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Late-season Weed Management in Conventional Canola Using Sethoxydim and Clopyralid

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ABSTRACT

Seed yield and seed quality of winter canola can be reduced by broadleaf and grass weeds that emerge and grow during the spring. The overall objective of this study was to assess the ability of registered, selective herbicides to control problematic weeds that can occur in New Mexico canola fields during the spring, after winter canola resumes growth. To accomplish this objective, a field study was conducted to determine the abilities of clopyralid to control broadleaf weeds and sethoxydim to control grass weeds. Results from the study suggest that clopyralid at both 0.105 and 0.210 kg active ingredient (ai) ha^{-1} was unable to control Brassicaceae weeds (flixweed [*Descurainia sophia*] and western tansymustard [*Descurainia pinnata*]). Sethoxydim at 0.210 and 0.525 kg ai ha^{-1} was able to control volunteer wheat and oat. Neither herbicide caused a significant reduction in canola seed yield, biomass, or harvest index. Combined results suggest grass weeds can be controlled; however, there is a gap in the current chemical catalog to control Brassicaceae weeds in conventional canola.

INTRODUCTION

Canola is a Brassicaceae crop that has recently generated interest from growers in eastern New Mexico due to the opening of a canola seed crushing facility in northwest Texas. Interest in canola is further fueled by the potential

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to increase yield and profitability of subsequent winter wheat crops, which is caused by canola's ability to reduce populations of problem grass weeds, disrupt the life cycles of several important wheat pathogens, and mobilize soil nutrients (Boyles et al., 2012; Bushong et al., 2012). Suppression of grass weeds in canola is partly a consequence of canola's herbicide catalogue that features grass-targeting herbicides that are not available for wheat. Finally, growers are increasingly interested in canola because they do not need to invest in new planting and harvest equipment—canola can be produced using wheat equipment.

In eastern New Mexico, early September planting is recommended for winter canola (Begna et al., 2016). This allows for adequate growth before the first killing frost (Boyles et al., 2012). After planting, winter canola develops a large rosette by December, halts growth throughout early winter, resumes growth in February, flowers in late April, and is ready for harvest in early summer. Winter canola in eastern New Mexico has two periods in which weeds must be eliminated to prevent yield loss (hereafter referred to as "critical periods of weed control"): shortly after crop emergence before the crop canopy closes (late October or early November) and shortly after the crop begins regrowth in the spring (February).

During the critical periods of weed control, Brassicaceae weeds, including flixweed (*Descurainia sophia*) and western tansymustard (*Descurainia pinnata*), can be present in the field. These Brassicaceae weeds are winter annuals that, much like canola, emerge in the fall, overwinter as a rosette, resume growth in early spring, and flower by late spring. A flixweed seed contamination rate of 10% can cause the erucic acid content of canola seed lots to go above acceptable levels (>2% erucic acid), which significantly lowers the value of the crop (Davis et al., 1999). This contamination level is easily achieved considering a single flixweed plant can produce over 75,000 seeds (Stevens, 1954).

In addition to Brassicaceae weeds, volunteer grain crops, such as volunteer winter wheat (*Triticum aestivum*) and volunteer oat (*Avena sativa*), are potentially problematic in winter canola. Volunteer crops can directly compete with canola for resources, including nutrients and light. A single volunteer wheat plant per m^{-2} competing throughout the growing season has the potential to reduce spring canola yield by 1% (O'Donovan et al., 1989). There is also the potential for herbicide resistance transfer (if the wheat variety is herbicide-resistant) between wheat and grass weeds such as jointed goatgrass (*Aegilops cylindrica*), which is a species that has gained resistance to imazamox through pollen flow from imazamox-resistant wheat (Seefeldt et al., 1998).

To eliminate weeds during the critical periods of weed control, growers have access to herbicide programs that can be used in herbicide-resistant canola varieties and herbicide programs for canola varieties that have not been modified to resist specific broad-spectrum herbicides. The herbicide-resistant varieties that are available in New Mexico are Roundup Ready (Monsanto Company Inc., St. Louis, MO), which is resistant to glyphosate; Clearfield (BASF Corporation, Florham Park, NJ), which is resistant to imazamox; and LibertyLink (Bayer Corporation, Robinson Township, PA), which is resistant to glufosinate. These varieties allow for the broadcast application of the specified broad-spectrum herbicide while the canola is present in the field. These varieties also offer several short-term advantages over conventional varieties such as the simplicity and convenience of applications (Owen, 2016). Despite these advantages, many growers may still wish to use conventional herbicide options to control weeds after crop emergence.

Postemergence (POST) herbicides are applied after the crop or weed species has emerged. POST herbicides can be further broken down into directed POST and broadcast POST. Directed POST herbicides are applied directly to the weeds while avoiding contact with the crop. Broadcast POST herbicides are applied over the top of the crop to control weeds either early or late in the crop's development (Ross and Lembi, 2009).

Currently, to control emerged broadleaf weeds with a broadcast POST application in conventional canola, growers only have access to clopyralid. Clopyralid is a Weed Science Society of America (WSSA) Group 4 herbicide (synthetic auxin) that is absorbed by roots and leaves and is thought to induce uncontrolled growth, resulting in destruction of vascular tissue (Shaner, 2014). Susceptible plants tend to develop curled leaves and twisted stems and often show chlorosis, followed by necrosis at the growing points. Weed species that are negatively affected by clopyralid include perennial sowthistle (*Sonchus arvensis*) and wild buckwheat (*Polygonum convolvulus*), which are problematic weeds in canola in Canada (O'Donovan et al., 2006).

To control emerged grass weeds in canola, growers can use clethodim, quizalofop, or sethoxydim. All three herbicides are in WSSA Group 1 (ACCase inhibitors), which prevents the production of phospholipids used in the formation of new cell membranes (Shaner et al., 2014). Susceptible grasses display chlorosis on the leaves, which tend to wilt and snap at the soil surface (Ross and Lembi, 2009). Sethoxydim has been shown to control green foxtail (*Setaria viridis*) and volunteer wheat in spring canola (Harker and O'Sullivan, 1988).

Because canola is a relatively new crop in New Mexico, herbicide options for conventional canola have yet to be studied under cropping conditions typical of eastern New Mexico. This study was conducted to improve understanding of late-season herbicide options for conventional canola in New Mexico. The objectives of this study were to 1) assess the ability of sethoxydim to control volunteer wheat and oat in winter canola that emerges in spring and 2) assess the ability of clopyralid to control emerged broadleaf weeds that emerge in the spring in winter canola.

MATERIALS AND METHODS

Study site

A field experiment was conducted at the New Mexico State University (NMSU) Agricultural Science Center at Clovis, NM (34° 35'N, 103° 12'W), from September 2014 to June 2015 and repeated from September 2015 to June 2016. Experimental runs were conducted in different fields, but both fields featured an Olton clay loam soil. In 2014–2015, soil pH was 7.6 and organic matter content was 1.7%, and in 2015–2016, soil pH was 7.8 and organic matter content was 1.4%. In the growing season prior to the 2014–2015 experimental run, the field was fallow. The 2015–2016 experimental run was planted into a field that was previously used for wheat. For both experimental runs, fields were tilled to the 10-cm depth using a Sunflower 6333 Land Finisher (AGCO, Duluth, GA) one day prior to planting.

Experimental units were plots (1.83 m by 9.14 m with a 15.24-cm row spacing) that were arranged in a randomized complete block design with four replications. 'Saffran', a hybrid winter canola variety that was previously determined to be suitable for the region (Sangu Angadi, personal communication, August 2014), was seeded into experimental plots on September 10, 2014, and September 9, 2015. Seeding was performed using a plot drill (Great Plains 3P600, John Deere, Moline, IL). Plots were irrigated via center pivot as needed from September to late November and from early February to late April in both experimental runs.

Experimental treatments and data collection

To assess POST herbicides for their ability to control broadleaf and grass weeds, a field study was conducted in canola described above. Wheat and oat were seeded into each plot at 52.7 kg ha^{-1} on January 30, 2015, and January 29, 2016, to simulate volunteer wheat and oat infestations that emerge in the spring.

POST treatments were clopyralid (Stinger, Dow AgroSciences LLC, Indianapolis, IN) at 0.105 or 0.210 kg ai ha^{-1}, sethoxydim (Poast, BASF Corporation, Research Triangle Park, NC) at 0.210 or 0.525 kg ai ha^{-1}, all possible tank mixes of each rate of clopyralid and sethoxydim, and a weedy check in which plots were not treated with any herbicide to allow for weed competition (Table 1). Rates of sethoxydim and clopyralid are the labeled high and low rates. Treatments were applied in the spring (March 17, 2015, and March 16, 2016)

Table 1. List of Treatments in the Postemergence (POST) Herbicide Study*

Treatment number**	Treatment and herbicide rate (kg ai ha^{-1})	Target weeds
1	Clopyralid (0.105)	Broadleaf
2	Clopyralid (0.210)	Broadleaf
3	Clopyralid (0.210) + sethoxydim (0.210)	Broadleaf and grass
4	Clopyralid (0.210) + sethoxydim (0.525)	Broadleaf and grass
5	Sethoxydim (0.210)	Grass
6	Sethoxydim (0.525)	Grass
7	Clopyralid (0.105) + sethoxydim (0.210)	Broadleaf and grass
8	Clopyralid (0.105) + sethoxydim (0.525)	Broadleaf and grass
9	Weedy check	

*Canola was planted on September 10, 2014, and September 9, 2015, at the New Mexico State University Agricultural Science Center at Clovis, NM. Treatments 3–10 were applied on March 17, 2015, and March 16, 2016. Treatments 3–9 were also treated with trifluralin at 0.140 kg ai ha^{-1} just prior to planting.

**Treatment numbers are used in Figures 1 and 2.

with a CO_2-powered backpack sprayer set to 207 kPa with a 1.5-m boom and 3 nozzles with TP 8002E spray tips (TeeJet Technologies, Wheaton, IL).

Weed densities were recorded just prior to herbicide application (March 17, 2015, and March 16, 2016) and 5 weeks after herbicide application (April 21, 2015, and April 25, 2016). Density data were collected separately for grass weeds (i.e., wheat and oat) and broadleaf weeds. Plots were initially scouted for areas with grass or broadleaf weeds. In areas with high weed densities (1 area $plot^{-1}$ weed $type^{-1}$), a 0.5 m by 0.5 m quadrat was placed. The center of the quadrat was marked with a flag, and weeds were counted. Weed densities in the 0.5 m by 0.5 m area from each plot were also recorded 5 weeks later.

Low weed densities throughout each plot prevented the use of a "percent control" measurement for both broadleaf and grass weeds. Instead, weed density data were used in the following equation to assess the herbicides' ability to control both broadleaf and grass weeds:

$$\textit{Change in weed density (CWD)} = T_2 - T_1$$

where T_1 is the weed density taken just prior to spraying and T_2 is the weed density at 5 weeks after spraying.

On June 29 to 30, 2015, and June 16 to 17, 2016, canola was harvested by first dividing each plot into two sections. One plot section was used to collect data on harvest index, which is the proportion of the aboveground biomass allocated to seeds (Hay, 1995). Harvest index was determined by hand-harvesting aboveground biomass

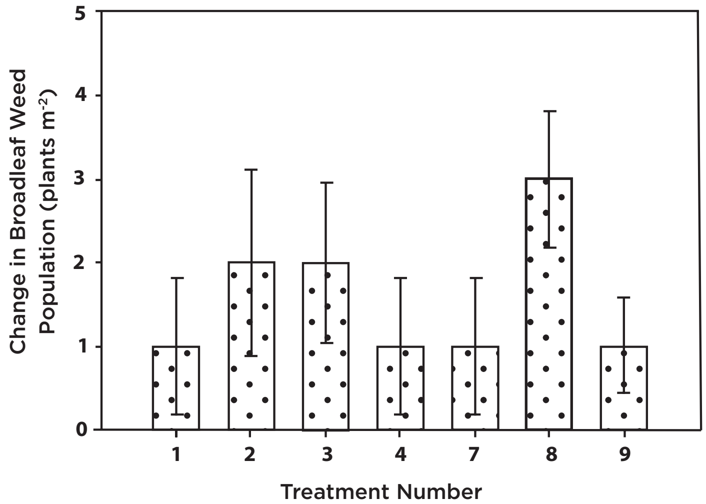

Figure 1. **Change in broadleaf weed density in winter canola following application of postemergence (POST) herbicides. Treatment numbers: 1) clopyralid at 0.105 kg ai ha^{-1}, 2) clopyralid at 0.210 kg ai ha^{-1}, 3) clopyralid at 0.210 kg ai ha^{-1} and sethoxydim at 0.210 kg ai ha^{-1}, 4) clopyralid at 0.210 kg ai ha^{-1} and sethoxydim at 0.525 kg ai ha^{-1}, 7) clopyralid at 0.105 kg ai ha^{-1} and sethoxydim at 0.210 kg ai ha^{-1}, 8) clopyralid at 0.105 kg ai ha^{-1} and sethoxydim at 0.525 kg ai ha^{-1}, and 9) weedy check. Herbicides were applied on March 17, 2015. Bars indicate means with 90% confidence intervals. Data are from a field study that took place at the New Mexico State University Agricultural Science Center at Clovis, NM, from September 10, 2014, to June 30, 2015.**

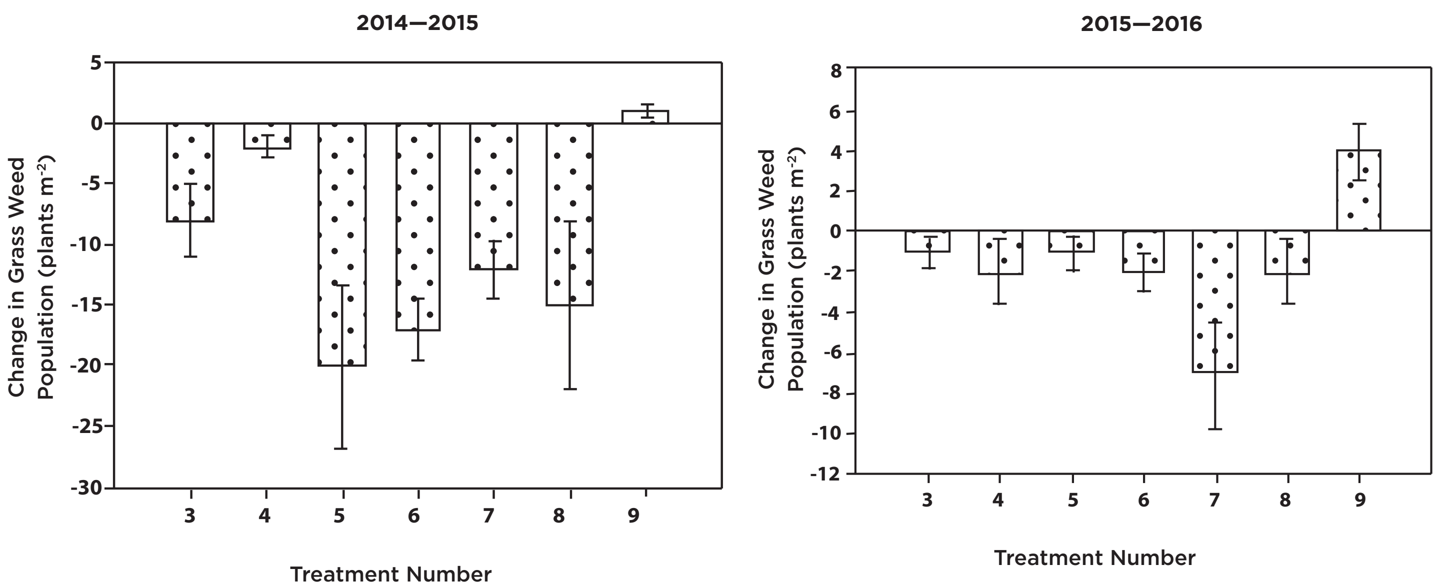

Figure 2. **Change in grass weed (i.e., volunteer wheat and oat) density in winter canola following application of postemergence (POST) herbicides. Treatment numbers: 3) clopyralid at 0.210 kg ai ha^{-1} and sethoxydim at 0.210 kg ai ha^{-1}, 4) clopyralid at 0.210 kg ai ha^{-1} and sethoxydim at 0.525 kg ai ha^{-1}, 5) sethoxydim at 0.210 kg ai ha^{-1}, 6) sethoxydim at 0525 kg ai ha^{-1}, 7) clopyralid at 0.105 kg ai ha^{-1} and sethoxydim at 0.210 kg ai ha^{-1}, 8) clopyralid at 0.105 kg ai ha^{-1} and sethoxydim at 0.525 kg ai ha^{-1}, and 9) weedy check. Bars indicate means with 90% confidence intervals. Data are from field studies that took place at the New Mexico State University Agricultural Science Center at Clovis, NM, from (A) September 10, 2014, to June 30, 2015, and (B) September 9, 2015, to June 17, 2016. Herbicides were applied on March 17, 2015, and March 16, 2016.**

from 1 m by 1 m quadrats. The collected aboveground biomass was then oven-dried for 5 days at 65°C. After drying, seeds were removed from stems and leaves, and each component (seeds and vegetative parts) was weighed separately. Following the collection of aboveground biomass for harvest index, the remaining section of each plot, which measured 15.7 m^2, was used to measure crop yield. Crop yield was determined with a plot combine (Nurserymaster Elite, Wintersteiger Inc., Salt Lake City, UT).

Statistical analysis

Data for crop yield, aboveground biomass, and harvest index were separated by experimental run due to a significant difference between the two experimental runs observed during initial ANOVAs. Following ANOVAs, LSD ($p > 0.05$) was used to assess POST herbicide treatment effects on crop yield, aboveground biomass, and harvest index. For all ANOVAs conducted in this study, normality of residuals were checked by visual interpretation of residual versus predicted graphs. Homogeneity of variance was checked with Levene's test (Levene, 1960).

Change in weed density (CWD) data for POST herbicides were assessed with 90% confidence intervals for treatment means. If the 90% confidence interval for the treatment mean overlapped with zero, that treatment was determined to have no effect on CWD. For CWD data for broadleaf weeds, only the first experimental run was used due to a lack of broadleaf weeds in the second experimental run. For grass weeds, CWD data were separated by experimental run due to a significant difference between the two experimental runs observed during initial ANOVA.

Table 2. Seed Yield, Aboveground Biomass, and Harvest Index for Canola Treatments in the Postemergence (POST) Herbicide Study*

Experimental run	Treatment and herbicide rate (kg ai ha^{-1})	Seed yield (kg ha^{-1})**	Aboveground biomass (kg ha^{-1})	Harvest index (%)
2014–2015	Clopyralid (0.105)	3835 a	12140 a	31.7 a
	Clopyralid (0.210)	3838 a	12163 a	31.3 a
	Clopyralid (0.210) + sethoxydim (0.210)	3975 a	12600 a	31.4 a
	Clopyralid (0.210) + sethoxydim (0.525)	4285 a	13238 a	32.4 a
	Sethoxydim (0.210)	4383 a	13030 a	33.6 a
	Sethoxydim (0.525)	4220 a	12258 a	34.5 a
	Clopyralid (0.105) + sethoxydim (0.210)	3995 a	12308 a	32.4 a
	Clopyralid (0.105) + sethoxydim (0.525)	4090 a	12870 a	31.8 a
	Weedy Check	3913 a	12830 a	30.3 a
2015–2016	Clopyralid (0.105)	3003 a	11955 a	25.0 a
	Clopyralid (0.210)	2760 a	10990 a	25.0 a
	Clopyralid (0.210) + sethoxydim (0.210)	3125 a	12918 a	24.1 a
	Clopyralid (0.210) + sethoxydim (0.525)	3003 a	11583 a	26.2 a
	Sethoxydim (0.210)	2830 a	11205 a	25.3 a
	Sethoxydim (0.525)	3208 a	11540 a	27.5 a
	Clopyralid (0.105) + sethoxydim (0.210)	2990 a	11295 a	26.4 a
	Clopyralid (0.105) + sethoxydim (0.525)	3075 a	12248 a	25.1 a
	Weedy check	2643 a	10963 a	23.8 a

*The study took place at the New Mexico State University Agricultural Science Center at Clovis, NM, from September 10, 2014, to June 30, 2015, and from September 9, 2015, to June 17, 2016.

**Means within a column, and each experimental run, followed by the same letter are not significantly different (LSD at $p \leq 0.05$).

RESULTS AND DISCUSSION

The weeds that were present were flixweed, western tansymustard, and volunteer wheat and oat. The heights and growth stages of weeds at the time of spraying were as follows: flixweed, 10 cm, 6 leaves; western tansymustard, 8 cm, 5 leaves; volunteer wheat and oat, 10 cm, 8 leaves. Wheat and oat heights were at the maximum height for control according to label guidelines. Clopyralid showed no ability to control flixweed and western tansymustard as CWD were generally positive for clopyralid treatments (Figure 1). These results were similar to a previous study that determined wild mustard (*Brassica kaber*) was not controlled with clopyralid applied at 0.15 and 0.30 kg ai ha^{-1} (Blackshaw and Harker, 1992). The inability of clopyralid to control Brassicaceae weed species may be due to increased metabolism of the herbicide in Brassicaceae species (Hall and Vanden Born, 1988).

Sethoxydim reduced densities of volunteer wheat and oat (Figure 2). Similar results were obtained by

Table 3. Monthly Average Temperature and Monthly Total Precipitation for the Study Periods*				
	Average monthly temperature		Total monthly precipitation	
	2014–2015	2015–2016	2014–2015	2015–2016
	°C		cm	
September	19.4	22.6	6.7	6.5
October	15.6	14.6	0.9	20.8
November	4.8	7.0	0.6	2.2
December	3.0	3.8	0.1	1.5
January	-0.5	2.1	3.1	0.2
February	3.7	6.0	1.6	0.4
March	7.8	9.6	1.5	0.0
April	12.3	12.0	1.5	1.2
May	15.2	15.5	18.9	3.9
June	22.3	22.0	4.5	9.5

*Data were recorded at the New Mexico State University Agricultural Science Center at Clovis, NM.

Harker and O'Sulivan (1988) who showed that sethoxydim at a rate of 0.25 kg ai ha^{-1} was able to reduce volunteer wheat densities by 96%. Harker and O'Sullivan (1991) determined that sethoxydim at 0.15 and 0.25 kg ai ha^{-1} reduced densities of green foxtail and wild oat (*Avena fatua*).

There were no significant differences among POST herbicide treatments for seed yield, aboveground biomass, or harvest index for either experimental run (Table 2). These results are similar to those of Lemerle and Hinkley (1991) who found that sethoxydim applied at 0.37 kg ai ha^{-1} did not significantly affect canola yield, whereas clopyralid at a rate of 0.18 kg ai ha^{-1} reduced yield in one canola variety. There was significant difference between the two experimental runs, which was likely caused by a large precipitation event that occurred in the first experimental run during seed fill that did not occur in the second run (Table 3). Unexpectedly, there was no significant difference between weedy check plots and the POST control plots in terms of crop yield, aboveground biomass, and harvest index. This may have been caused by the low weed densities in each plot mentioned above.

The results from this study suggest that Brassicaceae weeds may be problem weeds in this system due to a lack of POST herbicides for broadcast applications. Brassicaceae weeds in canola might be controlled with POST-directed application of carfentrazone-ethyl; however, a POST-directed spray is difficult when the canola canopy is dense. The use of an integrated weed management strategy that combines cultural control methods, such as increasing canola seeding rate or reducing the crop row spacing, with chemical control options may aid in the control of these Brassicaceae weeds. The results also suggest that sethoxydim can provide POST control of volunteer wheat and oat. Previous research indicates that sethoxydim also controls other grass weeds that could be problematic in the wheat–canola rotation (Harker and O'Sullivan, 1988).

Implications for management

Canola has two critical periods of weed control, shortly before canopy closure in the fall and immediately after growth resumes in the spring. During the two critical periods of weed control, growers must eliminate weed species to prevent yield loss. For conventional canola, it is recommended that growers apply a preplant incorporated (PPI) herbicide, such as trifluralin, to reduce weed densities during the first critical period of weed control. During the critical periods of weed control, emerged grass weeds can be controlled with a POST herbicide such as sethoxydim, quizalofop p-ethyl, or clethodim. Herbicides for Brassicaceae weeds in conventional canola do not exist for New Mexico. Thus, growers confronting Brassicaceae weeds in conventional canola should implement cultural strategies to suppress Brassicaceae weeds. Such strategies might include increasing canola seeding rate or changing the row spacing to reduce the time it takes for the canola canopy to close. If the Brassicaceae weeds are expected to be widespread in a canola field, growers may want to plant a grass crop that enables access to herbicides that target a broad spectrum of broadleaf weeds. For fields with infestations of Brassicaceae weeds, growers could also think about using an herbicide-resistant variety of canola. For a complete list of herbicides for canola, please see the article "Registered Herbicides for Canola in New Mexico" at http://eps.nmsu.edu/2016-news-you-can-use.html.

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