Tolerance of annual canarygrass (*Phalaris canariensis* L.) to combinations of MCPA, clopyralid, fluroxypyr and florasulam

W. E. May[1], E. N. Johnson[2], K. L. Sapsford[3], F. C. Stevenson[4], G. P. Lafond[†], C. B. Holzapfel[5], and F. A. Holm[3]

[1]*Agriculture and Agri-Food Canada, Indian Head Research Farm, RR#1 Gov Rd., P.O. Box 760, Indian Head, Saskatchewan, Canada S0G 2K0 (e-mail: william.may@agr.gc.ca); [2]Agriculture and Agri-Food Canada, Scott Research Farm, Box 10, Scott, Saskatchewan, Canada S0K 4A0; [3]Department of Plant Sciences, University of Saskatchewan, 51 Campus Drive, Saskatoon, Saskatchewan, Canada S7N 5A8; [4]Private Consultant, 142 Rogers Rd., Saskatoon Saskatchewan, Canada; and [5]Indian Head Agricultural Research Foundation, RR#1 Gov. Rd., Box 156, Indian Head, Saskatchewan, Canada S0G 2K0.*
Received 16 September 2013, accepted 10 December 2013, Published on the web 23 December 2013.

May, W. E., Johnson, E. N., Sapsford, K. L., Stevenson, F. C., Lafond, G. P., Holzapfel, C. B. and Holm, F. A. 2014. **Tolerance of annual canarygrass (*Phalaris canariensis* L.) to combinations of MCPA, clopyralid, fluroxypyr and florasulam**. Can. J. Plant Sci. **94**: 701–708. Annual canarygrass (*Phalaris canariensis* L.) is a cereal crop that is primarily grown on the Canadian prairies as feed for caged birds. To widen the spectrum of herbicide options for producers, two experiments were conducted with the following nine herbicide treatments (application rates in parentheses expressed as g a.i. ha^{-1}): weed-free control; single and double applications of MCPA (560) + clopyralid (100) (Curtail M); MCPA (562) + fluroxypyr (108) (Trophy); and MCPA (560) + clopyralid (100) + fluroxypyr (144) (Prestige); florasulam (5) + MCPA (420) (Frontline); difenzoquat (700) + MCPA (560) + clopyralid (100) (Avenge + Curtail M); and a single application of difenzoquat (700). Experiment 2 included the same herbicide treatments in factorial combinations with two application times; crop growth stages of two to three leaf (2–3 lf) and four to five leaf (4–5 lf). Experiments were conducted at Indian Head, Scott, and Saskatoon, SK, in 2001 to 2003. In exp. 1, difenzoquat caused up to 30% crop injury when combined with MCPA + clopyralid at the 2 × rate, but improved crop yield relative to other herbicides because it reduced yield interference from wild oat infestations at Indian Head in 2002. In exp. 2, the 2 × rate of florasulam + MCPA resulted in the greatest visual injury, with higher levels recorded at the 2–3 lf; however, seed yield reduction was greater when applied at the 4–5 lf. In summary, annual canarygrass was tolerant to combinations of MCPA, clopyralid, and fluroxypyr, herbicides which control important weed species in prairie fields.

Key words: Annual canarygrass, herbicide tolerance, crop injury, yield

May, W. E., Johnson, E. N., Sapsford, K. L., Stevenson, F. C., Lafond, G. P., Holzapfel, C. B. et Holm, F. A. 2014. **Tolérance de l'alpiste roseau (*Phalaris canariensis* L.) annuel aux mélanges de MCPA, de clopyralide, de fluroxypyr et de florasulam**. Can. J. Plant Sci. **94**: 701–708. L'alpiste roseau (*Phalaris canariensis* L.) est une céréale annuelle principalement cultivée dans les Prairies canadiennes pour servir de nourriture aux oiseaux en cage. Afin d'élargir les possibilités des producteurs en matière d'herbicides, les auteurs ont réalisé deux expériences avec les neufs traitements qui suivent (le taux d'application indiqué entre parenthèses est exprimé en grammes de matière active par hectare) : parcelle témoin désherbée, application simple et double de MCPA (560) + clopyralide (100) (Curtail M), de MCPA (562) + fluroxypyr (108) (Trophy), de MCPA (560) + clopyralide (100) + fluroxypyr (144) (Prestige), de florasulam (5) + MCPA (420) (Frontline), de difenzoquat (700) + MCPA (560) + clopyralide (100) (Avenge + Curtail M), et application simple de difenzoquat (700). La deuxième expérience supposait l'application du même herbicide en combinaison factorielle avec deux moments d'application, soit les stades de croissance des 2–3 feuilles et des 4–5 feuilles. Ces expériences se sont déroulées à Indian Head, à Scott et à Saskatoon, en Saskatchewan, de 2001 à 2003. Lors de la première expérience, le difenzoquat a causé jusqu'à 30 % de dommages à la culture quand il était combiné à du MCPA + clopyralide et appliqué à deux reprises, mais la culture a donné un meilleur rendement que celui obtenu avec les autres herbicides, le traitement ayant atténué les effets d'une infestation de folle avoine à Indian Head, en 2002. Dans la deuxième expérience, la double application de florasulam + MCPA a donné lieu aux plus grands dommages visibles, les plus importants étant survenus au stade des 2–3 feuilles; malgré cela, la baisse de rendement est plus élevée quand l'application survient au stade des 4–5 feuilles. En résumé, l'alpiste roseau annuel tolère les mélanges contenant du MCPA, du clopyralide et du fluroxypyr, herbicides qui combattent d'importantes adventices dans les Prairies.

Mots clés: Alpiste roseau annuel, tolérance aux herbicides, dommages aux cultures, rendement

[†]*Deceased.*

Abbreviations: **DAA**, days after application; **2–3 lf**, two- to three-leaf stage; **4–5 lf**, four- to five- leaf stage; **1 × and 2 × rates**, label recommended rate and twice the label recommended rate

Canada produces about 70% of the world's annual canarygrass or canaryseed (*Phalaris canariensis* L.), a crop primarily used for caged bird feed. Canadian production is mainly in Saskatchewan (FAOSTAT 2013); seeded acreage of annual canarygrass has ranged from 87 000 to 332 000 ha over the past 20 yr, which represented 89 to 98% of the production in Canada (Saskatchewan Ministry of Agriculture 2012).

Annual canarygrass was first evaluated as a hay crop and as a grain crop in the early 1900s at Indian Head, SK (MacKay 1897, 1907). Since its introduction, annual canarygrass has become an important alternative cereal crop to durum wheat [*Triticum turgidum* L. ssp. durum (Desf.) Husn.] and spring wheat (*Triticum aestivum* L.) because it allows Saskatchewan growers to diversify rotations and spread economic risk because the sale price of annual canarygrass tends to fluctuate independently of other cereal crops.

A set of best management practices including seeding date, seeding rate, seeding method, cultivar selection, fertility, disease management and weed management, is needed for annual canarygrass producers on the Canadian prairies. To address this need, May et al. (2012a, b, 2013) recently conducted a series of studies to determine the optimal seeding date, seeding rate, N and Cl fertilizer rate for annual canarygrass. These studies found that seeding on or before May 15, applying at least 9 kg Cl ha^{-1} and applying a fungicide at flag leaf increased the yield of annual canarygrass yield. In addition, 40 kg N ha^{-1} and a seeding rate of 35 kg ha^{-1} is recommended. Another area of annual canarygrass research requiring further attention is limited weed control options. Holt and Hunter (1987) was the first study in Saskatchewan to address the need for more information regarding herbicide options for annual canarygrass. They reported that annual canarygrass yields were reduced from the competitive effects of wild mustard (*Sinapis arvensis* L.), cow cockle (*Vaccaria pyramidata* Medik.), and wild oats (*Avena fatua* L.). These authors also reported excellent tolerance to bromoxynil, bromoxynil plus MCPA, linuron plus MCPA, propanil plus MCPA, and metribuzin plus MCPA. Moreover, broadleaf weed control from these herbicides allowed yields to be similar to that for the weed-free control. Graminicides such as difenzoquat provided acceptable levels of wild oat control (1 of 2 yr) and annual canarygrass tolerance (both years).

Herbicide options for annual canarygrass are limited to broadleaf weed control with combinations of MCPA with bromoxynil or dicamba. It is recognized that increased acreage of annual canarygrass will at least partly depend on improving the weed management package for producers. However, no recent studies have been conducted with newer annual canarygrass cultivars grown in no-till production systems on the Canadian prairies with the current spectrum of problematic weed species such as cleavers (*Galium aparine* L.), kochia [*Kochia scoparia* (L.) Roth] or Canada thistle [*Cirsium arvense* (L.) Scop.]. Therefore, research was undertaken to investigate the tolerance of a newer annual canarygrass cultivar to combinations of difenzoquat, MCPA, clopyralid, fluroxypyr, and florasulam.

MATERIALS AND METHODS

Site Description and Experimental Design

Two field experiments were conducted at Indian Head, Saskatoon, and Scott over a 3-yr period (2001 to 2003) to investigate herbicide options for annual canarygrass. These sites are located in or close to the regions where annual canarygrass is currently grown in Saskatchewan. The study sites were located on a new field each year that had been previously cropped to canola at Indian Head or chem-fallowed at Saskatoon and Scott. Soil types at the three locations were as follows: Indian Head heavy clay at Indian Head (16% sand, 20% silt, 63% clay, organic matter 4.0% and pH 7.5), Sutherland clay (10% sand, 40% silt, 50% clay, organic matter 4.5% and pH 7.5) at Saskatoon, and Elstow loam soil (31% sand, 42% silt, 37% clay, organic matter 3.5% and pH 6.0) at Scott. Environmental conditions at the sites are summarized in Table 1.

Both experiments were single factor experiments conducted as a randomized complete block design with four replications. Plot size was 7.6×4.0 m at Indian Head, 6.0×2.25 m at Saskatoon and 5.0×2.0 m at Scott. The first experiment was conducted at Indian Head, Scott and Melfort, SK, in 2001, and 2002. The treatment design for the first experiment included a weed-free check, an application of difenzoquat at the label rate (700 g a.i. ha^{-1}), and the following herbicide combinations applied at the label ($1\times$) and double the label rates ($2\times$): MCPA (560 g a.i. ha^{-1}) + clopyralid (100 g a.i. ha^{-1}); MCPA (562 g a.i. ha^{-1}) + fluroxypyr (108 g a.i. ha^{-1}); and MCPA (560 g a.i. ha^{-1}) + clopyralid (100 g a.i. ha^{-1}) + fluroxypyr (144 g a.i. ha^{-1}); florasulam (5 g a.i. ha^{-1}) + MCPA (420 g a.i. ha^{-1}); and difenzoquat (700 g a.i. ha^{-1}) + MCPA (560 g a.i. ha^{-1}) + clopyralid (100 g a.i. ha^{-1}). The second experiment was conducted at Indian Head, Scott and Melfort, SK, in 2003. The treatment design for this experiment included a factorial arrangement of time of application [two to three leaf (2–3 lf); and four to five leaf (4–5 lf)] with the same herbicide combinations for the first experiment along with recommended and double applications of MCPA (280 g a.i. ha^{-1}) + bromoxynil (280 g a.i. ha^{-1}) as an industry standard.

For both experiments, annual canarygrass was sown and managed using no-till production practices. Glyphosate was applied to control emerged weeds before seeding. Plots were sown with a no-till drill equipped with a knife opener with row widths of 30, 22, and 25 cm apart at Indian Head, Saskatoon and Scott, respectively. The canaryseed (cv. CDC Maria, Hucl et al. 2001) was sown at a rate of 35 kg ha^{-1} in May. Each site was soil sampled to a depth of 60 cm for nitrogen and 15 cm for

Table 1. Summary of climatic conditions at Indian Head, Saskatoon and Scott, Saskatchewan in 2001–2003

	Precipitation							Temperature					
	April	May	June	July	August		% of 30-yr	April	May	June	July	August	% of 30-yr
Location/year	(mm)					5-mo total	average	(°C)					average
Indian Head													
2001	8	21	28	42	12	111	40	2.9	11.3	14.7	18	18.8	97
2002	20	18	115	49	98	300	107	0.6	7.1	15.8	18.6	15.7	85
2003	55	24	18	23	11	131	47	4.3	11.4	15.5	18.6	19.5	103
30-yr average	25	56	79	67	53			4	11.4	16.1	18.4	17.5	
Scott													
2001	17	36	49	40	3	144	64	3.9	11.5	13.8	17.9	18.9	108
2002	6	3	69	32	42	151	67	−0.7	8.3	16.3	19.1	15.6	96
2003	24	22	34	66	44	190	85	4.4	10.7	14.5	17.8	19.8	110
30-yr average	23	36	61	61	44	224		3.1	10.2	14.5	17.1	16.2	
Saskatoon													
2001	15	24	40	59	8	146	62	4.5	12.4	15.3	21.2	20.4	109
2002	13	0	73	67	83	236	100	0.0	11.0	16.6	19.9	15.9	92
2003	0	9	31	44	31	115	49	5.4	12.1	16.0	18.9	20.9	108

phosphorus, potassium and sulphur. Nitrogen fertilizer was applied at a rate so that a total of 80 kg ha^{-1} of nitrate was available; N fertilizer rate plus soil test estimate of residual soil nitrate (0–60 cm soil layer). Phosphorus, potassium and sulphur fertilizers were applied during seeding operations according to soil test recommendations (ALS Laboratory Services, Saskatoon, SK). The herbicides were applied using a tractor sprayer, equipped with 110015 pre orifice nozzels (Airmix) with a pressure of 275 kPa. The sprayers were calibrated to deliver a carrier volume of 111 L ha^{-1} at Indian Head and 100 L ha^{-1} at Scott and Saskatoon.

Variables Measured

Crop tolerance to the herbicide combinations was assessed as a visual assessment of affected leaf area on a percentage basis for both experiments. Injury rating assessments were made at 7 and 40 d after application (DAA) for the first experiment and at 7, 20 and 40 DAA for the second experiment. The rating scale ranged from 0 to 100, with 0 for no injury and 100 causing complete death of the crop. Grain was cleaned and yield was expressed on a clean seed basis at 13% seed moisture content.

Statistical Analysis

Data from both experiments were separately analyzed with the GLIMMIX procedure of SAS software (Littell et al. 2006). The effect of replicate was considered random, and the effects of site (location by year combinations), stage of growth (second experiment only), and herbicide treatments were considered fixed. Yield data from both experiments and injury data from the second experiment were analyzed with a Gaussian error distribution. These analyses with Gaussian error distribution also accounted for heterogeneous residual variances among sites; a corrected Akaike's information criterion confirmed benefit of modeling variance heterogeneity. Differences of the means between the treatments and the weed-free checks for yield and crop injury (second experiment) were summarized using diffograms (Schaarschmidt and Vaas 2009).

Because some treatments had no observable crop injury and zero ratings were observed for treatments with injury, the 7 and 40 DAA injury data for the first experiment were analyzed for those treatments with notable levels of injury using a multinomial error distribution, which can handle data with numerous zeroes and responses that are more discrete rather than continuous. The results from this analysis, along with a summary of injury occurrences for other treatments, were used to assess crop tolerance from the first experiment.

RESULTS

The precipitation was below average, ranging from 40 to 85% of the 30-yr average, except at Indian Head and Saskatoon in 2002 (Table 1). The temperature was within 10% of the 30-yr average at all sites except Indian Head in 2002 (85%).

In exp. 1, the herbicide treatment by site interaction was significant for grain yield ($P < 0.001$), but not for crop injury. In exp. 2, the stage by treatment and site by stage by treatment interactions ($P < 0.001$) occurred for all annual canarygrass injury responses. Despite significant site interactions, treatment effects were generally similar across sites and the data were presented with the sites combined. For grain yield the site by stage by treatment interaction ($P = 0.304$) was not significant. Also, the stage × treatment interaction was not significant ($P = 0.438$); however, several preplanned contrasts were significant and the interaction was presented.

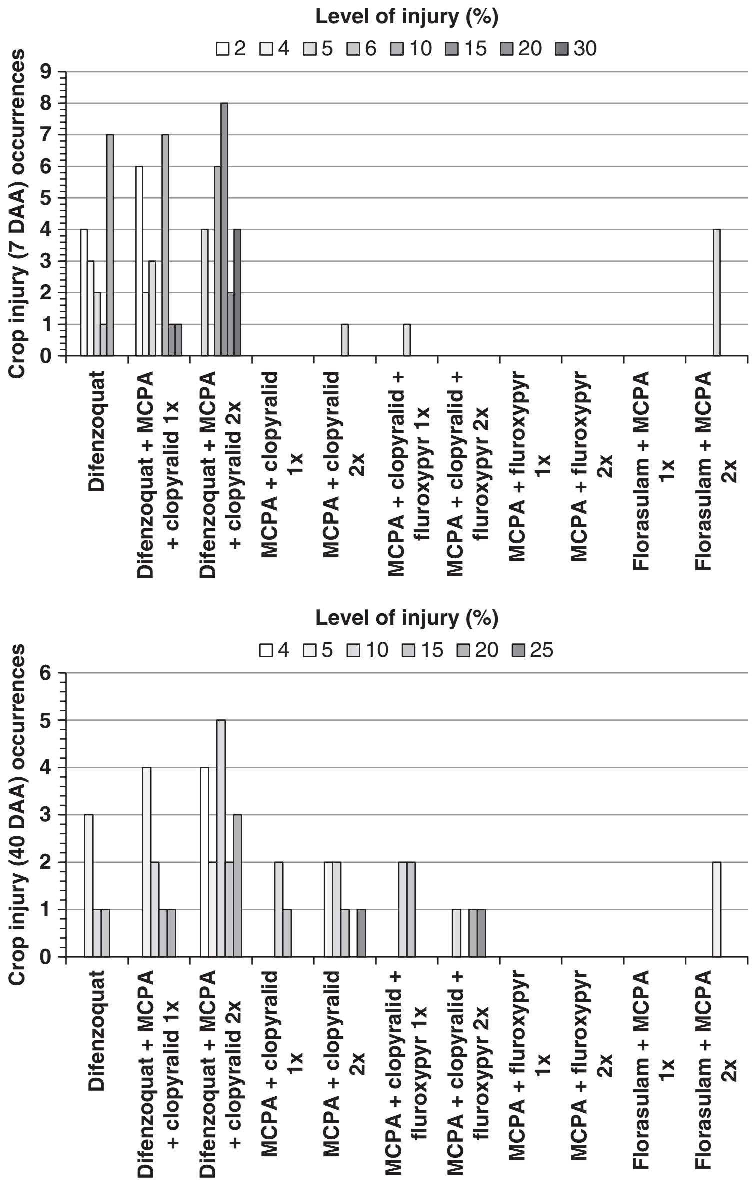

Fig. 1. Occurrences of different levels of injury on annual canarygrass from herbicide treatments at Indian Head, Saskatoon and Scott, SK, in 2001 and 2002. The legend across the top of each chart represents the levels of injury that were recorded.

Experiment 1 – Herbicide Treatments

Visual crop injury was not evident in exp. 1 for a number of the treatments (Fig. 1). The difenzoquat treatments, as a whole, often had more visible annual canarygrass injury, than the other treatments (Fig. 1). Difenzoquat more frequently caused greater levels of injury 7 DAA when applied with MCPA + clopyralid at the 2 × rate than when applied alone (Table 2 and Fig. 1). At 40 DAA this difference between Difenzoquat and Difenzoquat (1 ×) + MCPA (2 ×) + clopyralid (2 ×) was no longer significant (Table 2). The same difference did not occur when MCPA + clopyralid was applied at the 1 × rate and measure at 7 or 40 DAA. The analysis also indicated that crop injury response either 7 or 40 DAA did not vary among sites (location by year combinations) (Table 2).

Annual canarygrass yield differed among herbicide treatments ($P < 0.001$) and the herbicide treatment effects also differed among sites (site by herbicide treatment interaction: $P < 0.001$). The yield diffogram summarized differences for the treatment relative to weed-free control for each site (Fig. 2). The herbicide treatments had no negative effect on yield compared with the weed-free control at Indian Head in 2001, Saskatoon in 2002 and Scott in 2001. The MCPA + clopyralid + fluroxypyr, MCPA + clopyralid, and MCPA + fluroxypyr treatments

Table 2. Analysis of variance for injury data collected at Indian Head, Saskatoon and Scott, SK, in 2001 and 2002

Effect/contrast	7 DAA	40 DAA
	(*P* value)	
Site	0.013	0.011
Treatment	<0.001	1.000
Difenzoquat vs. Difenzoquat + MCPA + clopyralid 1 ×	0.740	1.000
Difenzoquat vs. Difenzoquat + MCPA + clopyralid 2 ×	<0.001	0.996
Site × Treatment	0.148	0.819

(1 × or 2 ×) caused a yield reduction of about 100–200 kg ha^{-1} at Saskatoon 2001 (does not include MCPA + fluroxypyr treatment) and Scott 2002, or a yield reduction of about 500 kg ha^{-1} at Indian Head in 2002 (Fig. 2). At Scott in 2002 the annual canarygrass received only 67% of the 30-yr average for precipitation with only 9 mm falling in April and May which contributed to the severely reduced yield (Table 1). At Indian Head there was a flush of wild oats that was only controlled in the weed-free control and the treatments that received difenzoquat. Difenzoquat alone or mixed with MCPA + clopyralid generally had yields similar to the weed-free control. In fact, there were a couple of instances where difenzoquat alone or tank-mixed with MCPA + clopyralid increased yield notably (200–300 kg ha^{-1}) relative to the weed-free control.

Experiment 2 – Herbicide Treatments and Stage of Application

Statistically significant ($P < 0.001$) stage of application by treatment interactions occurred for all canaryseed visible injury rating variables assessed in the second experiment. Injury of 5 to 20% (significantly different from weed-free control) occurred 7 DAA and 20 DAA when difenzoquat (alone and tank-mixed) and florasulam + MCPA was applied when the canaryseed was at 2–3 lf (Fig. 3). The same differences often were either not significant or less apparent with later applications, especially for either rate of florasulam + MCPA. One exception to the preceding occurred when difenzoquat was applied alone, which resulted in about 5% more visible injury than the weed-free control regardless of the time of application. Significantly more visible injury occurred for difenzoquat + MCPA + clopyralid 2 × and florasulam + MCPA (1 × or 2 ×) relative to weed-free control 40 DAA (Fig. 3). Annual canarygrass injury at 40 DAA followed a similar trend as injury ratings taken 7 DAA with greater injury when application occurred at the earlier growth stage compared with the later growth stage.

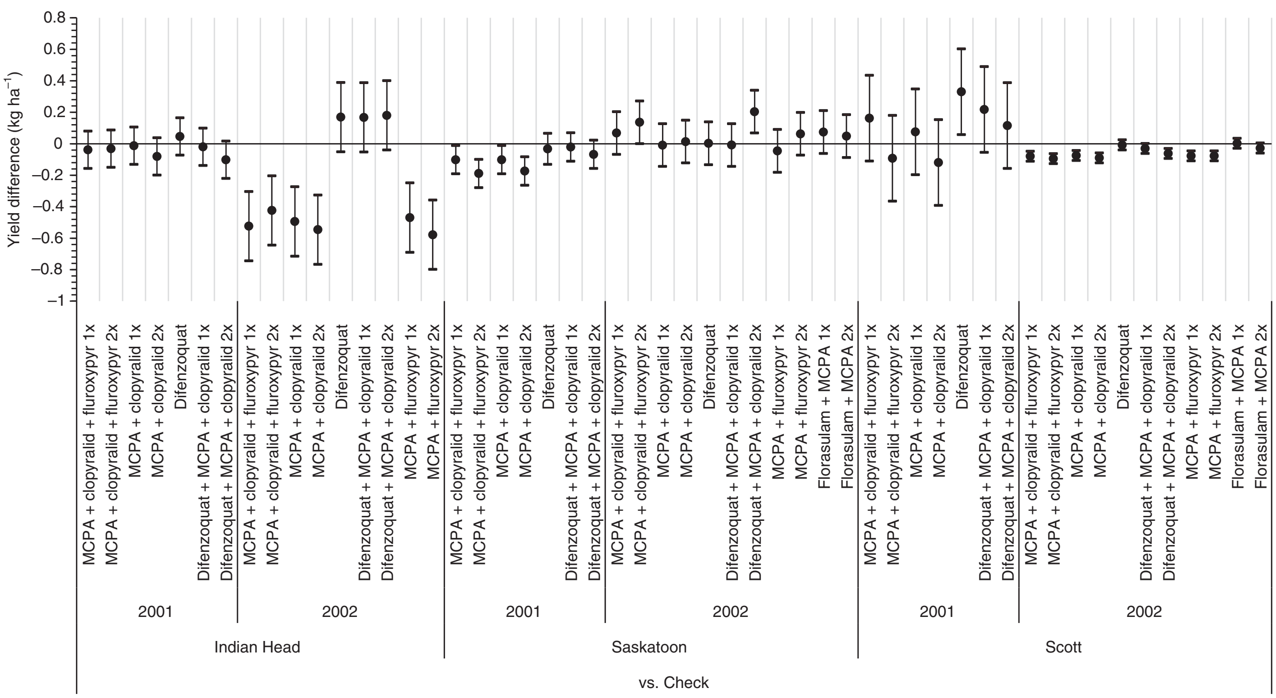

Fig. 2. The effect of herbicide treatments and stage of application on visual injury at Indian Head, Saskatoon and Scott, SK, in 2001 and 2002 Points in each chart represent mean differences for each treatment relative to the weed-free control. The sign of difference reflects direction of mean difference. Error bars represent confidence intervals for differences stated on the Y axis. Confidences intervals not including zero indicate statistically significant differences (α = 0.05).

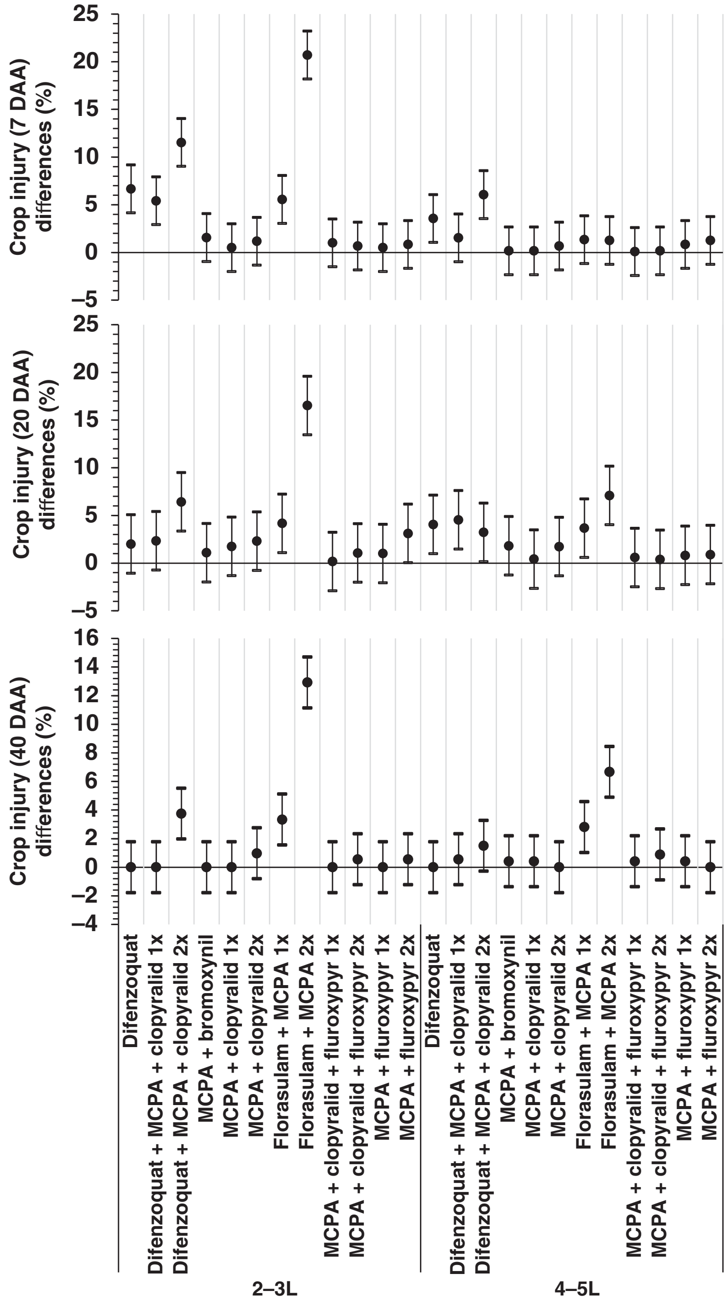

Fig. 3. The effect of herbicide treatments and stage of application on visual injury at Indian Head, Saskatoon and Scott, SK, in 2003. Points in each chart represent mean differences for each treatment relative to the weed-free control. The sign of difference reflects direction of mean difference. Error bars represent confidence intervals for differences stated on the Y axis. Confidences intervals not including zero indicate statistically significant differences ($\alpha = 0.05$).

Site by stage by treatment interactions ($P < 0.001$) occurred for all annual canarygrass injury responses. Despite site interactions, treatment effects were generally similar across sites with the following exceptions: (1) herbicide treatment effects did not occur for 7, 20, and 40 DAA injury responses when applications occurred at the later growth stage at Scott in 2003; and (2) herbicide treatment injury effects did not occur for 20, and 40 DAA when applications occurred at the later stage at Indian Head in 2003.

Analysis of variance results indicated the annual canarygrass yield did not respond to herbicide treatments ($P > 0.172$), regardless of the stage of application and site. Unprotected F tests using contrasts summarized in the yield diffogram indicated that 2 $\times$ applications applied at the 4–5 lf stage vs. weed-free control often resulted in a yield loss of about 200 kg ha^{-1} when averaged across all sites (Fig. 4).

DISCUSSION

An objective of this study was to identify in-crop herbicide options that provide adequate control of weeds species commonly occurring in no-till production systems (e.g., cleavers and Canada thistle), and that annual canarygrass was tolerant to. Although Holt and Hunter (1987) tested older chemistries, their results are similar with ours, that annual canarygrass shows reasonable tolerance to a broad spectrum of broadleaf herbicides. In this study annual canarygrass had good tolerance to combinations of MCPA, clopyralid and fluroxypyr. This is of particular interest because these herbicide combinations can control problematic weeds species such as cleavers, Canada thistle, or kochia.

Annual canarygrass injury was most evident in both experiments closer to the time of application and when herbicides were applied at earlier growth stages. Florasulam and to a lesser extent difenzoquat were the only herbicides that caused visual injury that could be observed through a large portion of the growing season, particularly when applied at 2 × rate and applied at the 2–3 lf vs. 4–5 lf growth stage of annual canarygrass. However, diminishing injury with time for all herbicides indicates that annual canarygrass has the ability to compensate for injury earlier in the growing season. Annual canarygrass has the potential to produce tillers later in the growing season if environmental conditions are conducive; this may account for canaryseed's ability to recover from early-season herbicide injury. One thing that needs to be considered is that later herbicide applications increases the amount of time that weeds can interfere with crop growth and adversely affect crop yield (Harker et al. 2001). Therefore, earlier applications may be beneficial under situations where weed pressure is greater.

Interestingly the greater crop injury that was observed at the 2–3 lf stage did not translate in to a decrease in yield. In fact the opposite occurred, the 2 × rates at the 4–5 lf stage tended to decrease seed yield. These results indicate that spray overlaps in the field may negatively impact yield; however, this impact on areas where overlap occurs is minor compared with the yield losses that can be inflicted by uncontrolled weeds such as Canada thistle (Donald and Khan 1996).

Yield results for difenzoquat suggest that the slightly comprised crop tolerance associated with difenzoquat applications were less important than the negative competitive effects of uncontrolled wild oats when difenzoquat was not applied. This was particularly evident in the first experiment at Indian Head in 2002, where wild oat infestations were greater than at other sites and were associated with annual canarygrass yield

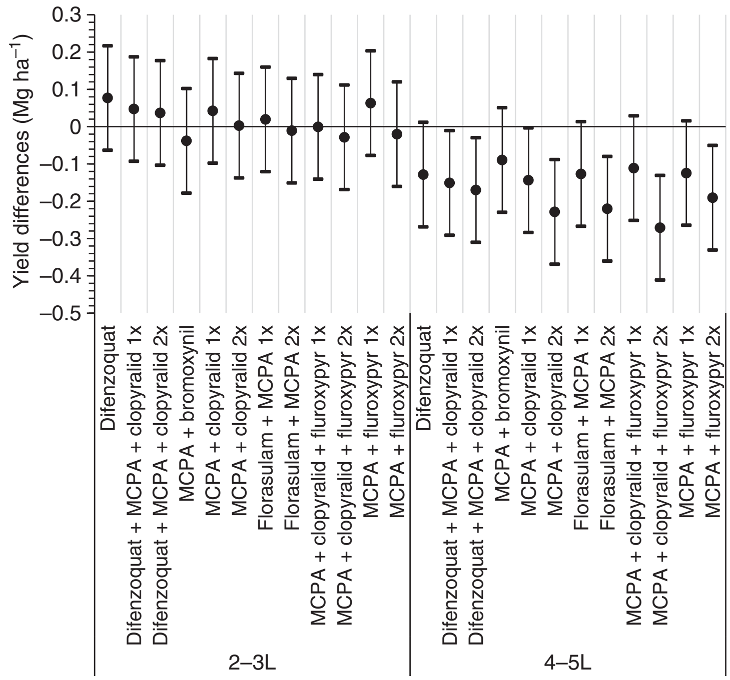

Fig. 4. The effect of herbicide treatments and stage of application on yield differences at Indian Head, Saskatoon and Scott, SK, in 2003. Points in each chart represent mean differences for each treatment relative to the weed-free control. The sign of difference reflects direction of mean difference. Error bars represent confidence intervals for differences stated on the Y axis. Confidences intervals not including zero indicate statistically significant differences ($\alpha = 0.05$).

reductions. Therefore, canaryseed growers would benefit from an in-crop application of difenzoquat to control wild oat if a dense infestation of wild oat was not controlled by a pre-plant application of triallate, because annual canarygrass yield loss from wild oats can be quite high (Holt and Hunter 1987).

In summary, annual canarygrass showed tolerance to most herbicides, except florasulam. Moreover, weed control options generally were not associated with injury-related yield loss, but greater than recommended herbicide rates can negatively affect annual canarygrass yield. Our results indicate that slight injury from herbicide is less important than ensuring that the herbicides chosen control the expected weed spectrum and concomitant yield loss. In conclusion, canaryseed is tolerant to herbicides combinations of MCPA, clopyralid and fluroxypyr that provide excellent control of several problematic weed species.

ACKNOWLEDGEMENTS

The technical support of Roger Geremia, Orla Willoughby and Steve Kopp at the Indian Head Research Farm and Herb Schell, and Cindy Gampe at the Scott Research Farm, and Gerry Stuber at the University of Saskatchewan.

Donald, W. W. and Khan, M. 1996. Canada thistle (*Cirsium arvense*) effects on yield components of spring wheat (*Triticum aestivum*). Weed Sci. **44**: 114–121.

FAOSTAT. 2013. Food and Agriculture Organization of the United Nations. [Online] Available: http://faostat3.fao.org/ [2013 Nov. 03].

Harker, K. N., Blackshaw, R. E. and Clayton, G. W. 2001. Timing weed removal in field pea (*Pisum sativum*). Weed Technol. **15**: 277–283.

Holt, N. W. and Hunter, J. H. 1987. Annual canarygrass (*Phalaris canariensis*) tolerance and weed control following herbicide application. Weed Sci. **35**: 673–677.

Hucl, P., Matus-Cadiz, M., Vandenberg, A., Sosulski, F. W., Abdel-Aal, E. S. M., Hughes, G. R. and Slinkard, A. E. 2001. CDC Maria annual canarygrass. Can. J. Plant Sci. **81**: 115–116.

Littell, R. C., Milliken, G. A., Stroup, W. W. and Wolfinger, R. D. 2006. SAS system for mixed models. 2nd ed. SAS Institute, Inc., Cary NC. 813 pp.

MacKay, A. 1897. Experimental farm for the North-West Territories. Page 378 *in* Experimental farms reports for 1896. Ministry of Agriculture, Government of Canada, Ottawa, ON.

MacKay, A. 1907. Experimental farm for Saskatchewan. Pages 338–375 *in* Experimental farms reports for 1906. Ministry of Agriculture, Government of Canada, Ottawa, ON.

May, W. E., Lafond, G. P., Gan, Y., Hucl, P., Holzapfel, C. B., Johnston, A. and Stevenson, C. 2012a. Yield variability in *Phalaris canariensis* L. due to seeding date, seeding rate and nitrogen fertilizer. Can. J. Plant Sci. **92**: 651–669.

May, W. E., Malhi, S. S., Holzapfel, C. B., Nybo, B. X., Schoenau, J. J. and Lafond, G. P. 2012b. The effects of chloride and potassium nutrition on seed yield of annual canarygrass. Agron. J. **104**: 1023–1031.

May, W. E., Holzapfel, C. B., Lafond, G. P. and Schoenau, J. J. 2013. Does the presence of the gene for glabrous hull in annual canarygrass affect the response to chloride fertilizer? Can. J. Plant Sci. **93**: 109–118.

Saskatchewan Ministry of Agriculture. 2012. Agricultural statistics. [Online] Available: http://www.agr.gov.sk.ca/Statistics-Crops [2013 Nov. 03].

Schaarschmidt, F. and Vaas, L. 2009. Analysis of trials with complex treatment structure using multiple contrast tests. HortScience **44**: 188–195.