

Research Paper

Sesame Tolerance to Herbicides Applied Postemergence-Directed

Abstract. Field studies were conducted during the 2006 and 2007 growing seasons under weed-free conditions in south Texas and the Texas High Plains to determine sesame tolerance to herbicides applied postemergence-directed to the lower 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 pyriithiobac at 0.07 kg ai/ha resulted in the greatest sesame stunting (28 to 90%) when applied up to 15 cm main stem height. 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 pyriithiobac applied 5 and 15 cm stem height consistently reduced sesame yield when compared with the non-treated 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 non-treated control.

Keywords: Injury, *Sesamum indicum*, yield.

1. Introduction.

1 Sesame (*Sesamum indicum* L.) is one of the oldest crops known to humans. There are
 2 archeological remnants of sesame dating to 5500 BC in the Harappa Valley in the Indian
 3 subcontinent [1]. Assyrian tablets from 4300 BC describe how before the gods battled to
 4 restore order to the universe, they ate bread and drank sesame wine [2]. Sesame was a
 5 major oilseed in the ancient world because of its ease of extraction, great stability, and
 6 drought resistance. In India today, almost as in olden days, a farmer can take his crop to
 7 an expeller which consist of grinding mortar and pestle stones driven by a bullock. They
 8 can place the oil in a vessel, take it back to their home and have cooking oil for a year
 9 without the oil going rancid (S.S. Rajan, personal communication).

10 Sesame was introduced to the US from Africa and was called beni/benne/benni [3].
 11 Betts [3] quotes letters from Thomas Jefferson that document his trials with sesame
 12 between 1808 and 1824. Jefferson stated that sesame “...*is among the most valuable*
 13 *acquisitions our country has ever made. ... I do not believe before that there existed so*
 14 *perfect a substitute for olive oil.*” He talks about the rule of thumb that still exists today -
 15 that sesame will grow well where cotton grows well.

16 Sesame was produced in Texas on a limited scale during the 1950’s and early 1960’s,
 17 first in northeast Texas and later shifting to the High Plains, where consistent yield
 18 increases resulted from irrigation and more favorable climate conditions [4]. The sesame
 19 was cut with a binder, hand-shocked, and manually fed into a combine when dry. Due to
 20 a change in guest worker laws in the mid 1960’s, the hand labor from Mexico became
 21 unavailable and the sesame crop disappeared [5]. Sesame returned to Texas in 1987 with
 22 varieties that did not require binding and shocking. Sesame could be swathed into a
 23 windrow, allowed to dry, and removed from the field with a pick-up attachment on a

1 combine. Since that time new varieties have been developed that can be left standing in
2 the field to dry down and then combined directly. Also, sesame has spread to other states
3 including Oklahoma and Kansas [5].

4 One of the more difficult problems in planting sesame is that the seeds are small and
5 need to be placed precisely in the soil [6]. Seeds cannot be too deep that the cotyledons
6 never reach the surface, and yet they cannot be too shallow that topsoil moisture around
7 the seed is lost. Once the cotyledons emerge they are small compared to other crops and
8 seedlings do not grow fast. This slow development is compounded by the nature of the
9 drought resistance of sesame in that it will partition a large portion of photosynthetic
10 resources to create more root mass to penetrate the soil as quickly as possible. In the first
11 30 days after planting, plants reach about 28 cm in height and will double to 60 cm in the
12 next 11 days, triple to 90 cm in the following 8 days, and quadruple to 120 cm in the
13 following 9 days. At this maturity point the sesame will begin to canopy. Depending on
14 row spacing and phenotype, mechanization of sesame requires good weed control for 50
15 to 60 days after planting [6].

16 The presence of weeds can negatively influence sesame yields. Kropff and Spitters [7]
17 reported that the major factor influencing sesame yield loss in a competitive situation
18 between the crop and weed is the ratio between the relative leaf area of the weed and the
19 crop at the time of canopy closure. The effects of weeds on sesame establishment and
20 growth have been well-documented. Balyan [8], Gurnah [9], Singh et al. [10], and
21 Upadhyay [11] reported weed-induced reductions of sesame yield up to 100% and a need
22 for a critical weed-free period up to 50 day after planting. Under weedy conditions,

1 Eagleton et al. [12] recorded a weed biomass six times that of sesame 48 days after planting
2 and Bennett [13] reported a weed biomass 1.3 fold that of sesame 42 days after planting.

3 Mechanically harvested non-dehiscent varieties present another problem that is not
4 present in manual harvest which comprises 99% of all sesame harvested in the world [5].
5 If there are weeds in manual harvest, only the sesame plants are cut and placed in shocks.
6 However, in mechanical harvest, sesame and weeds are cut together. In Venezuela, a
7 binder cuts the sesame and weeds together while they are still green. This is not a big
8 problem because the weeds dry down at the same time as the sesame. However, dense
9 population of weeds may delay combining because the leaves of the weeds may envelop
10 plants and trap moisture or thicker stem weeds such as pigweed (*Amaranthus* spp.) will
11 take longer to dry down. In direct combining, weeds can be a big problem because they
12 are normally green and add moisture to the combine bin. There are many instances
13 where the sesame seeds are dry and weed seeds are not. Thick stems can add moisture,
14 but the major problem is with weed seeds. Since it is logistically difficult to scalp off the
15 weed seeds at harvest, moisture from the weed seed will transfer to sesame seeds.
16 Sesame is 50% oil and needs to be harvested at 6% moisture or below in order to be
17 handled in lots of 25 tons in trucks and in 2,000 ton silos. High moisture under these
18 conditions may lead to heating and ruining of the seed. A second concern is that
19 mechanically harvested sesame moves through a series of augers from the combine
20 screen, to the combine bin, to the truck, to the silo, to the cleaning equipment, and within
21 the cleaning process. Moist sesame seeds may be damaged by this movement forming
22 free fatty acids which leads to spoiling [5].

The size of sesame seed is similar to the size of many weed seeds [14,15]. In the production of oil from sesame, weed seeds within the sesame samples are not as critical unless they are toxic. However, a large percentage of sesame is used in edible markets that require 99.99% purity. There are seeds such as johnsongrass [*Sorghum halepense* (L.) Pers] that would seemingly be easy to remove because of their size and shape, and yet the johnsongrass seed go through the round holes end first and are difficult to separate in gravity tables because they have a similar specific gravity to sesame [14]. In decortication of the seed for bakery products and tahini, the seed from lanceleaf sage (*Salvia reflexa* Hornem.) causes a unique problem. When the lanceleaf sage seed is hydrated, the seed surface forms a gelatinous substance that will cause adjacent sesame seeds to stick; therefore, forming balls. Kochia [*Kochia scoparia* (L.) Schrad] and grass weeds produce seeds that are difficult to remove from sesame. Any weed seed that is in a sesame sample in a large percentage is difficult to clean out, no matter the size and specific gravity, without having to slow down the processing or reprocessing. In Japan, purity needs to be 100% since processors have to pay claims to customers that find anything other than pure sesame seeds [5].

Sesame is mainly grown in countries where abundant and inexpensive labor is available [16]. However, the trend in agriculture around the world is towards mechanization. Sesame has disappeared in Japan and parts of Mexico as the sesame growing areas mechanized. In Korea, sesame hectares have continually decreased since 1987 as the labor migrates to the cities (C. Kang, personal communication). With weak seedling vigor, limited competitive ability, and a lack of cheap labor, the use of preemergence (PRE) or

1 postemergence (POST) herbicides are essential for commercial mechanized sesame
2 production.

3 All POST herbicides which control broadleaf weeds in sesame have caused some
4 sesame injury or yield reduction [17,18,19]. For broadleaf weed problems in sesame, the
5 use of soil-applied herbicides still appear to be the only option [17,20]. However, since
6 sesame hectares are increasing in portions of the southern United States and since no POST
7 broadleaf herbicides are presently cleared for use on sesame or have shown sesame
8 tolerance [17,19], the objective of these studies was to identify herbicides that could be
9 used postemergence-directed (PDIR) to control broadleaf weeds and not injure sesame.

10 **2.0 Materials and Methods**

11 *2.1 Research sites.* Field studies were conducted during the 2006 and 2007 growing
12 seasons near Uvalde in south Texas and near Lorenzo in the Texas High Plains to
13 evaluate sesame response to herbicides applied PDIR. Fields were selected that had low
14 weed populations since weed efficacy of each herbicide is known; however, nothing is
15 known about sesame response to herbicides applied PDIR. Soil type at Uvalde was a
16 Winterhaven silty clay loam (fine-silty, carbonatic, hyperthermic Fluventic Ustochrepts)
17 with less than 1.0% organic matter and pH 7.8. Soil type at Lorenzo was a Amarillo
18 sandy clay loam (fine-loamy, mixed, thermic Aridic Paleustalf) with 0.8% organic matter
19 and pH 7.8.

20 *2.2 Plot design.* A randomized complete-block experimental design was used and
21 treatments were replicated three times. Treatments consisted of a factorial arrangement
22 of fifteen herbicides applied at two different PDIR spray heights. A non-treated control
23 was included for comparison. Plot size was five rows (76 cm apart) by 9.1 m. in south

1 Texas and four rows (101 cm apart) by 7.3 m. in the Texas High Plains. Only the two
 2 middle rows were sprayed and the other rows were untreated and served as buffers.

3 *2.3 Herbicides and spraying information.* Herbicides included carfentrazone-ethyl
 4 (Aim®, FMC, 1735 Market Street, Philadelphia, PA 19103) at 0.02 kg ai/ha, glufosinate-
 5 ammonium (Ignite 280®, Bayer Crop Science, 2 T. W. Alexander Drive, Research
 6 Triangle Park, NC 27709) at 0.58 kg ai/ha, glyphosate (Roundup Weathermax®, a
 7 potassium salt of glyphosate plus surfactant, Monsanto Company, 800 North Lindbergh
 8 Boulevard, St. Louis, MO 63167 or Durango®, a potassium salt of glyphosate plus
 9 surfactant, Dow AgroSciences, LLC, Indianapolis, IN 46268) at 0.84 kg ae/ha, lactofen
 10 (Cobra®, Valent USA Corporation, P. O. Box 8025, Walnut Creek, CA 94596-8025) at
 11 0.22 kg ai/ha, linuron (Linex®, DuPont Crop Protection, Laurel Run Building, Chestnut
 12 Run Plaza, Wilmington, DE 19898) at 1.12 kg ai/ha, paraquat (Gramoxone Max®,
 13 Syngenta Crop Protection, Inc., P. O. Box 18300, Greensboro, NC 27419) at 0.28 kg
 14 ai/ha, propazine (Milo-Pro®, Albaugh, Inc., Ankeny, IA 50021) at 1.12 kg ai/ha,
 15 pyraflufen-ethyl (ET®, Nichino America, Inc., 4550 New Linden Hill Road, Wilmington,
 16 DE 19808) at 0.002 kg ai/ha, pyriithiobac (Staple®, E. I. DuPont de Nemours,
 17 Wilmington, DE 19898) at 0.07 kg ai/ha, trifloxysulfuron-sodium (Envoke®, Syngenta
 18 Crop Protection, Inc., P. O. Box 18300, Greensboro, NC 27419) at 0.008 kg ai/ha,
 19 trifloxysulfuron-sodium at 0.008 kg/ha plus prometryn (Suprend®, Syngenta Crop
 20 Protection, Inc., P. O. Box 18300, Greensboro, NC 27419) at 1.12 kg ai/ha, linuron at
 21 0.56 kg ai/ha plus diuron at 0.56 kg ai/ha (LaybyPro, Tessengerlo Kerley, Inc., 2255 N.
 22 44th St., Suite 300, Phoenix, AZ 85008), glyphosate plus prometryn (Caparol®,
 23 Syngenta Crop Protection, Inc., P. O. Box 18300, Greensboro, NC 27419) at 0.84 kg/ha

1 plus 1.12 kg ai/ha, and glyphosate plus diuron (Direx®, DuPont Crop Protection, Laurel
2 Run Building, Chestnut Run Plaza, Wilmington, DE 19898) at 0.84 kg ai/ha plus 1.12 kg
3 ai/ha. Spray heights were up to 5 cm and 15 cm up the sesame main stem. All PDIR
4 applications, with the exception of glufosinate-ammonium, included a crop oil
5 concentrate (Agri-Dex®, a blend of 83% paraffin-based petroleum oil and 17%
6 surfactant, Helena Chemical Company, Suite 500, 6075 Poplar Avenue, Memphis, TN
7 38137) at 1.0% v/v or a nonionic surfactant (X-77®, 90% nonionic surfactant, Loveland
8 Industries, P.O. Box 1289, Greeley, CO 80632) at 0.25% v/v.

9 At Uvalde, herbicides were applied in water using a CO₂ pressurized backpack
10 sprayer calibrated to deliver 190 L/ha at 180 kPa. Spray tips were two Teejet 8004E
11 (Teejet Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60188) nozzles per row
12 adjusted as to spray a PDIR spray band on sesame stem and 15 to 25 cm band on the soil
13 to simulate spray of a PDIR spray application. At the Lorenzo location, a tractor-mounted
14 compressed-air Red Ball sprayer with Teejet 8002E spray tips (Teejet Spraying Systems
15 Co., P.O. Box 7900, Wheaton, IL 60188) calibrated to deliver 93 L/ha at 207 kPa was
16 used. Herbicides were applied when sesame was 38 to 76 cm in height.

17 *2.4 Sesame varieties, planting, and harvesting.* Sesame variety in 2006 was S29 while in
18 2007 S32 was planted at both locations. Planting dates at the Uvalde location was late May
19 in 2006 and early June in 2007 while at the Lorenzo location, sesame was planted mid-June
20 in both years. Each sesame cultivar was seeded approximately 1.0 cm deep at 3.4 kg/ha at
21 both locations. At maturity, sesame in the plots was hand-harvested, dried, and threshed
22 with a harvester.

1 *2.5 Data analysis.* The treatment design was a factorial arrangement using a randomized
 2 complete block design with herbicides and PDIR spray height as factors. An analysis of
 3 variance was performed using the ANOVA procedure for SAS (SAS Institute. 1998. SAS
 4 user's guide. SAS Inst., Cary, NC.) to evaluate the significance of herbicides and spray
 5 height on sesame response and yield. The Fishers Protected LSD at the 0.05 level of
 6 probability was used for separation of mean differences.

7 **3.0 Results**

8 Since there was a treatment by location or year interaction for sesame stunting and yield,
 9 data by location and year is presented separately. Data was not collected in Uvalde in
 10 2006 due to uneven distribution of irrigation water which resulted in inconsistent plant
 11 growth and sesame development.

12 *3.1 High Plains (Lorenzo).*

13 *3.1.1 Sesame stunt.* In 2006, glyphosate and pyriithiobac applied to the 15 cm stem height
 14 resulted in 28 and 42% sesame stunting, respectively. When applied up to the 5 cm
 15 sesame stem height, stunting was no greater than 15% with either herbicide (Table 1).
 16 Glyphosate is cleared in the US for use in sesame as a burndown, with wiper applicators,
 17 and using hooded sprayers in row middles [21]. For burndown use, glyphosate should be
 18 applied before, during, or just after planting but before the sesame seedlings emerge.
 19 Glyphosate applied POST to sesame will result in plant death or yellowing and a lack of
 20 capsule formation for one to three weeks [21]. When capsule formation does somewhat
 21 recover, the capsules will be smaller and contain less seeds and have a reduced seed
 22 weight. Glyphosate plus diuron stunted sesame 10% when applied up to 15 cm; however,
 23 no other herbicides stunted sesame more than 4% when applied to sesame at either height

(Table 1). In Venezuela, diuron at 0.6 and 1.2 kg/ha applied preemergence reduced sesame yield, but yield would have been much lower without weed control [22]. In the U.S., in one year, diuron at 0.8 and 1.7 kg/ha applied preemergence resulted in adequate weed control without apparent crop injury whereas in another year, there was stand reduction and chlorosis [23]. In later work by Grichar et al. [18], they reported that diuron at 1.12 kg/ha reduced sesame stands and caused 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.

In 2007, sesame stunting was more severe with glyphosate, glufosinate, pyriproxyfen, and trifloxysulfuron applied up to 15 cm in sesame height compared with applications made up to 5 cm in height (Table 1). Only glufosinate-ammonium, pyraflufen-ethyl, linuron + diuron, and linuron applied up to 5 cm caused less than 10% sesame stunting. Pyriproxyfen caused the greatest sesame stunting whether applied up to 5 or 15 cm sesame.

3.1.2 Sesame yield. In 2006, glyphosate or paraquat applied up to the 15 cm height, resulted in a yield reduction when compared with applications made to lower stem height (Table 1). Trifloxysulfuron plus prometryn reduced yield when applied up to 5 cm height but not up to the 15 cm height while lactofen, pyriproxyfen, and glyphosate plus either prometryn or diuron reduced sesame yield regardless of application height. Although sesame stunting appeared greater in 2007, not as many herbicides caused a reduction in yield from the non-treated control as 2006. Pyriproxyfen and trifloxysulfuron applied to sesame at either height and glyphosate applied up to 15 cm sesame reduced yield when compared to the non-treated control. Glyphosate applied up to 15 cm sesame reduced yield; however, the application made up to 5 cm on sesame stem did not.

1 3.2 *South Texas*

2 3.2.1 *Sesame stunt*. In 2007, glyphosate, glufosinate-ammonium, paraquat, lactofen,
 3 pyriithiobac, trifloxysulfuron, and glyphosate plus diuron caused greater sesame stunting
 4 when applied to the sesame stem up to the 15 cm height than the 5 cm height (Table 1).
 5 Pyraflufen-ethyl, trifloxysulfuron + prometryn, linuron + diuron, linuron alone,
 6 propazine, and glyphosate + prometryn applied either up to 5 or 15 cm resulted in sesame
 7 stunting that was not different from the untreated check.

8 Preemergence applications of prometryn at 0.5 kg/ha caused no sesame injury, but
 9 prometryn applied preplant incorporated almost completely wiped out the sesame (D.
 10 Howell, unpublished data). Prometryn at 0.6 and 1.1 kg/ha resulted in lower sesame
 11 populations, lowered plant height, and also reduced yields compared with metolachlor at
 12 1.1 or 2.2 kg/ha [24]. However, in a later study in south Texas and the Texas High
 13 Plains, prometryn injured sesame but yields were not reduced from that of *S*-metolachlor
 14 [18].

15 3.2.2 *Sesame yield*. Glyphosate, glufosinate-ammonium, carfentrazone-ethyl, paraquat,
 16 and trifloxysulfuron + prometryn applied up to 5 cm did not reduce sesame yield when
 17 compared with the untreated check although these herbicides applied up to the 15 cm
 18 height did reduce yield (Table 1). Pyriithiobac, trifloxysulfuron, and glyphosate + diuron
 19 reduced sesame yield when applied at either height. The premix of linuron + diuron,
 20 linuron alone, pyraflufen-ethyl, or propazine resulted in little or no sesame stunting and
 21 did not affect sesame yield when applied at either height up the sesame stem.

22 4.0 Discussion

1 As height of herbicide spray up the main stem of sesame increased, the chances of
 2 sesame stunting and a reduction in yield also increased. The combination of linuron +
 3 diuron produced the least sesame injury whether applied 5 or 15 cm up the sesame main
 4 stem. Work by Grichar et al., [18] reported that diuron at 1.12 kg/ha reduced sesame
 5 stands and caused sesame injury in one year in the Texas High Plains area; however, in
 6 south Texas no adverse effects with diuron were seen in the two years of research.
 7 Limited information is available on linuron use in sesame. Santelmann et al. [25] found
 8 slight phytotoxicity and a reduction in sesame yield with linuron at 2.24 kg/ha

9 Although glyphosate stunted sesame when applied up to the 5 cm height it did not
 10 result in a reduction in yield. Under close examination, the sesame population was high
 11 and the glyphosate appeared to kill the less vigorous (minor) plants under the canopy and
 12 thus thinned the population. In a high population situation, the minor plants are actually
 13 a weed because they use moisture and fertility without giving commensurate yield.
 14 Glyphosate is cleared in the U.S. for use in sesame as a burndown, with wiper
 15 applicators, and /or hooded sprayers in row middles [21]. For burndown use, glyphosate
 16 should be applied before, during, or just after planting but before the sesame seedlings
 17 emerge. When applied after sesame has emerged, any amount of glyphosate on a sesame
 18 plant will usually result in injury. Glyphosate applied POST to sesame will result in plant
 19 death or yellowing of the sesame and a lack of capsule formation for one to three weeks
 20 [21]. When capsule formation does somewhat recover, the capsules will be smaller and
 21 will have less seeds and seed weight.

22 Glufosinate is also a nonselective POST herbicide that may have potential for use in
 23 sesame in many of the same ways that glyphosate can be used. It controls a wide range

1 of weed species and is especially effective on some species such as morningglory
2 (*Ipomoea* spp.) that can be difficult to control with glyphosate [26,27,28].

3 **Conflict of Interest**

4 The authors declare there is no conflict of interest regarding the publication of this paper.

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Table 1. Sesame stunt and yield as influenced by height of postemergence-directed herbicides sprays.^{a,b}

				Lorenzo				Uvalde ^c	
				Stunt		Yield			
Treatment	Rate	Height ^d	2006	2007	2006	2007	Stunt	Yield	
		cm	— % —	—	— kg/ha —		%	kg/ha	
Non-treated	-	-	0	0	612	810	0	1223	
Glyphosate	0.84	5	12	18	526	830	20	984	
		15	28	50	268	399	90	426	
Glufosinate-ammonium	0.58	5	2	8	556	1047	7	1173	
		15	4	27	538	754	45	786	
Carfentrazone-ethyl	0.02	5	0	22	608	1080	24	996	
		15	3	19	540	777	37	654	
Pyraflufen-ethyl	0.002	5	2	9	588	1068	0	1446	
		15	3	15	582	1015	2	-	
Paraquat	0.28	5	0	13	630	1014	5	1062	
		15	0	15	516	963	30	705	
Lactofen	0.22	5	0	20	494	882	13	1191	
		15	2	19	452	812	38	1194	
Pyriithiobac	0.07	5	15	52	412	298	65	345	

1			15	42	67	392	117	85	129
2	Trifloxysulfuron	0.008	5	0	27	588	477	20	687
3			15	5	47	528	468	57	273
4	Trifloxysulfuron	0.008	5	0	22	520	690	10	1194
5	+ prometryn	+ 1.12	15	2	33	574	942	17	933
6	Linuron	0.56	5	2	7	552	567	8	1386
7	+ diuron	0.56	15	0	11	540	1005	0	1215
8	Linuron	1.12	5	-	8	-	1046	0	1272
9			15	-	18	-	1014	7	1068
10	Propazine	1.12	5	-	19	-	750	0	1317
11			15	-	18	-	822	0	1272
12	Glyphosate	0.84	5	0	13	462	964	2	1440
13	+ prometryn	1.12	15	3	17	398	843	1	1425
14	Glyphosate	0.84	5	2	17	382	760	12	917
15	+ diuron	1.12	15	10	28	280	611	35	773
16	LSD (0.05)			5	15	90	210	17	264

17 ^a All POST herbicides, except glufosinate, included a non-ionic surfactant at 0.25 % v/v

18 or a crop oil concentrate at 1.0 % v/v.

19 ^b Stunt ratings taken approximately 30 d after herbicide application.

20 ^c Uvalde data for 2007 only.

21 ^d Height that herbicides sprays reached up the main stem of sesame.

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