Can harvest weed seed management be used to control kochia, cleavers and wild buckwheat?

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Background

In recent years herbicide resistant weeds have become increasingly problematic in canola. Although the rapid adoption of herbicide tolerant canola initially resulted in excellent weed control and lower levels of weeds, the latest Saskatchewan weed survey results indicate that weed control in canola has become more difficult. In 2012 only 13% of the quadrats in commercial canola fields were weed free following herbicide application compared to 40% in 2003 (Leeson 2013). Weed density has increased approximately three-fold in comparison with the survey in 2003 and is now higher than weed densities in the 80's and 90's. Weed populations in canola are now higher partially because weeds and weed communities have either evolved to either select for difficult to control species, or those that are completely resistant to the herbicide system.

Harvest weed seed management has emerged recently as a strategy to manage herbicide resistant and hard to kill weeds. Shirtliffe and Entz (2005) first demonstrated that harvest weed seed management could be used to reduce seed dispersal in wild oat, although the efficacy was limited because of early seed shed in wild oat (*Avena sativa* L.; Shirtliffe et al, 2000). In Western Australia a variety of harvest weed seed management systems have been successfully used which have resulted in reduced population of herbicide resistant weeds. In on-farm trials, using harvest weed seed management resulted in ryegrass populations declining much more quickly compared to where harvest weed seed management was not practiced (Walsh et al. 2013). Three methods of harvest weed seed management have been used: 1) chaff collection –the chaff (containing weed seeds) is collected in a wagon and left in field piles which are later removed or burnt; 2) seed destruction – the chaff is pulverized by a mill either behind or mounted on the combine; and 3) narrow harvest windrow burning – the chaff in concentrated in narrow windrow behind the combine and then burnt following harvest. All three of these methods have similar efficacy in destroying weed seeds and reduced weed emergence the year following year by 55% (Aves and Walsh, 2013). Farmers and machinery manufactures have greatly improved the practicality of these systems and they are now commonly used in many regions. However before these radically different systems can be recommended for western Canada the timing of seed shed in the target weed species must be assessed.

Utilizing herbicides to reduce weed seed production before harvest has also been previously used to reduce weed seed production (Walsh et al. 2007). The concept is similar to utilizing a pre-harvest desiccant, except that the weed target is a species that survived the in-crop herbicide application. Applying herbicides in this fashion is known as “topping” or “crop topping” and has been used successfully to control herbicide resistant weeds in Australia (Powles and Matthews, 2006; Walsh and Powles, 2006). Under optimum conditions this practice can reduce weed seed production by up to 90% (Gill and Holmes, 1997). However, the effectiveness of topping depends on the development stage of both the crop and the weed at the time of herbicide application, as well as the efficacy of the herbicide. Ideally the weed seeds would still be immature while the crop is mature. Because of concerns about crop damage from late season herbicide application the effectiveness of crop topping varies depending on the crop and weed combination (Walsh and Powles, 2006). In kochia, the effect of late season herbicides on seed production has not been determined. However, Mickelson et al. (2004) found that glyphosate and paraquat were the most effective herbicides at preventing seed production in kochia after crop harvest.

The objective of this study is to evaluate the potential of harvest weed seed management techniques to manage seed production of cleavers, kochia, and wild buckwheat in canola. Two experiments were conducted in 2014, 2015, and 2016 in central Saskatchewan with the following sub-objectives:

1) Determine the timing of seed shed in cleavers, kochia, and wild buckwheat growing in canola

2) Assess the efficacy of pre-harvest herbicides in reducing viable weed seed production in cleavers, kochia, and wild buckwheat

Materials and Methods

Objective 1: *determine the timing of seed shed in cleavers, kochia, and wild buckwheat growing in canola*

The timing of seed shed was sampled for both naturally occurring weed populations and transplanted weeds. Catch trays (cleavers, wild buckwheat) or mesh bags (kochia) were set up to capture seeds falling off of weeds, and emptied weekly. Seeds fallen off the plants each week were weighed and quantified for each species. At the conclusion of the experiment at each site the sampled plants were collected, and remaining seeds were threshed off the plants, weighed, and quantified to determine the proportion of total seeds produced that were shed by plants on each sampling date. Weed seed shed in response to thermal time (Growing Degree Days (GDD) base 5^{o}C) was fitted to a modified exponential growth curve in SigmaPlot version 13 (Systat Software Inc.) based on best visual fit and highest adjusted R^2 values.

Natural Weed Populations

Three fields with endemic populations of the targeted weed species were identified in 2015 and 2016 and seeded to canola. In 2015 the field was located at Goodale Crop Research Farm 30 km southeast of Saskatoon, and in 2016 the two fields (North and South) were located at Kernen Crop Research Farm on the east edge of the city of Saskatoon, SK. At each location a known number of weeds of the three species were identified, flagged, and numbered (Table 1), and monitored for the duration of the season.

Table 1: Number of plants of each weed species sampled in each site-year to determine the timing of seed shed.

Site-Year	**Cleavers**	**Kochia**	**Wild Buckwheat**
2015 Goodale	9	20	20
2016 North	10	20	10
2016 South	10	20	0
Total Plants Sampled	*29*	*60*	*30*

Transplanted Weeds

In 2015 weeds were transplanted into plots seeded to canola at two sites, one at Goodale Crop Research Farm, and the other at Nasser Farm adjacent to Kernen Crop Research Farm. The transplanted experiment had a factorial treatment arrangement on a randomized complete block design. The two factors tested were weed species (cleavers, kochia, wild buckwheat), and timing of weed emergence relative to the crop (with crop, 1 week following crop, 2 weeks following crop). Weeds were grown in the greenhouse, and small seedlings with 1-3 leaf whorls (cleavers), ≤1cm diameter (kochia), or 1 true leaf (wild buckwheat) were transplanted into canola at canola emergence, 1 week, or two weeks later. Canola seedlings growing within a 1m radius of transplanted weeds were cleared at transplanting to aid in weed establishment. Two weeds of each species were transplanted into each plot, and the total seed production per plot was divided by two to estimate average seed production per plant. Since the relative timing of weed emergence did not affect seed production of kochia nor wild buckwheat ($P \geq 0.23$), and only affected seed production of cleavers at one location (site-year x time of emergence $P=0.03$), the seed production of transplanted weeds was averaged across all timings of weed emergence for presentation.

Objective 2: *assess the efficacy of pre-harvest herbicides in reducing viable weed seed production in cleavers, kochia, and wild buckwheat*

The pre-harvest herbicide study tested the efficacy of diquat and glyphosate in reducing weed seed production and viability compared with untreated control. Pre-harvest herbicides were applied at the recommended canola swathing stage, 60% seed colour change on the main raceme (Canola Council of Canada, n.d.). Weed seeds were collected from catch trays (cleavers, wild buckwheat) or mesh bags (kochia) prior to (pre-) and 10-14 days following (post-) herbicide treatment. The experiment was conducted in both natural (2016 Kernen North and South) and transplanted weed populations (2014, 2015 Nasser, 2015 Goodale). Since not all weed species were present at each site in each year, a separate dataset was made and analyzed for each weed species, with each dataset containing at least

14 weeds per herbicide treatment (Table 2). The dataset for cleavers included data from 2014, 2015, and 2016 (5 sites total); kochia included data from 2015 and 2016 (4 sites total), and for wild buckwheat included 2014, 2015, and 2016 (5 sites total). Although the dataset for each weed species included sites with both natural weed populations and transplanted weeds, pre-harvest herbicide treatment efficacy did not differ between natural and transplanted sites. Since the location of specific herbicide treatments at 2016 sites depended on where weeds were present, the experiment was analyzed as a completely randomized design, with site-year and site-year x herbicide treatment as the only random effects.

Table 2: Number of plants sampled for untreated, diquat-, and glyphosate-treated cleavers, kochia, and wild buckwheat.

	Cleavers	**Kochia**	**Wild Buckwheat**
Control	17	16	14
Diquat	17	17	14
Glyphosate	20	18	14
Total Plants Sampled	*54*	*51*	*42*

Results and Discussion

Objective 1: *determine the timing of seed shed in cleavers, kochia, and wild buckwheat growing in canola*

Natural populations of cleavers and wild buckwheat required fewer growing degree days than kochia to shed 10% of seeds produced on the plant (Figure 1; Table 3). Seed shed of cleavers and wild buckwheat began at approximately 1390 GDD, which coincided with the last week of August in 2015, and the third week of August in 2016. Kochia seed shed began at approximately 1585 GDD, which coincided with the last week of September in 2015, and the second week of September in 2016. Wild buckwheat shed a higher proportion of the seeds it produced over the duration of the experiment, while kochia shed a higher total number of seeds, than the other weed species (Table 3). On average, each kochia plant released an average of nearly 3500 seeds, compared with 194 and 152 for cleavers and wild buckwheat, respectively, over the duration of the experiment.

The proportion and number of seeds diverted from the soil seedbank is dependent on the date the crop is harvested. Harvest at 1390 GDD, when cleavers and wild buckwheat had shed 10% of their seeds, would result in an average of 42, 55, and 22 seeds per plant added to the soil seedbank for cleavers, kochia, and wild buckwheat, respectively. Harvest at 1585 GDD, when kochia had shed 10% of its seeds, would result in an average of 114, 792, and 78 seeds per plant added to the seedbank for cleavers, kochia, and wild buckwheat, respectively. These data highlight that harvesting the crop as soon as possible is essential in keeping the number of weed seeds returned to a minimum.

Transplanted weeds held seeds till later in the season, shed a smaller proportion, and a lower number of seeds overall than natural weed populations (Figure 2; Table 3). Transplants of all weed species did not shed 10% of their seeds until an average of 1563 GDD. By calendar date this occurred during the third week of September, at the very end of the growing season. Compared with natural weed populations, this was consistent with the timing of seed shed for kochia only. As the patterns of seed shed between natural and transplanted weeds differed so greatly, we believe that transplanted weeds did not accurately reflect the situations growers are encountering in their fields.

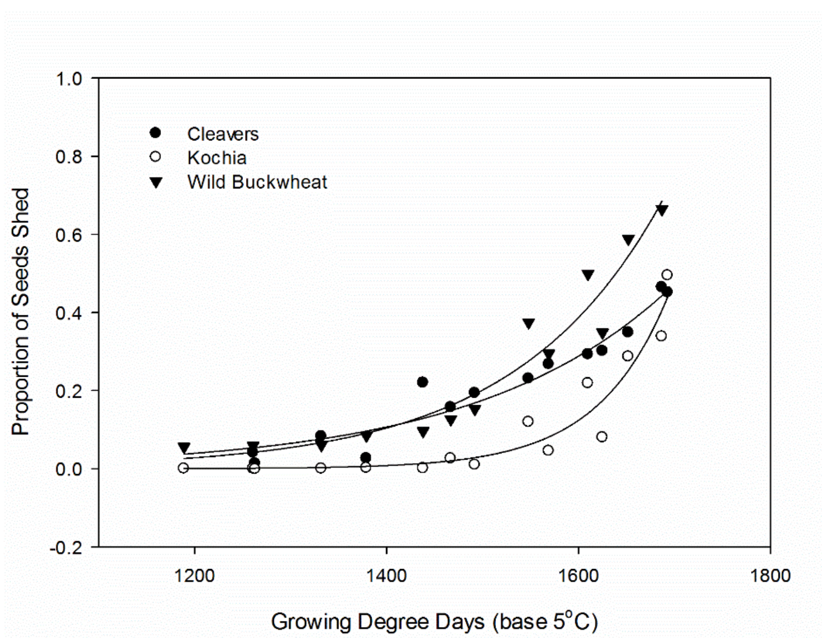

Figure 1: Seed shed of natural populations of cleavers, kochia, and wild buckwheat in response to thermal time. Data are averaged across three site-years in 2015 and 2016 in central Saskatchewan.

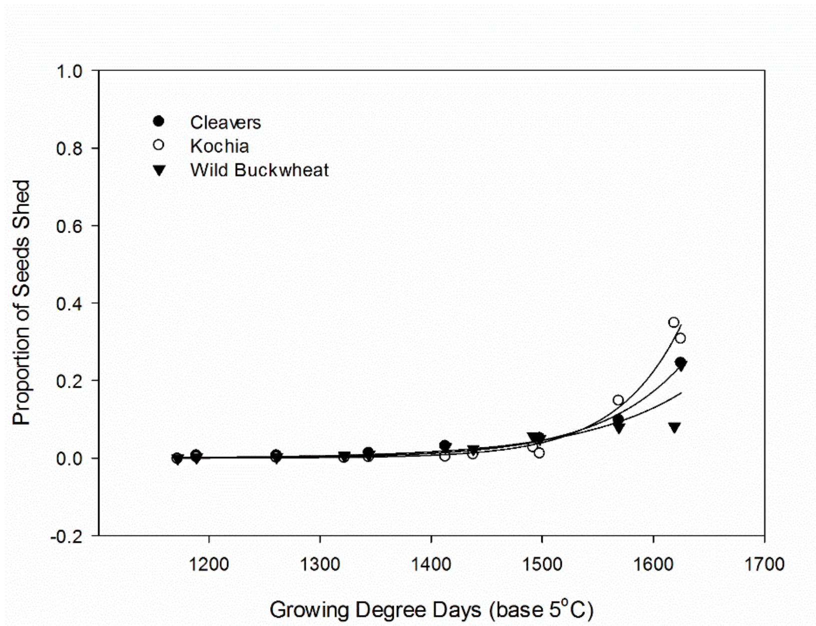

Figure 2: Seed shed of transplanted populations of kochia, wild buckwheat, and cleavers in response to thermal time. Data for kochia and wild buckwheat populations represent the average of Goodale and Nasser field sites in 2015, while cleavers is from Nasser only.

Table 3: Growing degree days required for plants to shed 10% of their seeds (GDD10), average proportion of seeds shed, and average number of seeds shed over the duration of the experiment, for natural and transplanted populations of cleavers, kochia, and wild buckwheat. Data are averaged across three site-years for natural weed populations, and two site-years for transplanted weed populations.

	GDD10		**Average Proportion Shed (per plant)**		**Average # of Shed Seeds (per plant)**	
	Natural	Transplanted	Natural	Transplanted	Natural	Transplanted
Cleavers	1388	1560	0.46	0.24	194 b	99
Kochia	1585	1554	0.44	0.34	3483 a	762
Wild Buckwheat	1395	1575	0.68	0.17	152 b	82

Objective 2: *assess the efficacy of pre-harvest herbicides in reducing viable weed seed production in cleavers, kochia, and wild buckwheat*

Pre-harvest herbicide application did not reduce the number of seeds shed by harvest time for cleavers, kochia, nor wild buckwheat (Table 4). This suggests that herbicide application at canola swathing time is not early enough to prevent seed formation for the three weed species tested. For cleavers and kochia, there was a trend of higher seed shed by plants treated with diquat than the untreated control. This trend can likely be attributed to diquat accelerating dry-down of weeds that had already produced mature seeds, causing premature shattering.

Viability of seeds produced in untreated plots and those treated with pre-harvest herbicides was tested in 2016, but did not differ between treatments ($P \geq 0.24$). Average percentage germination was 20 ± 7.7 and 72 ± 4.6% for cleavers and kochia, respectively. Very few wild buckwheat seeds were produced in the pre-harvest herbicide experiment in 2016, so wild buckwheat seed viability data are not available. However the lack of difference in seed viability between herbicide treatments and untreated in the other two species is consistent with the observation that weeds had already produced mature seed by the time of pre-harvest herbicide application.

Table 4: Average number of weed seeds shed by cleavers, kochia, and wild buckwheat following pre-harvest treatment with diquat or glyphosate versus untreated control. Data presented are averaged across four site-years each for kochia and wild buckwheat, and five site-years for cleavers.

	Cleavers	**Kochia**	**Wild Buckwheat**
Control	28 ± 35	596 ± 414	58 ± 38
Diquat	85 ± 35	980 ± 412	67 ± 38
Glyphosate	44 ± 35	448 ± 410	70 ± 38
P value	*0.39*	*0.33*	*0.74*

Conclusions

Seed shed of cleavers, kochia, and wild buckwheat can be predicted based on growing degree days (GDD). Cleavers and wild buckwheat began to shed seed up to a month earlier than kochia, losing 10% of their seeds at approximately 1390, compared with 1585 GDD for kochia. Kochia, however, shed a much larger number of seeds than cleavers and wild buckwheat over the course of the experiment, averaging approximately 20.5x more seed per plant. Therefore at 1390 GDD the three weed species had shed a similar number of seeds (≤55 seeds per plant), despite the fact that 99% of seeds remained on kochia plants. Delaying harvest to 1585 GDD would result in approximately 114, 792, and 78 seeds per plant added to the soil seed bank for cleavers, kochia, and wild buckwheat, respectively. This information highlights that harvesting as early as possible, with the use of chaff collection or pulverization techniques, will minimize the number of seeds returned to the weed seed bank. Early planting and/or growing early maturing varieties may aid producers in collecting more weed seeds at harvest.

There was no evidence that pre-harvest herbicide application was beneficial in preventing weed seed set, nor reducing weed seed viability. To the contrary, there appeared to be some evidence that pre-harvest herbicides encouraged shattering of mature weed seeds compared with direct harvesting. Thus farmers can save time and money by avoiding pre-harvest herbicide application, and focus instead on timely harvest to prevent problematic weeds from spreading seeds in their fields.