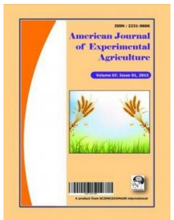

American Journal of Experimental Agriculture
8(2): 75-86, 2015, Article no.AJEA.2015.149
ISSN: 2231-0606

SCIENCEDOMAIN *international*
www.sciencedomain.org

SCIENCEDOMAIN

Influence of Spray Tip and Spray Volume on the Efficacy of Imazapic and Imazethapyr on Selected Weed Species

W. James Grichar[1*] and Peter A. Dotray[2]

[1]Department of Soil and Crop Science, Texas A&M AgriLife Research, l0345 State Highway 44, Corpus Christi, TX 78406, United States of America.
[2]Department of Soil and Crop Science, Texas A&M AgriLife Research, 1102 FM 1294, Lubbock, TX 79403, United States of America.

Authors' contributions

This work was carried out in collaboration between both authors. Author WJG designed the study, wrote the protocol and wrote the first draft of the manuscript. Author PAD reviewed the experimental design and all drafts of the manuscript. Authors WJG and PAD performed the statistical analysis. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJEA/2015/17209
Editor(s):
(1) Anonymous.
Reviewers:
(1) Anonymous, Poland.
(2) Anonymous, Brazil.
(3) Anonymous, Brazil.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=1076&id=2&aid=8694

Original Research Article

Received 3rd March 2015
Accepted 21st March 2015
Published 4th April 2015

ABSTRACT

Aims: To evaluate control of weeds commonly found in peanut fields when using imazapic or imazethapyr applied post emergence with different spray tips and at different spray volumes.
Study Design: Experimental design was a randomized complete block with three replications and a seven spray volume (47, 71, 94, 117, 140, 164, and 187 L ha^{-1}) or a six spray tip [110015 flat fan (FF), 110015 Turbo TeeJet (TT), 110015 drift guard (DG), 110015 air induction (AI), 110015 turbo drop (TD), and 110015 extended range (XR)] by two herbicides (imazapic or imazethapyr) factorial arrangement of treatments.
Place and Duration of Study: Field studies were conducted during the 2006 and 2007 growing seasons in the south Texas and in the Texas High Plains peanut growing regions.
Methodology: Spray volumes and spray nozzle tips were compared for control of the annual

**Corresponding author: E-mail: James.Grichar@agnet.tamu.edu; w-grichar@tamu.edu;*

grasses *Urochloa texana* (Buckl.) R. Webster, and *Digitaria ciliaris* (Retz.) Koel. and the broadleaf weeds *Amaranthus palmeri* L., *Cucumis melo* L. var. DudaimNaud., *Ipomoea lacunose* L., *Sida spinosa* L., *Solanum elaeagnifolium* Cav., *Tribulus terrestris* L., and *Proboscidea louisianica* (Mill.) Thellung.
Results: *U. texana* control was not affected by spray volume but *D. ciliaris* control was affected. With *D. ciliaris*, as spray volume increased, herbicide efficacy decreased. Spray volume did affect *A. palmeri* efficacy. In both years at the High Plains location, a spray volume of 47 L ha^{-1} provided better control than 187 L ha^{-1}. *C. melo*, *I. lacunose*, *T. terrestris*, and *S. spinosa* control with both herbicides decreased as spray volume increased. Annual grass control was not affected by spray tip application while *A. palmeri* efficacy was reduced at one location with 110015XR nozzle tips. *C. melo*, *I. lacunose*, and *S. spinosa* control was not affected by spray tip; however, 110015TT and 110015FF provided the best control of *S. elaeagnifolium* and *P. louisianica*, respectively.
Conclusion: Depending on weed species the amount of carrier volume and spray tip can affect weed efficacy under similar conditions as found in this study.

Keywords: Carrier volume; coverage; annual grasses; broadleaf weeds.

1. INTRODUCTION

The use of low spray volumes is preferred by growers and pesticide applicators because of time savings in filling sprayer tanks and traveling to and from fields [1]; however, growers have expressed concern that reduced efficacy may result with the use of lower spray volumes. Herbicide concentration increases as spray volume decreases, thereby enhancing efficacy of systemic herbicides in low spray volumes [2,3]. Also, Sandberg et al. [4] reported that spray runoff from plants may occur at volumes above 187 L ha^{-1}, leading to reduced herbicide efficacy.

Herbicide concentration in the spray droplet is important for determining absorption and toxicity of certain herbicides. Glyphosate absorption, translocation, and phytotoxicity to *Abutilon theophrasti* Medik. Increased as concentration of glyphosate or surfactant (or both) in the droplet decreased [5,6]. Buhler and Burnside [2] found that glyphosate efficacy increased as spray volume decreased from 190 to 24 L ha^{-1}, and they attributed the increased efficacy to smaller spray droplets and higher glyphosate or surfactant concentration in the commercial glyphosate formulation with low spray volumes (or both). Similarly, glyphosate phytotoxicity to *Cynodon dactylon* (L.) Pers. increased as spray volume decreased from 370 to 47 L ha^{-1}, which was attributed to greater glyphosate and surfactant concentrations at low spray volumes [3]. Likewise, Ambach and Ashford [7] found that glyphosate phytotoxicity to *Hordeum vulgare* L. was greater with a single concentrated droplet than with a number of dilute droplets.

Spray technology has evolved toward faster moving spray equipment and lower carrier volumes in an effort to reduce fuel cost from transporting large quantities of water and the need to cover more hectarage per tank-load [8]. In an effort to reduce the drift potential of these faster moving sprayers, many growers employ the use of drift-reducing nozzles. Air induction (AI) nozzles produce larger droplets, which are less susceptible to drift than extended range (XR) nozzles at the same pressure [8,9,10]. Although these larger droplets reduce drift, spray coverage may be reduced. Knocke [11] reported that smaller droplets from the XR nozzles were more effective than larger droplets when applying post emergence (POST) herbicides at a constant carrier volume. Recent research reported that control of *Abutilon theophrasti* Medik. And *Chenopodium album* L. with fomesafen, a PPO herbicide, was improved as carrier volume was increased for both XR and AI nozzles [12]. However, Ramsdale and Messersmith [13] noted that paraquat provided effective grass control regardless of nozzle type or carrier volume. Other studies have shown that nozzle type, carrier volume, and spray pressure provide varying levels of control that are herbicide and weed species specific [2,12,14].

Imazethapyr and imazapic are imidazolinone herbicides commonly used in peanut production in the southwestern US [15]. Imazethapyr applied POST provides broad spectrum and most consistent control when applied within 10 days of weed emergence [16-19]. Imazethapyr and imazapic are the only POST herbicides to effectively control both *Cyperus esculentus* L. and *Cyperus rotundus* L. [20,21]. Control was most effective when imazethapyr was applied to the soil or to *C. esculentus* that was no more than 13 cm tall [19,21,22].

Imazapic is similar to imazethapyr and controls all the weeds controlled by imazethapyr [22-24]. In addition, imazapic provides control or suppression of *Desmodium tortuosum* (S.W.) D.C. and *Senna obtusifolia* (L.) Irwin & Barneby, which are not adequately controlled by imazethapyr [25]. Imazethapyr provides consistent control of many broadleaf and *Cyperus* spp. if applied within 10 days after emergence; however, imazapic has a longer effectiveness period when applied POST [21,22,24,26]. Imazapic also is effective for control of rhizome and seedling *Sorghum halepense* (L.) Pers., *U. texana*, *Digitaria sanguinalis* (L.) Scop., *Digitaria ciliaris* (Retz.) Koel., and *Urochloa platyphylla* (Griseb.) Nash [22].

Work has been done on the use of various spray volumes and spray tip with other herbicides, mainly glyphosate; however, no reports could be found that discussed spray volume and spray tip research when using imazapic or imazethapyr. Therefore, the objective of this research was to determine the influence of spray tips and spray volumes on weed efficacy when using imazapic and imazethapyr under field conditions found in the Texas peanut growing areas.

2. MATERIALS AND METHODS

2.1 Research Sites

Studies were conducted during the 2006 and 2007 growing seasons at Texas A&M AgriLife Research site near Yoakum in south Texas and at the Texas A&M AgriLife Research and Extension Center at Lubbock in the Texas High Plains. Soil type at the Yoakum site was a Tremona loamy fine sand (thermic Aquic Arenic Palenstalf), 64% sand, 14% silt, and 22% clay with less than 1% organic matter and pH 7.2. The soils at Halfway were a Acuff clay loam (fine, loamy, mixed, superaactive, thermic Aridic Paleustolls), 42% sand, 38% silt, and 20% clay with less than 1% organic matter and pH 7.7.

2.2 Herbicides, Spray Tips, and Spray Volume

Imazapic and imazethapyr at a dose of 0.07 kg ai ha^{-1} for each herbicide was evaluated in four separate small-plot studies during the 2006 and 2007 growing seasons in the south Texas and in the High Plains of Texas peanut growing regions for weed control when using different spray tips and spray volumes. Spray tips (Spraying Systems Company, P.O. Box 7900, North Avenue, Wheaton, IL 60188) evaluated included 110015 flat fan (FF), 110015 Turbo TeeJet (TT), 110015 drift guard (DG), 110015 air induction (AI), 110015 turbo drop (TD), and 110015 extended range (XR). With this study, spray volume at the High Plains location was 93.5 L ha^{-1} while at the south Texas location, the spray volume was 187 L ha^{-1} with a spray pressure of 180 kPa at both locations. A crop oil concentrate (Agridex, a blend of 83% paraffin-based petroleum oil and 17% surfactant, Helena Chemical Company, Suite 500, 6075 Poplar Ave., Memphis, TN 38137) was included with all treatments at the rate of 1% v/v.

The spray volume study was conducted with imazapic or imazethapyr at 0.07 kg ai ha^{-1} using Agridex at 1% (v/v). Spray volumes evaluated included 47, 71, 94, 117, 140, 164, and 187 L ha^{-1} applied with 11001DG spray tips using a CO_2 pressurized backpack sprayer in south Texas while in the High Plains herbicides were applied with a tractor-mounted compressed air small plot sprayer using 110015TT tips with a spray pressure of 180 kPa at both locations. Spray volume was regulated by varying ground speed such that a change in efficacy with spray volume was not attributed to droplet size.

2.3 Environmental Conditions

At the High Plains location all sprays were applied under dry to moderate soil moisture conditions with no signs of plant stress. Relative humidities varied from 30 to 65% with one exception. With the spray tip study in 2006, when herbicide applications were made in the early afternoon, the relative humidity was 12%. Dew was not present at any time. Air temperature varied from 25 to 36ºC while soil temperatures varied from 25 to 28ºC with one exception. With the spray volume study in 2006 applied near mid-day, the soil temperature was 30ºC.

At the south Texas location all herbicide applications were made soon after rainfall or irrigation; therefore, growing conditions were excellent. Relative humidities varied from 84 to 90% and since all applications were made early morning a dew was always present. Air and soil temperatures varied from 26 to 29ºC.

2.4 Weed Populations and Size

Weed ratings recorded 28 days after treatment are reported based on a scale of 0 (no control in the untreated check) to 100 (complete control). Weed populations for *A. palmeri* in 2006 and 2007 at the High Plains location were 24 to 30 plants m^2 while *S. elaeagnifolium* and *P. louisianica* populations in 2006 and *T. terrestris* and *S. spinosa* populations in 2007 ranged from 2 to 5 plants m^2. *T. terrestris* was present in dense enough populations to evaluate in the spray volume but not the spray tip study. At the south Texas location, *U. texana* and *A. palmeri* were present at 6 to 8 plants m^2 in 2006. In 2007 *D. ciliaris* populations were 4 to 6 plants m^2 while *C. melo* and *I. lacunosa* populations were 8 to 10 plants m^2.

At the time of herbicide application, *A. palmeri*, *P. louisianica*, *S. elaeagnifolium*, *S. spinosa*, *S. elaeagnifolium*, and *T. terrestris* were less than 16 cm tall at the High Plains location in both years while at the south Texas location, *A. palmeri*, *D. ciliaris*, and *U. texana* were less than 20 cm tall and C. *melo* and *I. lacunose* were less than 15 cm in length.

2.5 Plot Size and Experimental Design

Peanut (Tamrun OL01) at 100 kg ha^{-1} was planted both years at the south Texas location but the area was fallow at the High Plains location. Each plot in south Texas was two rows 7.6 m long spaced 96 cm apart or 4 m wide by 15 m long at the High Plains location. In 2006 at the south Texas location, supplemental irrigation was applied as needed (four irrigation events at 25.4 mm per event) while in 2007 no irrigation was required due to above average rainfall received in June and July (81 cm above average in June, 38 mm above average in July). No supplemental irrigation was used at the High Plains location.

The experimental design was a randomized complete block with three replications and either a seven spray volume (47, 71, 94, 117, 140, 164, and 187 L ha^{-1}) or a six spray tips (110015FF, 110015TT, 110015DG, 110015AI, 110015TD, and 110015XR) by two herbicides (imazapic or imazethapyr) factorial arrangement of treatments. Data for percentage of weed control were transformed to the arcsine square root prior to analysis; however, nontransformed means are presented because arscine transformation did not affect interpretation of the data. Treatment means were separated using Fisher's Protected LSD at $P < 0.10$. The nontreated control was included for visual comparison of weed control and was not included in any data analysis.

3. RESULTS AND DISCUSSION

3.1 Weed Control with Different Spray Volumes

For annual grass control there was a spray volume by year interaction while for *A. palmeri* control, there was a spray volume and herbicide by year interaction; therefore, these variables are presented separately. For *C. melo*, *S. elaeagnifolium*, *P. louisianica*, *T. terrestris*, *I. lacunose*, and *S. spinosa*, which were present at one location, there was only a herbicide by spray volume interaction.

3.1.1 Annual grass control

In 2006, imazethapyr and imazapic applications with all spray volumes controlled *U. texana* at least 94% and only applications with the spray volume of 47 L ha^{-1} provided less control than the 94 L ha^{-1} spray volume (Table 1). In 2007, herbicide applications with spray volumes of 94 L ha^{-1} or less controlled *D. ciliaris* at least 86% while applications with spray volumes of 117 L ha^{-1} or greater controlled 75% or less (Table 1). In another study, imazethapyr, nicosulfuron, and sethoxydim with methylated vegetable oil applied on an area basis were equally or more effective when applied in 37 to 75 L ha^{-1} than in 94 to 187 L ha^{-1} [27]. Ramsdale and Nalewaja [28] reported that high herbicide concentrations increased imazethapyr absorption when sufficient adjuvant was present. Absorption also increased as herbicide concentration increased for glyphosate, sethoxydim, fluazifop-butyl, and haloxyfop-methyl [2,5,6].

When imazapic was compared with imazethapyr for annual grass control, no difference in *U. texana* or *D. ciliaris* control was noted with either herbicide in 2006 or 2007 (Table 2). In 2006, imazapic and imazethapyr controlled *U. texana* at least 96% while in 2007 both herbicides provided no better than 74% control of *D. ciliaris*. In a previous study evaluating POST herbicides, imazapic controlled *U. texana* at least 80% when used without a soil-applied herbicide [15]. The imidazolinone herbicides usually provide partial control of annual grasses [22]. Imazethapyr, when soil-applied, will provide virtually no annual grass control; however, imazapic applied POST will control *U. texana* 60 to 70% and will provide greater than 90% control of *D. ciliaris* and *U. platyphylla* when applied to grasses less than 3 cm tall [15,22]. The use of a dinitroaniline herbicide with either imazapic or imazethapyr improved *U. texana* control over the dinitroaniline herbicide alone [29].

3.1.2 *Amaranthus palmeri* control

In 2006, at the High Plains location, imazethapyr and imazapic applications at any spray volume provided no better than 65% control of *A. palmeri* which was no taller than 16 cm (Table 1). This agrees with the research of Grichar [30] and Berger et al. [31] who found that *A. palmeri* was easier to control with lactofen when small than when allowed to grow taller. Grichar [30] reported lactofen provided at least 92% control of *A. palmeri* when applied to 5 to 10 cm tall plants but only 48% control when applied to 15 to 20 cm tall plants. Berger et al. [31] reported similar results with lactofen controlling small *A. palmeri* at least 94% but less control when applied to taller plants. Applications at spray volumes of 47 to 94 Lha^{-1} controlled *A. palmeri* 57 to 65% while applications at spray volumes of 117 to 187 Lha^{-1} controlled no better than 50%. At the south Texas location, herbicide applications at all spray volumes controlled *A. palmeri* at least 98%. In 2007, at the High Plains location, herbicides applied at the spray volume of 187 Lha^{-1} controlled less *A. palmeri* than applications at a spray volume of 47, 71, 117, and 140 Lha^{-1}.

The improved control of A. *palmeri* at the south Texas location may be due to higher air temperatures (26 to 29ºC) and relative humidities (84 to 90%) during the June to August growing period when herbicides were applied. Typically, air temperatures in south Texas during this time period in the daytime range from 32 to 38ºC while nighttime temperatures seldom fall below 27ºC. Also, relative humidity usually ranges from 75 to 90%. Daytime temperatures in the High Plains may be similar but temperatures typically

Table 1. Annual grass and *A. palmeri* control 4 weeks after treatment when using different spray volumes averaged over imazapic or imazethapyr treatments [a,b]

Spray volume			*A. palmeri*		
	Annual grass[c]		2006		2007
$L\ ha^{-1}$	2006	2007	High Plains	South Texas	High Plains
			%		
47	94	86	65	99	72
71	99	91	57	99	74
94	100	97	64	100	71
117	96	75	44	98	74
140	9	52	50	99	72
164	99	58	47	99	70
187	98	58	47	100	65
LSD (0.10)	5	14	13	NS[d]	7

[a]No herbicide by spray volume interaction; therefore, data presented separately by spray volume; [b]11001DG spray tips were used at the south Texas location while 110015TT spray tips were used at the High Plains location; [c]Urochloa texana present in 2006 with Digitaria ciliaris present in 2007; [d] Not significant (P < 0.10)

Table 2. Annual grass and *A. palmeri* control 4 weeks after treatment when using imazapic or imazethapyr averaged over spray volumes [a,b]

			A. palmeri		
Herbicide[c]	Annual grass[d]		2006		2007
	2006	2007	High Plains	South Texas	High Plains
			%		
Imazapic	100	74	59	100	75
Imazethapyr	96	73	48	99	73
LSD (0.10)	NS[e]	NS	7	NS	NS

[a] No herbicide by spray volume interaction; therefore, data presented separately by herbicide; [b] Spray tip 11001DG used at the south Texas location while spray tip 110015TT used at the High Plains location. [c]Dose for each herbicide was 0.07 kg ha-1; [d]Urochloa texana present in 2006 with Digitaria ciliaris present in 2007; [e] Not significant (P < 0.10)

fall to less than 27ºC during the night time while the relative humidity rarely gets above 40%. Air temperature and relative humidity directly influence herbicide absorption and translocation in plants [32]. In general, the uptake and translocation of most POST herbicides increases with rising temperature and humidity [32]. Relative humidity enhances the absorption and translocation of herbicides in plants by prolonging the drying of the spray droplets on the leaf surface, increasing cuticle hydration, and to a smaller extent by favoring stomatal opening [33].

In 2006, at the High Plains location, there was a difference in *A*. *palmeri* control between imazapic and imazethapyr; however, both levels of control were unacceptable (less than 60%) and at the south Texas location both herbicides provided at least 99% control (Table 2). In 2007 at the High Plains location, both herbicides provided 73 to 75% control (Table 2). In earlier work by Grichar [34], imazapic at 0.04 to 0.07 kg ha^{-1} controlled A. *palmeri* at least 95% when applied early post emergence (EPOST) while imazethapyr provided at least 90% control in 2 of the 3 years.

3.1.3 *Proboscidea louisianica* control

No herbicide or applications with any spray volume controlled *P*. *louisianica* more than 63% (Table 3). Imazapic applied at 94 or 187 L ha^{-1} (> 62 to 63%) and imazethapyr applied at either 47 or 94 L ha^{-1} (57%) provided the best control for each of the herbicides. Thompson et al. [35] reported that imazapic at 0.04 to 0.07 kg ha^{-1} controlled *P*. *louisianica* 88 to 94% when applied EPOST or late post emergence (LPOST).

3.1.4 *Solanum elaeagnifolium* control

No herbicide or applications with any spray volume controlled *S*. *elaeagnifolium* greater than 65% (Table 3). Imazapic (65%) and imazethapyr (57%) applied at a spray volume of 94 L ha^{-1} provided the best control for each herbicide. No data could be found on using imazapic or imazethapyr to control *S*. *elaeagnifolium*.

3.1.5 *Tribulus terrestris* control

With all spray volumes, imazapic provided better *T*. *terrestris* control than imazethapyr (Table 3). No data could be found for control of this weed when using imazapic or imazethapyr. In work with other herbicides, Geier et al. [36] reported that *S*-metolachlor alone provided variable *T*. *terrestris* control which ranged from 70 to 99%, while the addition of atrazine to *S*-metolachlor provided more consistent control of 95 to 100%.

3.1.6 *Cucumis melo* control

Both imazapic and imazethapyr controlled *C*. *melo* at least 97% when applied at 94 L ha^{-1} or less (Table 3). However, when the spray volume was increased to 117 L ha^{-1} or greater, *C. melo* control with both imazapic and imazethapyr was no greater than 80% with the exception of imazethapyr applied at 187 L ha^{-1} and imazapic applied at 117 L ha^{-1} which controlled *C*. *melo* 90 and 100%, respectively. *C*. *melo* is becoming more of a problem in south Texas peanut production fields and has become a problem in several crops along the Texas Gulf coast [15,29]. *C*. *melo* can be a problem at peanut harvest as the melon can become broken apart when run through the combine and increase drying time because of the high moisture content of the melon itself. In *Zea mays* L., Thompson et al. [35] reported that imazapic at 0.07 and 0.14 kg ha^{-1} applied pre emergence (PRE), EPOST, or LPOST controlled *C*. *melo* greater than 90%.

3.1.7 *Ipomoea lacunose* control

Both imazapic and imazethapyr controlled *I*. *lacunose* at least 98% when applied at a spray volume of 94 L ha^{-1} or less (Table 3). Imazapic applied at a spray volume of 117 L ha^{-1} controlled *I*. *lacunose* 99%, but imazethapyr at this spray volume provided only 77% control. When imazapic was applied at a spray volume of 140 to 187 L ha^{-1}, *I*. *lacunose* control was 78 to 87% while imazethapyr at these same spray volumes provided 83 to 94% control. Imazapic and imazethapyr provided excellent *Ipomoea* spp. control [37,38]. Grichar [37] reported that imazapic at 0.04 and 0.07 kg ha^{-1} provided at least 80% *I. lacunose* control with EPOST and POST applications. In other studies, imazapic at 9 g ha^{-1} has provided *I*. *lacunose* control which varied from 33 to 85% [39]. Research by Wilcut et al. [16] found that imazapic was more effective at controlling *I*. *lacunose* than imazethapyr applied either preplant incorporated (PPI), PRE, or early POST.

3.1.8 *Sida spinosa* control

S. *spinosa* was controlled no less than 99% when applied at a spray volume of 47 to 94 L ha^{-1} (Table 3). At a spray volume of 117 L ha^{-1}, imazapic controlled *S*. *spinosa* 100% while imazethapyr provided only 67% control. At spray volumes at 140 L ha^{-1} or higher, only imazethapyr applied at a spray volume of 164 L ha^{-1} or imazapic at a spray volume of 187 L ha^{-1} provided at least 85% control. *S. spinosa* is mainly a problem in the southeastern peanut growing region [16]. Bentazon and imazethapyr POST will control *S. spinosa* when applied to small sized plants, but if larger than two-leaf, imazethapyr POST was found to be ineffective [16]. Wilcut [40] noted that imazapic controlled five-leaf S. *spinosa* at least 95%.

Several studies have reported that spray volume did not influence control of other weeds such as *Cyperus esculentus* L. [41]. In contrast, low spray volumes increased annual grass control with glyphosate [42]. Other studies have reported that herbicide efficacy in low spray volumes is often dependent on the specific adjuvant and adjuvant amount. Conversely, herbicide efficacy generally increased as spray volume increased when adjuvants were applied as a percentage of spray volume [28,43].

3.2 Weed Control with Different Spray Tips

For annual grass and *A. palmeri* control, there was either no spray tip or herbicide by year interaction; therefore, these variables are presented separately. For *C. melo*, *I. lacunose*, P. *louisianica*, *S. elaeagnifolium*, and *S. spinosa* there was no spray tip by herbicide interaction; therefore, these variables are presented separately.

3.2.1 Annual grass control

No difference in *U. texana* (2006) or *D. ciliaris* (2007) control was noted between the different spray tips (Table 4). *U. texana* control varied from 87 to 100% while *D. ciliaris* control varied from 66 to 78%.

In both years, imazapic provided better annual grass control than imazethapyr (Table 5). In 2006, imazapic controlled 100% *U. texana* while imazethapyr provided 89% control and in 2007 imazapic provided 85% *D. ciliaris* control while imazethapyr only controlled 59% (Table 5).

3.2.2 *A. palmeri* control

At the High Plains location in 2006, poor (27 to 69%) *A. palmeri* control was noted with all spray tips (Table 4). *A. palmeri* was controlled 61 to 69% when FF, TT, and DG spray tips were used, while control with AI and XR tips was less than 50%. At the south Texas location, *A. palmeri* was controlled at least 98% with all spray tips.

Table 3. Broadleaf weed control with imazapic and imazethapyr when applied at different spray volumes [a]

Spray volume	Herbicide[b]	Broadleaf weeds					
		PROLO	SOLEL	TRBTE	CUMME	IPOLA	SIDSP
L ha^{-1}		%					
47	Imazapic	50	50	97	99	98	100
	Imazethapyr	57	37	87	99	98	100
71	Imazapic	58	45	98	99	98	99
	Imazethapyr	52	45	87	97	99	100
94	Imazapic	63	65	100	99	99	100
	Imazethapyr	57	57	88	100	98	100
117	Imazapic	50	40	100	100	99	100
	Imazethapyr	28	35	93	77	77	67
140	Imazapic	57	52	95	70	80	63
	Imazethapyr	45	45	85	80	90	57
164	Imazapic	57	40	95	75	87	57
	Imazethapyr	43	40	72	70	83	96
187	Imazapic	62	53	75	77	78	85
	Imazethapyr	53	55	67	90	94	77
LSD (0.10)		12	12	9	10	13	24

[a] Bayer code for weeds: PROLO, Proboscidealouisianica; SOLEL, Solanumelaeagnifolium; TRBTE, Tribulusterrestris; CUMME, Cucumismelo; IPOLA, Ipomoea lacunose; SIDSP, Sidaspinosa.
[b]Imazapic and imazethapyr dose was 0.07 kg ha^{-1}

Table 4. Annual grass and *A. palmeri* control 4 weeks after treatment averaged over imazapic or imazethapyr treatments when using different spray tips [a,b]

			A. palmeri		
	Annual grass[d]		2006		2007
Spray tips[c]	2006	2007	High Plains	South Texas	High Plains
			%		
110015FF	98	74	61	99	73
110015TT	91	66	69	99	72
110015DG	87	76	65	100	73
110015AI	100	78	47	98	79
110015TD	97	68	-[e]	99	-
110015XR	-	-	27	-	73
LSD (0.10)	NS[f]	NS	16	NS	NS

[a] No herbicide by spray tip interaction; therefore, data presented separately by spray tip; [b] Spray volume in south Texas was 187 L ha^{-1} while 93.5 L ha^{-1} was used at the High Plains location; [c] Abbreviations: FF, flat fan; TT, turbo teejet; DG, drift guard; AI, air induction; TD, turbo drop; XR, extended range; [d]Urochloa texana present in 2006 while Digitaria ciliaris present in 2007; [e] Missing data; [f]Not significant (P < 0.10)

Table 5. Annual grass and *A. palmeri* control 4 weeks after treatment when using imazapic or imazethapyr averaged over spray tips [a,b]

			A. palmeri		
	Annual grass[d]		2006		2007
Herbicide[c]	2006	2007	High Plains	South Texas	High Plains
			%		
Imazapic	100	85	60	100	75
Imazethapyr	89	59	48	99	72
LSD (0.10)	2	20	NS[e]	NS	2

[a] No herbicide by spray tip interaction; therefore, data are presented separately by herbicide; [b]Spray volume in south Texas was 187 L ha^{-1} while 93.5 L; ha^{-1}was used at the High Plains location; [c]Imazapic and imazethapyr dose was 0.07 kg ha^{-1}; [d]Urochloa texana present in 2006 with Digitaria ciliaris present in 2007; [e] Not significant (P< 0.10)

In 2007 at the High Plains location, *A. palmeri* was controlled 72 to 79% with all spray tips (Table 4). This is consistent with the results of Berger et al. [31] who reported that nozzle type had not effect on *A. palmeri* control with lactofen. No difference in *A. palmeri* control was noted in 2006 between imazapic and imazethapyr at either location; however, at the southern High Plains location in 2007 imazapic provided better control than imazethapyr (Table 5).

3.2.3 *C. melo* control

C. melo was controlled at least 95% with all spray tips regardless of herbicide (Table 6). Imazapic controlled *C. melo* better than imazethapyr (Table 7). Grichar [30], in a two year study in peanut, reported that imazapic controlled *C. melo* 86 to 89% while imazethapyr controlled this weed 61 to 76%.

3.2.4 *I. lacunose* control

No difference in *I. lacunose* control was noted with any spray tip (Table 6) and imazapic provided better control than imazethapyr (Table 7). Imazapic and imazethapyr have provided excellent *Ipomoea* spp. control (at least 80%) [37,38,44]. Grichar [37] reported that imazapic at 0.04 and 0.07 kg ha^{-1} provided at least 80% *I. lacunosa* control with early POST and POST applications while Newsom and Shaw [39] reported imazapic at 9 g ha^{-1} provided *I. lacunose* control which varied from 33 to 85%. Wilcut et al. [16] reported that imazapic was more effective than imazethapyr applied either PPI, PRE, or early POST.

3.2.5 *P. louisianica* control

The FF spray tips provided better control (65%) of *P. louisianica* than the AI or XR spray tips (Table 6). No difference in control was noted between imazapic and imazethapyr (Table 7). In earlier work, Grichar et al. [45] reported that ethalfluralin alone did not control *P. louisianica*; however, ethalfluralin followed by imazapic applied POST provided 100% control. In commercial fields, imazapic has provided excellent (> 80%) *P. louisianica* control [46].

Table 6. Weed control 4 weeks after treatment when using different spray tips averaged over imazapic or imazethapyr treatments [a,b]

Spray tips[c]	Weeds[d]				
	CUMME	IPOLA	PROLO	SOLEL	SIDSP
			%		
110015FF	96	95	65	46	73
110015TT	96	87	51	62	77
110015DG	95	81	48	57	70
110015AI	97	96	45	42	68
110015TD	96	95	-[e]	-	70
110015XR	-	-	40	45	-
LSD (0.10)	NS[f]	NS	20	12	NS

[a] No herbicide by spray tip interaction; therefore, data presented separately by spray tip; [b] Spray volume in south Texas was 187 L ha^{-1} while 93.5 Lha^{-1} was used at the High Plains location; [c]Abbreviations: FF, flat fan; TT, turbo teejet; DG, drift guard; AI, air induction; TD, turbo drop; XR, extended range; [d]Bayer code for weeds: IPOLA, Ipomoea lacunose; CUMME, Cucumis melo; SIDSP, Sida spinosa; SOLEL, Solanum elaeagnifolium; PROLO, Proboscidea louisianica; [e] Missing data; [f]Not significant (P < 0.10)

Table 7. Broadleaf weed control 4 weeks after treatment when using imazapic or imazethapyr averaged over spray tips [a,b]

Herbicide[c]	Weeds[d]				
	CUMME	IPOLA	PROLO	SOLEL	SIDSP
			%		
Imazapic	99	94	49	52	100
Imazethapyr	93	87	50	49	43
LSD (0.10)	4	1	NS[e]	NS	17

[a] No herbicide by spray tip interaction; therefore, data presented separately by herbicide; [b] 11001DG spray tip was used at the south Texas location while 110015TT spray tip was used at the High Plains location; [c]Imazapic and imazethapyr dose was 0.07 kg ha^{-1}; [d] Bayer code for weeds: IPOLA, Ipomoea lacunose; CUMME, Cucumis melo; SIDSP, Sida spinosa; SOLEL, Solanum elaeagnifolium; PROLO, Proboscidea louisianica; [e] Not significant (P<0.10)

3.2.6 *S. elaeagnifolium* control

S. elaeagnifolium control was 62% or less with all spray tips (Table 6). The TT spray tip provided better control than all other tips. No difference in *S. elaeagnifolium* control was noted between imazapic and imazethapyr (Table 7).

3.2.7 *S. spinosa* control

No difference in *S. spinosa* control was noted with any spray tip with control ranging from 68 to 77% (Table 6). Imazapic provided perfect control (100%) while imazethapyr controlled only 43% (Table 7). Previously, Ducar et al. [47] reported 99 to 100% control of *S. spinosa* in corn with imazapic at 0.035 and 0.07 kgha^{-1}, respectively.

4. CONCLUSION

In south Texas under extremely dry conditions (2006), supplemented by irrigation, spray volume had no effect on *U. texana* control. However, in an above average rainfall year (2007), herbicide efficacy on *D. ciliaris* decreased as spray volume was increased above 94 Lha^{-1}. Control of *C. melo* and *I. lacunose* also decreased as spray volume increased. No response to spray volume was noted at the High Plains location with the exception of *S. spinosa* and *T. terrestris* and this may be due to lower humidities which are generally found in this area. Relative humidity can directly influence herbicide absorption and translocation in plants by prolonging the drying of the spray droplets on the leaf surface [32], increasing cuticle hydration [33], and to a smaller extent by favoring stomatal opening [33]. This may explain why there was little or no difference in herbicide efficacy under the low humidity conditions of the High Plains (15 to 30%); however, under the high humidity conditions observed in south Texas (at least 85%), differences in weed control were noted.

For the majority of the weeds, control was not influenced by the use of different spray tips. However, *A. palmeri*, *P. louisianica*, and *S. elaegnifolium* control was influenced by spray tip and these were all at the High Plains location.

Typically, the FF, TT, and DG tips performed better than the AI or XR tips (data from TD tips were not available). Standard low-input nozzles typically used for low volume applications have a small orifice that is subject to plugging and produce fine spray droplets that are susceptible to spray drift. These nozzle characteristics have deterred the use of low spray volumes, even though low volumes are known to be effective with certain herbicides [48].

ACKNOWLEDGEMENTS

The authors would like to thank Lyndell Gilbert, Kevin Brewer, Dwayne Drozd, and Bill Klesel for technical assistance in this research. Appreciation is also extended to the National Peanut Board for financial support.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Ramsdale BK, Messersmith CG. Adjuvant and herbicide concentration in spray droplets influence phytotoxicity. Weed Technol. 2002;16:631-637.
2. Buhler DD, Burnside OC. Effect of application factors on post emergence phytotoxicity of fluazifop-butyl, haloxyfop-methyl, and sethoxydim. Weed Sci. 1984; 32:574-583.
3. Jordan TN. Effects of diluent volumes and surfactant on the phytotoxicity of glyphosate to bermudagrass (*Cynodon dactylon*). Weed Sci. 1981;29:79-83.
4. Sandberg CL, Meggitt WF, Penner D. Effect of diluent volume and calcium on glyphosate efficacy. Weed Sci. 1978;26: 476-479.
5. Cranmer JR, Linscott DL. Droplet makeup and the effect on phytotoxicity of glyphosate in velvetleaf (*Abutilon theophrasti*). Weed Sci. 1990;38:406-410.
6. Cranmer JR, Linscott DL. Effects of droplet composition on glyphosate absorption and translocation in velvetleaf (*Abutilon theophrasti*). Weed Sci. 1991;39:251-254.
7. Ambach RM, Ashford R. Effects of variations in drop makeup on the phytotoxicity of glyphosate. Weed Sci. 1982;30:221-224.
8. Etheridge RE, Womac AR, Mueller. Characterization of the spray droplet spectra and patterns of four venture-type drift reduction nozzles. Weed Technol. 1999;13:765-770.
9. Miller PCH, Lane AG. Relationship between spray characterisics and drift risk into field boundaries of different structure. Aspects Appl. Biol. 1999;45:45-51
10. Ellis MCB, Swam T, Miller PCH, Waddelos S, Bradley A, Tuck CR. Design factors affecting spray characteristics and drift performance of air induction nozzles. Biosyt. Eng. 2002;82:289-296.
11. Knocke M. Effect of droplet size and carrier volume on performance of foliage-applied herbicides. Crop Prot. 1994;13:163-178.
12. Sikkema PH, Brown L, Shropshire C, Spieser H, Soltani N. Flat fan and air induction nozzles affect soybean herbicide efficacy. Weed Biol. Mang. 2008;8:31-38.
13. Ramsdale BK, Messersmith CG. Drift-reducing nozzle effects on herbicide performance. Weed Technol. 2001;15:453-460.
14. Brown L, Soltani N, Shropshire C, Spieser H, Sikkema PH. Efficacy of four corn (*Zea mays* L.) herbicides when applied with flat fan and air induction nozzles. Weed Biol. Mang. 2007;7:55-61.
15. Grichar WJ, Lemon RG, Dotray PA, Besler BA. Control of problem weeds and net returns with herbicide programs in peanut (*Arachis hypogaea*). *In* Inderjit, editor. Weed Biology and Management. Kluwer Academic Publ. Dordrecht, The Netherlands. 2003;485-515.
16. Wilcut JW, Richburg III JS, Wiley G, Walls Jr FR, Jones SR, Iverson MJ. Imidazolinone herbicide systems for peanut (*Arachis hypogaea* L.). Peanut Sci. 1994;21:23-28.
17. Grey TL, Wehtje GR, Walker RH, Paudel KP. Comparison of imazethapyr and paraquat-based weed control systems in peanut. Weed Technol. 1995;9:813-818.
18. Wilcut JW, Walls Jr. FR, Norton DN. Imazethapyr for broadleaf weed control in peanuts (*Arachis hypogaea*). Peanut Sci. 1991;18:26-30.
19. Wilcut JW, Richburg III JS, Eastin EF, Wiley GR, Walls Jr FR, Newell S. Imazethapyr and paraquat systems for weed management in peanut (*Arachis hypogaea*). Weed Sci. 1994;42:601-607.
20. Grichar WJ, Nester PR, Colburn AE. Nutsedge (*Cyperus* spp.) control in peanuts (*Arachis hypogaea*) with imazethapyr. Weed Technol. 1992;6:396-400.

21. Richburg III JS, Wilcut JW, Wehtje GR. Toxicity of foliar and/or soil applied AC 263,222 to purple (*Cyperus rotundus*) and yellow nutsedge (*C. esculentus*). Weed Sci. 1993;42:398-402.
22. Wilcut, JW, York AC, Grichar WJ, Wehtje GR. The biology and management of weeds in peanut (*Arachis hypogaea*). *In* Pattee HE, Stalker HT, editors. Advances in Peanut Science. Amer. Peanut Res. Educ. Soc. Inc., Stillwater, OK. 1995;207-244.
23. Wilcut JW, York AC, Wehtje GR. The control and interaction of weeds in peanut (*Arachis hypogaea*). Rev. Weed Sci. 1994; 6:177-205.
24. Wilcut JW, Richburg, III JS, Wiley G, Walls Jr FR, Jones SR, Iverson MJ. Imidazolinone herbicide systems for peanut (*Arachis hypogaea*). Peanut Sci. 1994;21:23-28.
25. Grey TL, Bridges DC, Eastin EF, Prostko EP, Vencil WK, Johnson III WC, Brecke, BJ, MacDonald GE, Tredaway JA, Everest JW, Wehtje GR, Wilcut JW. Residual weed control for peanut (*Arachis hypogaea*) with imazapic, diclosulam, flumioxazin, and sulfentrazone in Alabama, Georgia, and Florida: A multi-state and year summary. Proc. Amer. Peanut Res. And Educ. Soc. 2001;33:19.
26. Richburg III JS, Wilcut JW, Colvin DL, Wiley GR. Weed management in southeastern peanut (*Arachis hypogaea*) with AC 263,222. Weed Technol. 1996; 10:145-152.
27. Kirkwood RC. Use and mode of action of adjuvants for herbicides: A review of some current work. Pestic. Sci. 1993;38:93-102.
28. Ramsdale BK, Nalewaja JD. Adjuvants influence herbicide efficacy at low spray volumes. In de Ruiter H, editor. Adjuvants for Agrochemicals, Sixth International Symposium, Amsterdam, The Netherlands. 2001;224-229.
29. Grichar WJ, Dotray PA, Sestak DC. Diclosulam for weed control in Texas peanut. Peanut Sci. 1999;26:23-28.
30. Grichar WJ. Horse purslane (*Trianthema portulacastrum*), smellmelon (*Cucumis melo*), and Palmer amaranth (*Amaranthus palmeri*) control in peanut with post emergence herbicides. Weed Technol. 2007;21:688-691.
31. Berger ST, Dobrow MH, Ferrell JA, Webster TM. Influence of carrier volume and nozzle selection on Palmer amaranth control. Peanut Sci. 2014;41:120-123.
32. Wanamarta G, Penner D. Foliar absorption of herbicides. In Foy CL, editor. Reviews of Weed Science. WSSA. Imperial Printing Co., Champaign, Ill. 1989;4:215-231.
33. Hull HM. Leaf structure as related to absorption of pesticides and other compounds. In Gunther FA, Gunther JD, editors. Residue Rev. Springer-Verlag, New York. 1970;31:1-155.
34. Grichar WJ. Control of palmer amaranth (*Amaranthus palmeri*) in peanut (*Arachis hypogaea*) with post emergence herbicides. Weed Technol. 1997;11:739-743.
35. Thompson AM, Rosales-Robles E, Chandler JM, Nester PR, Tingle CH. Crop tolerance and weed management systems in imidazolinone-tolerant corn (*Zea mays* L.). Weed Technol. 2005;19:1037-1044.
36. Geier PW, Stahlman PW, Frihauf JC. KIH-485 and *S*-metolachlor efficacy comparisons in conventional and no-tillage corn. Weed Technol. 2006;20:622-626.
37. Grichar WJ. Influence of herbicides and timing of application on broadleaf weed control in peanut (*Arachis hypogaea*). Weed Technol. 1997;11:708-713.
38. Richburg III JS, Wilcut JW, Wiley GL. AC 263,222 and imazethapyr rates and mixtures for weed management in peanut (*Arachis hypogaea*). Weed Technol. 1995; 9:801-806.
39. Newsom LJ, Shaw DR. Influence of cultivation timing on weed control in soybean (*Glycine max*) with AC 263,222. Weed Technol. 1994;8:760-765.
40. Wilcut JW. Economic yield response to peanut (*Arachis hypogaea*) to post emergence herbicides. Weed Technol. 1991;5:416-420.
41. Nelson KA, Renner KA, Penner D. Yellow nutsedge (*Cyperus esculentus*) control and tuber yield with glyphosate and glufosinate. Weed Technol. 2002;16:360-365.
42. Buhler DD, Burnside OC. Effects of application variables on glyphosate phytotoxicity. Weed Technol. 1987;1:14-14.
43. Nalewaja JD, Ahrens WH. Adjuvants and spray volume affect herbicide efficacy. In McMullan PM, editor. Adjuvants for Agrochemicals, Fifth Internal. Symposium of Adjuvants for Agrochemicals, Memphis, TN. 1998;434-441.

44. Webster TM, Wilcut JW, Coble HD. Influence of AC 263,222 rate and application method on weed management in peanut (*Arachis hypogaea*). Weed Technol. 1997;11:520-526.
45. Grichar WJ, Dotray PA, Besler BA, Langston VB. Weed control programs in peanut (*Arachis hypogaea*) with diclosulam and ethalfluralin combinations. Texas J. Agriculture and Natl. Resour. 2006;19:62-71.
46. Grichar WJ, Dotray PA. Weed control and peanut tolerance with ethalfluralin-based herbicide systems. Inter. J. Agron; 2012. DOI:10.1155/2012/597343. Accessed 19 February 2015. Available:http://www.hindawi.com/journals/ija/
47. Ducar JT, Wilcut JW, Richburg III JS. Weed management in imidazolinone-resistant corn with imazapic. Weed Technol. 2004;18:1018-1022.
48. Ramsdale BK, Messersmith CG, Nalewaja JD. Spray volume, formulation, ammonium sulfate, and nozzle effects on glyphosate efficacy. Weed Technol. 2003;17:589-598.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=1076&id=2&aid=8694