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Author(s) :Krishna N. Reddy, Charles T. Bryson, Ian C. Burke
Source: Weed Technology, 21(4):982-986. 2007.
Published By: Weed Science Society of America
DOI: http://dx.doi.org/10.1614/WT-07-053.1
URL: http://www.bioone.org/doi/full/10.1614/WT-07-053.1

Ragweed Parthenium (*Parthenium hysterophorus*) Control with Preemergence and Postemergence Herbicides

Krishna N. Reddy, Charles T. Bryson, and Ian C. Burke*

Field and greenhouse experiments were conducted during 2005 and 2006 at Stoneville, MS, to determine control of ragweed parthenium with several preemergence (PRE) and postemergence (POST) herbicides registered for use in corn, cotton, peanut, rice, and soybean. Norflurazon, pendimethalin, clomazone, diuron, fluometuron, pyrithiobac, dimethenamid, flumetsulam, imazaquin, *s*-metolachlor, metribuzin, chlorimuron, atrazine, simazine, flumioxazin, and quinclorac were applied PRE. Ragweed parthenium control was highest with norflurazon (100%) and clomazone (100%) followed by fluometuron (96%), metribuzin (90%), diuron (87%), flumioxazin (84%), chlorimuron (77%), and quinclorac (67%) at 6 wk after treatment (WAT) under greenhouse conditions. Control of ragweed parthenium was less than 58% with all other herbicides. Ragweed parthenium appears to be highly sensitive to pigment and photosynthetic inhibitors compared to herbicides with other modes of action. Glyphosate, glufosinate, paraquat, bentazon, acifluorfen, chlorimuron, halosulfuron, MSMA, bromoxynil, atrazine, 2,4-D, flumioxazin, trifloxysulfuron, and clomazone were applied POST to field-grown rosette and bolted plants. Glyphosate, glufosinate, chlorimuron, and trifloxysulfuron applied at rosette stage provided greater than 93% control of ragweed parthenium at 3 WAT. Halosulfuron, MSMA, bromoxynil, 2,4-D, and flumioxazin controlled 58 to 90% rosette ragweed parthenium at 3 WAT. Ragweed parthenium control with all other POST herbicides was less than 38%. At bolted stage, glyphosate, glufosinate, and trifloxysulfuron controlled 86 to 95% ragweed parthenium and control was 61 to 70% with chlorimuron, halosulfuron, and 2,4-D 3 WAT. Overall, efficacy of POST herbicides was better on rosette plants than on bolted plants. Amino acid synthesis and glutamine synthase inhibitors were more active than herbicides with other modes of action. These results indicate that norflurazon, clomazone, fluometuron, flumioxazin, halosulfuron, chlorimuron, and trifloxysulfuron could provide effective control of ragweed parthenium.

Nomenclature: Acifluorfen; atrazine; bentazon; bromoxynil; chlorimuron; clomazone; 2,4-D; dimethenamid; diuron; flumetsulam; flumioxazin; fluometuron; glufosinate; glyphosate; halosulfuron; imazaquin; *s*-metolachlor; metribuzin; MSMA; paraquat; quinclorac; simazine; trifloxysulfuron; ragweed parthenium, *Parthenium hysterophorus* L. PTNHY; corn, *Zea mays* L.; cotton, *Gossypium hirsutum* L.; peanut, *Arachis hypogaea* L.; rice, *Oryza sativa* L.; soybean, *Glycine max* (L.) Merr.

Key words: Biology, distribution, invasive, management.

Ragweed parthenium is an annual herb in the *Asteraceae* family. It is a troublesome and noxious weed native to tropical and subtropical America. It is now widely distributed in many countries of North and South America, Africa, Asia, and Australia (Anonymous 2004; Batish et al. 2004; Evans 1997; Kohli et al. 2006; Navie et al. 1998; Pandey et al. 2003; Rosales-Robles et al. 2005; Singh et al. 2004; Tamado and Milberg 2000). Since its introduction in the mid-1950s, ragweed parthenium has achieved status as a major weed in India and Australia within a relatively short period (Evans 1997; Kohli et al. 2006). In the United States, ragweed parthenium is distributed from Florida to Texas and northward to Massachusetts and Michigan and disjunct in Hawaii. It is more common in the southern United States than in the northern United States and is widely spread in many counties in Florida, Louisiana, and Texas (USDA-NRCS 2007). In Mississippi, ragweed parthenium is found in row crops, around barns, near farm equipment and storage areas, in poorly maintained lawns, and along roadsides and railroads (Reddy and Bryson 2005). Increased occurrences have been observed in Georgia (E. P. Prostko, personal communication) and North Carolina (J. C. Neal, personal communication). In the southern United States, the frequency of detection of ragweed parthenium is on the rise in recent years. The increased detection may be due both to increased awareness of invasive nonnative plants as well as seed dispersal from southern to northern United States by humans, vehicles, farm machinery, farm produce, seed, animals, and feral animals, especially during summer months.

Ragweed parthenium can germinate and flower throughout the year in tropical environments. In Mississippi, ragweed parthenium seeds normally start germinating in late March to early April and plants produce flowers by May. Seeds continue to germinate throughout the growing season. Plants produce large quantities of seed, and then die with the onset of frost in the fall (authors' personal observation). Seedlings initially develop as a rosette. Mature plants are erect with several branches and can grow to 2 m tall. Ragweed parthenium is often confused with other weeds such as common ragweed (*Ambrosia artemisiifolia* L.) and poison-hemlock (*Conium maculatum* L.). Ragweed parthenium reproduces only by seed. It is a prolific seed producer with a seed bank range of 3,000 to 45,000 seed/m^2 (Navie et al. 2004). Seeds buried in soil

DOI: 10.1614/WT-07-053.1

* Research Plant Physiologist, Botanist, and Postdoctoral Research Associate, USDA-ARS, Southern Weed Science Research Unit, P.O. Box 350, Stoneville, MS 38776. Current address of the third author: Assistant Professor, Department of Crop and Soil Sciences, Johnson Hall 201, Washington State University, Pullman, WA 99164. Corresponding author's E-mail: krishna.reddy@ars.usda.gov

remain viable for more than 2 yr, but seeds on the soil surface may not be viable longer than 6 mo (Navie et al. 1998; Tamado et al. 2002).

Ragweed parthenium has infested almost all field crops, pastures, wastelands, yards, fencerows, and rights-of-ways (Anonymous 2004; Evans 1997; Kohli et al. 2006; Navie et al. 1998; Pandey et al. 2003; Singh et al. 2004; Tamado and Milberg 2000). There is a rapid increase in populations following initial establishment and appears to be mainly due to its prolific seed production and lack of effective control. It can adversely impact agriculture, the environment, human and animal health, and biodiversity through aggressive plant growth, abundant pollen and seed production, and release of allelochemicals (Anonymous 2004; Evans 1997; Kohli et al. 2006; Pandey et al. 2003). When left uncontrolled, ragweed parthenium can reduce crop yields by 40 to 97% (Singh et al. 2004, Tamado and Milberg 2004). Although ragweed parthenium is widely distributed in a number of tropical and subtropical countries, in the United States it is not considered a major weed problem despite close proximity to its geographic center of origin, Central America (Reddy and Bryson 2005).

Research on control of ragweed parthenium with herbicides in the United States is mostly lacking. Many herbicides used to control weeds in crop and noncrop lands provide various levels of ragweed parthenium control. For example, atrazine, fomesafen, imazaquin, linuron, metribuzin, and oxyfluorfen applied PRE and acifluorfen, bentazon, cyanazine, dinoseb, fomesafen, glyphosate, imazaquin, and metribuzin applied POST to plants $<$ 7.5 cm tall controlled ragweed parthenium $>$ 80% in Florida (Tyson and Bryan 1987). In a Texas study, flumioxazin applied 0 to 30 d prior to planting grain sorghum [*Sorghum bicolor* (L.) Moench ssp. *bicolor*] controlled ragweed parthenium from 92 to 100% (Grichar 2006). Chlorimuron and metsulfuron controlled ragweed parthenium less than 40% when applied to bolted plants (Singh et al. 2004). Glyphosate controlled 95 to 100% of bolted ragweed parthenium up to 18 WAT (Singh et al. 2004). However, the glyphosate rates (2.7 to 5.4 kg ae/ha) used in their study were above the registered use rates suggested for glyphosate-resistant crops such as corn, cotton, and soybean.

A plethora of herbicides with PRE and POST activity are available, but only a few herbicides have been evaluated for ragweed parthenium control. Information on efficacy of several commonly used herbicides such as trifloxysulfuron, clomazone, dimethenamid, flumetsulam, flumioxazin, quinclorac, norflurazon, and diuron is lacking. Because ragweed parthenium is not a ubiquitous weed in the United States, it has not been included in routine herbicide evaluation trials as with other more troublesome weeds. Thus, information on the efficacy of herbicides on ragweed parthenium is sparse or limited to a few herbicides. Therefore, the objective of this study was to determine the efficacy of several PRE and POST herbicides used in corn, cotton, peanut, rice, and soybean on ragweed parthenium. This is not an exhaustive herbicide screening study on ragweed parthenium, but rather a more focused study with a few selected herbicides. Herbicides selected are generally active on broadleaf weeds and represent several modes of action or a large herbicide family with the same mode of action.

Table 1. Ragweed parthenium control with herbicides applied PRE under field conditions at Stoneville, MS, in 2006.

Herbicide	Rate	Control[a] 4 WAT[b]	Control[a] 6 WAT
	g ai/ha	%	%
Norflurazon	2,240	99	96
Pendimethalin	1,120	32	21
Clomazone	1,120	100	98
Diuron	1,790	65	60
Fluometuron	2,240	100	99
Pyrithiobac	80	92	70
Dimethenamid	1,100	60	43
Flumetsulam	60	97	81
Imazaquin	140	97	87
S-Metolachlor	2,130	41	36
Metribuzin	700	99	98
Chlorimuron	10	100	100
Atrazine	1,790	86	53
Simazine	3,360	96	78
Flumioxazin	110	34	20
Quinclorac	560	100	98
LSD (0.05)	—	40	34

[a] Data from the no-herbicide treatment were deleted before statistical analysis. Ragweed parthenium density in the no-herbicide treatment averaged 69 and 119 plants per 9.1 m^2, respectively, at 4 and 6 WAT.

[b] Abbreviation: WAT, weeks after treatment.

Materials and Methods

Preemergence Control. A field study was conducted in 2006 to determine PRE activity of herbicides on ragweed parthenium at the Southern Insect Management Research Unit farm, Stoneville, MS. Herbicides used in the study were norflurazon, 2,240 g ai/ha; pendimethalin, 1,120 g ai/ha; clomazone, 1,120 g ai/ha; diuron, 1,790 g ai/ha; fluometuron, 2,240 g ai/ha; pyrithiobac, 80 g ai/ha; dimethenamid, 1,100 g ai/ha; flumetsulam, 60 g ai/ha; imazaquin, 140 g ai/ha; *s*-metolachlor, 2,130 g ai/ha; metribuzin, 700 g ai/ha; chlorimuron, 10 g ai/ha; atrazine, 1,790 g ai/ha; simazine, 3,360 g ai/ha; flumioxazin, 110 g ai/ha; quinclorac, 560 g ai/ha; and a no-herbicide control (Table 1). The herbicide rates used in the study correspond to the highest registered rates. Treatment solutions were prepared using commercial formulations of herbicides. Treatments were applied with a CO_2–pressurized backpack sprayer that delivered 140 L/ha of spray solution at 193 kPa on April 5, 2006. The experiment was conducted on a noncrop land at the edge of the farm with natural infestation of ragweed parthenium. The herbicide treatments were arranged in a randomized complete block design with three replications. The plot size was 2 m wide and 9.1 m long. Ragweed parthenium seedlings were counted in each plot from a 9.1-m^2 (middle 1 m wide by 9.1 m long) area weekly for 6 wk. Ragweed parthenium control was expressed as percent reduction in seedlings compared to a no-herbicide treatment. Data from the no-herbicide treatment were deleted prior to statistical analysis to stabilize variance. Data were subjected to analysis of variance and means were separated at the 5% level of significance using Fisher's protected LSD test (SAS 2006).

Greenhouse studies were conducted during April to May and September to October of 2006 to determine PRE activity

Table 2. Ragweed parthenium control with herbicides applied PRE under greenhouse conditions.

Herbicide	Rate	Control[a] 4 WAT[b]	Control[a] 6 WAT
	g ai/ha	%	
Norflurazon	2,240	100	100
Pendimethalin	1,120	29	22
Clomazone	1,120	100	100
Diuron	1,790	80	87
Fluometuron	2,240	91	96
Pyrithiobac	80	34	35
Dimethenamid	1,100	52	54
Flumetsulam	60	33	34
Imazaquin	140	51	58
s-Metolachlor	2,130	56	58
Metribuzin	700	84	90
Chlorimuron	10	55	77
Atrazine	1,790	35	38
Simazine	3,360	59	53
Flumioxazin	110	89	84
Quinclorac	560	40	67
LSD (0.05)	—	18	15

[a] Data were averaged over two experiments. Data from the no-herbicide treatment were deleted before statistical analysis. Ragweed parthenium density in the no-herbicide treatment averaged 101 and 111 plants/tray (0.125 m^2), respectively, at 4 and 6 WAT.

[b] Abbreviation: WAT, weeks after treatment.

of herbicides on ragweed parthenium using plastic trays. The herbicides and rates used were identical to the PRE field study and included a no-herbicide control (Table 2). Soil (Bosket sandy loam, fine-loamy, mixed thermic Mollic Hapludalf) was placed in 0.5 m by 0.25 m plastic trays without holes to a depth of 0.04 m. Two-hundred fifty milligrams of seed (about 500 seed) was planted in five rows 0.25 m long and thinly covered with soil. After planting, herbicide solutions were prepared as previously described and were applied to the soil surface using an air-pressurized indoor spray chamber equipped with an 8002E flat-fan nozzle to deliver a volume of 190 L/ha at 140 kPa. After herbicide application, trays were placed in a greenhouse maintained at 26/22 C (± 3 C) temperature with a 13/11 h light/dark photoperiod. Immediately, trays were watered in the form of a mist (or gentle shower) to activate herbicides and subsequently as needed. The experiment was conducted in a randomized complete block design with four replications and was repeated. Ragweed parthenium seedlings were counted in each tray on a weekly basis for 6 wk. Ragweed parthenium control was expressed as percent reduction in seedlings compared to a no-herbicide treatment. Data from the no-herbicide treatment were deleted prior to statistical analysis to stabilize variance. Data were subjected to combined analysis of variance and means were separated at the 5% level of significance using Fisher's protected LSD test (SAS 2006).

Postemergence Control. Field studies were conducted during 2005 and 2006 to determine POST activity of herbicides on ragweed parthenium at the Southern Insect Management Research Unit farm, Stoneville, MS. The experiment was conducted on a noncrop area at the edge of the farm using field-grown plants. Ragweed parthenium plants were treated with herbicides at rosette and bolted growth stages (Table 3). Herbicides used in the study were glyphosate, 840 g ai/ha; glufosinate, 410 g ai/ha; paraquat, 1,120 g ai/ha; bentazon, 1,120 g ai/ha; acifluorfen, 560 g ai/ha; chlorimuron, 13 g ai/ha; halosulfuron, 70 g ai/ha; MSMA, 1,120 g ai/ha; bromoxynil, 560 g ai/ha; atrazine, 2,240 g ai/ha; 2,4-D, 806 g ai/ha; flumioxazin, 90 g ai/ha; trifloxysulfuron, 8 g ai/ha; clomazone, 1,400 g ai/ha; and a no-herbicide control (Table 4). The herbicide rates used in the study correspond to the highest registered rates. Treatment solutions were prepared using commercial formulations of herbicides. Glyphosate, glufosinate, and bromoxynil were applied without additional adjuvant. A paraffinic petroleum oil adjuvant[1] at 1.5% v/v was added to atrazine and a nonionic surfactant[2] at 0.25% v/v was added to all other herbicides. Treatments were applied with a CO_2–pressurized backpack sprayer that delivered 140 L/ha of spray solution at 193 kPa. Herbicides were applied on May 18, 2005, and May 26, 2006, to rosette plants, and on June 6, 2005, and June 22, 2006, to bolted plants. The experiment was conducted in a randomized complete block design with four replications separately for each growth stage. The plot size was 2 m wide and 6 m long. Ragweed parthenium control was visually estimated by two authors based on reduction in plant population and plant vigor on a scale of 0 (no control) to 100% (complete control) at 1, 2, and 3 WAT. Data from the no-herbicide treatment were deleted prior to statistical analysis to stabilize variance. Data from bolted-stage POST studies were subjected to combined analysis of variance and means were separated at the 5% level of significance using Fisher's protected LSD test (SAS 2006). Data for rosette-stage POST studies were analyzed separately for each year due to unbalanced treatments.

Results and Discussion

Preemergence control. Under field conditions, norflurazon, clomazone, fluometuron, metribuzin, chlorimuron, and quinclorac provided at least 96% ragweed parthenium control up to 6 WAT (Table 1). Ragweed parthenium control ranged from 60 to 87% with diuron, pyrithiobac, flumetsulam, imazaquin, and simazine. Control of ragweed parthenium was less than 53% with all other herbicides. The experimental area was naturally infested with ragweed parthenium and density in the no-herbicide treatment was 8 to 13 plants/m^2 in 2006. This study could not be repeated for lack of a field with natural infestation, hence the study was conducted in the greenhouse.

In the greenhouse study, clomazone and norflurazon were most effective and completely controlled ragweed parthenium up to 6 WAT (Table 2). Clomazone and norflurazon were followed by fluometuron (96%), metribuzin (90%), diuron (87%), and flumioxazin (84%) which controlled at least 84% ragweed parthenium at 6 WAT. However, flumioxazin controlled 97% ragweed parthenium at 2 WAT (data not shown). Chlorimuron controlled 77% of ragweed parthenium which was similar to quinclorac (67%) at 6 WAT. Control of ragweed parthenium was 22 to 58% with pendimethalin, pyrithiobac, dimethenamid, flumetsulam, imazaquin, *s*-meto-

Table 3. Ragweed parthenium density and size at the time of POST application at Stoneville, MS, in 2005–2006.

Growth stage	Density	Plant diameter	Plant height	Leaves	Flowering
	plants/m^2	——— cm	———	no./plant	
Rosette	19–29	8–28	2–7	4–10	No
Bolted	8–22	26–58	42–90	21–30	Yes

lachlor, atrazine, and simazine at 6 WAT. Ragweed parthenium control was lowest with pendimethalin (22%) at 6 WAT. A similar trend in ragweed parthenium control was observed at 4 WAT with three exceptions. Control increased from 55 to 77% with chlorimuron and 40 to 67% with quinclorac and slightly decreased from 29 to 22% with pendimethalin at 4 WAT compared to 6 WAT.

Overall, ragweed parthenium control with norflurazon, pendimethalin, clomazone, fluometuron, dimethenamid, metribuzin, chlorimuron, and atrazine in the greenhouse is similar to that observed under field conditions (± 20%). However, control with all other herbicides differed between greenhouse and field. These differences may have been due to inherent variability in the seed bank. Variable control of ragweed parthenium has been reported with several herbicides. In a Florida study, Tyson and Bryan (1987) reported greater than 96% control of ragweed parthenium 6 WAT with atrazine (2.24 kg/ha), imazaquin (0.56 kg/ha), and metribuzin (0.84 kg/ha). Ragweed parthenium control in this study was lower than that reported by Tyson and Bryan (1987), partly because of differences in experimental conditions and higher rates used in their study.

Postemergence Control. Under field conditions, glyphosate, glufosinate, chlorimuron, and trifloxysulfuron applied at rosette stage controlled ragweed parthenium greater than

Table 4. Ragweed parthenium control at rosette stage with herbicides applied POST under field conditions at Stoneville, MS, in 2005–2006.[a]

Herbicide	Rate[c]	Control, 3 WAT[b] 2005	2006
	g ai/ha	——— %	———
Glyphosate	840	93	100
Glufosinate	410	93	95
Paraquat	1,120	24	0
Bentazon	1,120	31	30
Acifluorfen	560	26	3
Chlorimuron	13	95	95
Halosulfuron	70	82	90
MSMA	1,120	90	63
Bromoxynil	560	58	90
Atrazine	2,240	25	74
2,4-D	806	89	90
Flumioxazin	90	—	85
Trifloxysulfuron	8	—	95
Clomazone	1,400	—	38
LSD (0.05)	—	4	9

[a] Data from the no-herbicide treatment were deleted before statistical analysis.

[b] Abbreviation: WAT, Weeks after treatment.

[c] Rates were in g ai/ha for all herbicides except for glyphosate and 2,4-D in g ae/ha.

Table 5. Ragweed parthenium control at bolted stage with herbicides applied POST under field conditions at Stoneville, MS, in 2005–2006.

Herbicide	Rate[b]	Control[a] 1 WAT[c]	3 WAT
	g/ha	——— %	———
Glyphosate	840	69	95
Glufosinate	410	84	89
Paraquat	1,120	21	8
Bentazon	1,120	23	19
Acifluorfen	560	49	28
Chlorimuron	13	31	68
Halosulfuron	70	35	61
MSMA	1,120	18	45
Bromoxynil	560	51	33
Atrazine	2,240	43	36
2,4-D	806	28	70
Flumioxazin	90	53	13
Trifloxysulfuron	8	56	86
Clomazone	1,400	64	39
LSD (0.05)	—	5	5

[a] Data were averaged over 2 yr. Data from the no-herbicide treatment were deleted before statistical analysis.

[b] Rates were in g ai/ha for all herbicides except for glyphosate and 2,4-D in g ae/ha.

[c] Abbreviation: WAT, weeks after treatment.

93% at 3 WAT (Table 4). Halosulfuron, MSMA, bromoxynil, 2,4-D, and flumioxazin controlled 58 to 90% rosette ragweed parthenium at 3 WAT. Ragweed parthenium control with all other POST herbicides was less than 38%. Flumioxazin, trifloxysulfuron, and clomazone data for 2005 are not available as these herbicides were added later. Ragweed parthenium control with paraquat, acifluorfen, and MSMA decreased slightly (23 to 27%) and control with atrazine increased (49%) in 2006 compared to 2005. This may have been partly due to differences in weather conditions between the years. At bolted stage, glyphosate, glufosinate, and trifloxysulfuron controlled 86 to 95% ragweed parthenium and control was 61 to 70% with chlorimuron, halosulfuron, and 2,4-D 3 WAT (Table 5). Overall, efficacy of POST herbicides was better on rosette plants than on bolted plants. Interestingly, paraquat had negligible activity (less than 8% at 3 WAT) on ragweed parthenium, regardless of growth stage.

In other research, 2,4-D provided variable control of ragweed parthenium in grain sorghum and repeat applications were necessary (Tamado and Milberg 2004). The levels of control of rosette ragweed parthenium with bromoxynil (58 to 90%) in our study was similar to control of ragweed parthenium (four-leaf stage) in grain sorghum with bromoxynil (47 to 82%) (Rosales-Robles et al. 2005). Singh et al. (2004) reported that 2,4-D, atrazine, metribuzin, metsulfuron, chlorimuron, and glufosinate failed to control ragweed parthenium while glyphosate at 2.7 and 5.4 kg/ha provided greater than 95% control of bolted plants at 18 WAT. Acifluorfen, bentazon, cyanazine, dinoseb, fomesafen, glyphosate, imazaquin, and metribuzin applied POST to plants less than 7.5 cm tall controlled greater than 80% ragweed parthenium in Florida (Tyson and Bryan, 1987). Chlorimuorn and metsulfuron controlled less than 40% ragweed parthenium when applied to bolted plants (Singh et al. 2004).

Flumioxazin was more effective in controlling ragweed parthenium when applied PRE and POST on rosette plants compared to POST on bolted plants. Control of ragweed parthenium with flumioxazin applied PRE in this study is similar to control observed in grain sorghum in Texas (Grichar 2006).

These results indicate that several herbicides registered for PRE and POST control of weeds in corn, cotton, peanut, rice, and soybean could provide effective control of ragweed parthenium. Furthermore, several of the herbicides studied were more active than herbicides previously reported in the literature. Among the PRE herbicides studied, ragweed parthenium appears to be highly sensitive to pigment (norflurazon and clomazone) and photosynthetic (fluometuron, diuron, and metribuzin) inhibitors compared to herbicides with other modes of action. To our knowledge, this is the first report of norflurazon and clomazone activity on ragweed parthenium. Among the POST herbicides studied, amino acid synthesis (chlorimuron, glyphosate, halosulfuron, and trifloxysulfuron) and glutamine synthase (glufosinate) inhibitors were more active than herbicides with other modes of action. These findings indicate that norflurazon, clomazone, fluometuron, flumioxazin, halosulfuron, chlorimuron, and trifloxysulfuron could provide effective control of ragweed parthenium in the crops for which they are registered.

Sources of Materials

[1] Agri-Dex is a proprietary blend of heavy range paraffin-based petroleum oil, polyol fatty acid esters, and polyethoxylated derivative nonionic adjuvant (99% active ingredient), Helena Chemical Company, Suite 500, 6075 Poplar Avenue, Memphis, TN 38119.

[2] Induce is a nonionic low foam wetter/spreader adjuvant contains 90% nonionic surfactant (alkylaryl and alcohol ethoxylate surfactants) and fatty acids and 10% water, Helena Chemical Company, Suite 500, 6075 Poplar Avenue, Memphis, TN 38119.

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Received April 4, 2007, and approved June 30, 2007.