weeds in cotton [56], is selective to sesame as a PRE, POST [7], or as a PDIR treatment and is effective against both broadleaf weeds and grasses [57]. In Venezuela, diuron at 0.6 and 1.2 kg/ha reduced sesame yield, but yield would have been much lower without effective weed control [58]. In the USA, in one year, diuron at 0.8 and 1.7 kg/ha resulted in adequate weed control without apparent crop injury, whereas in another year, there was stand reduction and chlorosis [59]. In later work by Grichar et al. [27], they reported that diuron at 1.12 kg/ha reduced sesame stands and caused sesame injury in one year in the Texas High Plains area; however, in south Texas no adverse effects with diuron were seen in the two years.

2. Linuron, a substituted urea herbicide, is selective to sesame as a PRE or PDIR treatment [7] but may severely damage sesame as a POST treatment [7,29,30]. Multiple direct applications of linuron, when the sesame was 15–30 cm tall, did not kill the sesame

	Lorenzo				Uvalde				
	Kg/ha								Deviation[a]
Treatment	2006	2007	2008	2010	2007	2008	2009	2010	%
Nontreated	612	810	818	302	1223	1233	1309	1230	
Acetochlor	-	-	-	330	-	-	1334	1159	1.8
Carfentrazone-ethyl	608	1080	859		996	336			-10.7
Diuron	-	-	751	333	-	1159	1061	1344	-2.7
Flumioxazin	-	-	650	351	-	717	446	724	-30.6
Fluometuron	-	-	-	314	-	-	1183	1282	-0.5
Glufosinate-ammonium	556	1047	789	-	1173	1054	-	-	-0.4
Glyphosate	526	830	-	-	984	-	-	-	-10.4
Glyphosate + diuron	382	760	-	-	917	-	-	-	-22.9
Glyphosate + prometryn	462	964	-	-	1440	-	-	-	4.1
Imazethapyr	-	-	-	-	-	583	-	-	-52.7
Lactofen	494	882	-	-	1191	-	-	-	-4.3
Linuron	-	1046	664	367	1272	986	1033	1234	-0.7
Linuron + diuron	552	567	661	430	1386	901	919	1272	-7.1
Paraquat	630	1014	-	-	1062	-	-	-	5.0
Prometryn	-	-	706	313	-	1168	1122	1294	-4.9
Propazine	-	750	706	430	1317	968	536	1180	-8.6
Pyraflufen-ethyl	588	1068	859	-	1446	975	-	-	6.1
Pyrithiobac	412	298	-	-	345	-	-	-	-55.9
Trifloxysulfuron	588	477	-	-	687	-	-	-	-29.6
Trifloxysulfuron + prometryn	520	690	-	-	1194	-	-	-	-10.7
LSD (0.05)	90	210	200	87	264	213	235	327	

[a] Average deviation from the nontreated.

Table 4. Sesame yields for all trials from 2006 through 2010.

and controlled morningglory and smellmelon (author's personal observation). Linuron is effective against both broadleaf weeds and grasses [60]. Santelmann et al. [61] found slight phytotoxicity and a reduction in sesame yield with linuron at 2.24 kg/ha.

3. Linuron plus diuron (marketed in the USA as Layby Pro) is selective to sesame as a PRE or PDIR treatment but may severely damage sesame as a POST application [7]. Linuron plus diruon is effective against both broadleaf weeds and grasses [62].

4. Prometryn may prevent sesame germination when applied PRE, will severely damage sesame when applied POST [7], and is selective to sesame when applied PDIR. Prometryn is effective against both broadleaf weeds and grasses [63] and has been effective against morningglory (*Ipomoea* spp.) in field studies (author's personal observations). In irrigated studies in Ethiopia, prometryn at 1.0 kg/ha was safely used on sesame and at the 1.9 kg/ha dose resulted in less than 10% sesame injury. In a similar trial under natural rainfall, prometryn at 2.2 kg/ha completely eliminated the crop [64]. In other studies in Ethiopia under irrigated conditions, prometryn applied PRE at 3.2 kg/ha provided excellent weed control with negligible crop damage. However, under rain-fed conditions, prometryn at 0.8 kg/ha caused 100% sesame mortality [65].

5. Fluometuron has produced mixed results when applied PRE [7] and is selective to sesame as a POST [7] or PDIR treatment. Flumeturon provides control of annual grasses and broadleaf weeds [66]. However, fluometuron is not as effective against many weeds as the previously mentioned herbicides (author's personal observations). In India, fluometuron did not perform as well as alachlor or dichlormate [67]. In Bulgaria, fluometuron at 1.0 kg/ha applied 2 d after sowing controlled annual broadleaf weeds [68]. In the USA, fluometuron doses of 0.3 and 1.1 kg/ha had no effect on sesame height or population, provided good weed control, and had comparable yields to the nontreated control in south Texas [25]. Later, Grichar et al. [27] reported that fluometuron at 1.12 kg/ha in the High Plains region of Texas reduced sesame stand and caused injury in one of two years, while no stand reduction or injury was noted at the south Texas location. Fluometuron applied POST may injure cotton and delay maturity [69]. Guthrie and York [69] stated that growers may resort to this type of application when an insufficient height differential between the crop and weeds prohibits PDIR herbicide applications.

4.2. Herbicides that should not be used

The results of these studies clearly show that the following herbicides should not be used PDIR on sesame: flumioxazin, glyphosate plus diuron, imazethapyr, pyrithiobac, and trifloxysulfuron. With 100% potential reduction in sesame yield if weeds overtake a field, herbicides that cause about 10% sesame injury or yield reduction should not be ruled out. These include carfentrazone, glyphosate, and propazine. Although trifloxysulfuron plus prometryn resulted in just over 10% reduction in yield from the nontreated (Table 4), this combination should probably be avoided since a serious reduction in yield resulted from the use of trifloxysulfuron alone (30%).

Glyphosate is an interesting option because at times it appears to not cause much sesame injury and at other times it will kill many sesame plants. In one instance in a field with a very high sesame population, which resulted in dominant and minor plants [5], the glyphosate killed the majority of the minor plants and resulted in high yields. In this situation, the minor plants are similar to weeds in that they utilize moisture and fertility and yet do not contribute a commensurate amount of seed yield. Even though the glyphosate plus prometryn treatment actually increased yield, it is difficult to recommend its use since there is only one trial where

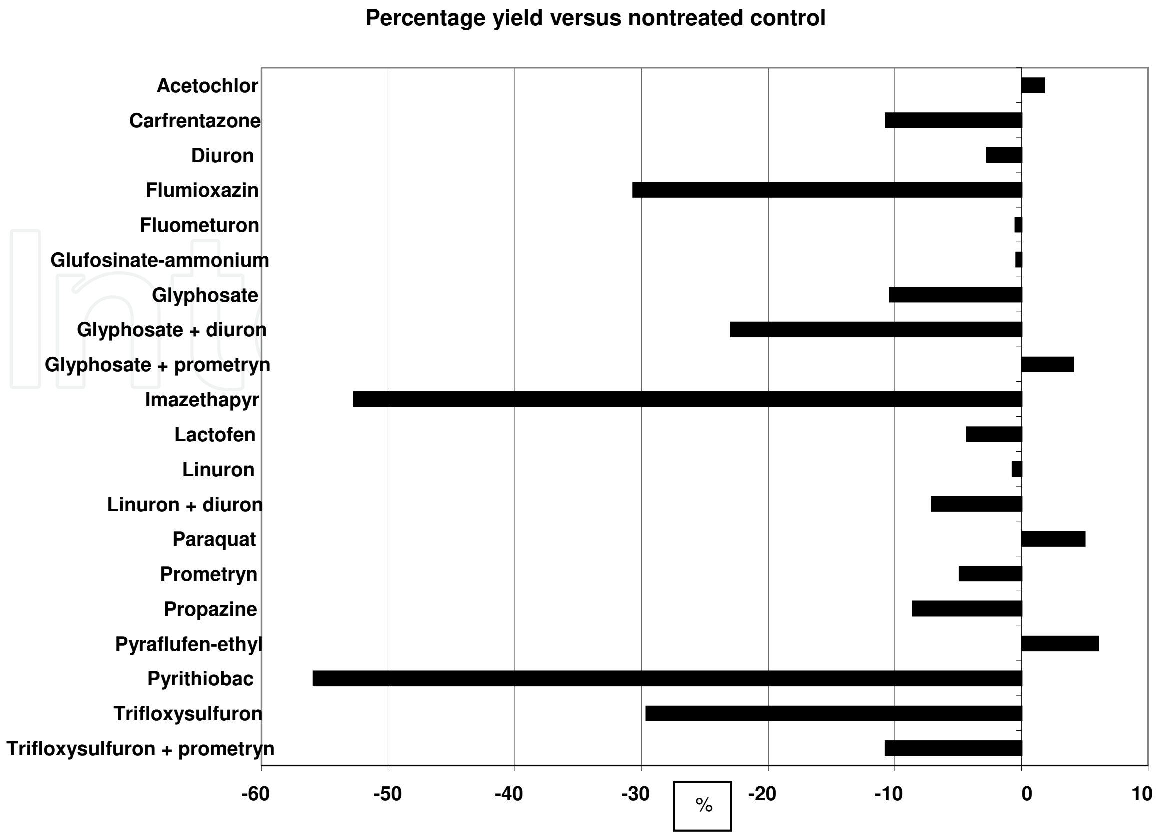

Figure 3. Influence of herbicides applied PDIR to sesame yield.

the results were positive, and glyphosate has been too inconsistent with respect to sesame injury. Carfentrazone and propazine should be considered in a rescue situation when no other herbicides are available.

4.3. Other considerations

As with all herbicides, plant stress may reduce systemic herbicide activity and account for relatively poor herbicide performance. Buhler and Burnside [70] noted that glyphosate was less effective on drought-stressed annual grass species than actively growing plants. Contact herbicides such as carfentrazone-ethyl, diuron, or lactofen are not as dependent on translocation for activity and their activity is not as adversely affected by drought-stressed plants [71,72]. Also the size of the sesame and the weed are important factors [73,74]. One of the weeds that has become more prevalent in the southwestern USA is false ragweed (*Parthenium hysterophorus* L.). Once this weed reaches 30–60 cm in height, spraying the lower 5 cm (as with a PDIR herbicide) will not kill the weed. Similarly, large smellmelon plants are not totally killed with POST herbicides; however, smellmelon growth is slowed and the vines do not climb the sesame plants to sunlight.

Further research is needed on timing of the herbicide application. In all of these trials, the herbicides were applied 4–5 wks after planting when the sesame was in the late juvenile stage and sesame plants were about 38–70 cm tall and only one sesame variety was tested. One of the practical issues in farming is: what is the earliest time that the herbicide can be applied without damaging the sesame? Because all of the studies were done on fields that had been planted in late May or early June, the heights of the plants and the heights of the first capsule were similar. The herbicide spray contacted the sesame stem below the lowest leaf; thus, there was virtually no damage to any of the leaves. The exception was with the use of paraquat where the effects of physical drift could be seen on the lower leaves (author's personal observations).

Treatment	Residual	Contact	Systemic	Mode of action	Sesame[a]
Acetochlor	Yes	No	No	Shoot growth inhibitor	Sel
Carfentrazone-ethyl	No	Yes	No	PPO inhibitor	Stox
Diuron	Yes	Yes	No	Photosynthesis II (P II) inhibitor	Sel
Flumioxazin	Yes	Yes	No	PPO inhibitor	Tox
Fluometuron	Yes	No	No	P II inhibitor	Sel
Glufosinate-ammonium	No	No	Yes	Glutamine synthase inhibitor	Sel
Glyphosate	No	No	Yes	EPSP synthase enzyme inhibitor	Tox
Glyphosate + diuron	Yes	Yes	Yes	EPSP synthase enzyme inhibitor + P II inhibitor	Tox
Glyphosate + prometryn	Yes	Yes	Yes	EPSP synthase enzyme inhibitor + P II inhibitor	Tox
Imazethapyr	Yes	No	Yes	ALS or AHAS synthesis inhibitor	Tox
Lactofen		Yes	No	PPO inhibitor	Ssel
Linuron	Yes	Yes	No	P II inhibitor	Sel
Linuron + diuron	Yes	Yes	No	P II inhibitor	Sel
Paraquat	No	Yes	No	P I inhibitor	Sel
Prometryn	Yes	Yes	No	P II inhibitor	Sel
Propazine	Yes	No	No	P II inhibitor	Stox
Pyraflufen-ethyl	No	Yes	No	PPO inhibitor	Sel
Pyrithiobac	Yes	Yes	No	ALS or AHAS synthesis inhibitor	Tox
Trifloxysulfuron	Yes	No	Yes	ALS or AHAS synthesis inhibitor	Tox
Trifloxysulfuron + prometryn	Yes	Yes	Yes	ALS or AHAS synthesis inhibitor + P II inhibitor	Stox

Abbreviations: Sel, selective to sesame (does not damage sesame); SSel, somewhat selective to sesame (some damage to sesame, sesame recovers); Tox, toxic (substantial reduction of sesame production); STox, somewhat toxic (enough reduction that probably cannot be used).

Table 5. Mode of action of herbicides on weeds and effect on sesame.

When using the number of days after planting as a criterion for applying a herbicide, the ratio of the portion of the stem being struck by the herbicide to the rest of the plant may be significantly different in some situations. The height of the first leaf at 4–5 wks after planting is affected by the following:

- Daylength. Commercial crops planted in late March to early April in the Lower Rio Grande Valley of Texas have much shorter internodes and when 5–10 cm tall, the herbicide spray would come in contact with the leaves. The plants also start flowering earlier and may be in the prereproductive stage instead of the juvenile stage. The longest day of the year is 21 June and crops planted around this time have the longest internodes in areas with high temperatures.
- Temperatures. In years when the air temperatures are low during the early portion of the growing season (such as 2014), the internodes are shorter and the plants are generally more susceptible to stresses in the early weeks.
- Moisture and fertility. High moisture and fertility in the first 2–3 wks will lead to longer internodes and not be a problem. However, in low resource crops, the internodes may be short enough to affect the interaction between the herbicide and the plants.

In waiting for the sesame plants to get tall enough to spray, the weeds also getting taller and will likely be less susceptible to the herbicides [75,76]. Grichar and Dotray [75] reported that lactofen control of Palmer amaranth (*Amaranthus palmeri* S. Wats) was greater when applied to 2–5 cm tall compared with either 15–20 cm or 25–30 cm tall plants. Mayo et al. [76] concluded that Palmer amaranth control generally decreased as application timing was delayed for aciflurofen, imazethapyr, and lactofen.

Also, it has been observed, when diuron and fluometuron were applied in a time of application study, damage to sesame was more severe 2 wks after planting than at any other stage of sesame growth (unpublished data). It is reasonable to expect that a PDIR application at this growth stage would result in more damage. However, research needs to be conducted because it is different to have a PDIR spray contact only the lower leaves versus a POST over the top application where all of the top leaves and the apical meristem are contacted.

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