What is the Cost to Manage Herbicide-Resistant Wild Oat and Green Foxtail?

Hugh J. Beckie[1], A. Gordon Thomas[1], Anne Légère[2], David J. Kelner[3], Rene C. Van Acker[4], and Scott Meers[5]

[1]Saskatoon Research Centre, Agriculture and Agri-Food Canada, 107 Science Place, Saskatoon, SK, S7N 0X2; [2]Soils and Crops Research and Development Centre, Agriculture and Agri-Food Canada, 2560 Hochelaga Boulevard, Sainte-Foy, QC, G1V 2J3; [3]Westco, Rosser, MB, R0H 1E0; [4]Department of Plant Science, University of Manitoba, Winnipeg, MB, R3T 2N2; and [5]Alberta Agriculture, Food and Rural Development, 280B Ridge Road, Strathmore, AB, T1P 1B6

Extent of Herbicide-Resistant Grass Weeds in the Prairies

Wild oat (*Avena fatua* L.) and green foxtail (*Setaria viridis* [L.] Beauv.) are the two most abundant weeds in the prairies. Surveys were conducted across Alberta, Saskatchewan, and Manitoba in 1996 and 1997 to determine the nature and occurrence of herbicide-resistant (R) biotypes of these species (Beckie et al. 1998 a, b; Beckie and Juras 1998). The surveys indicated that resistance in these two species to Group-1 herbicides (refer to Guide to Crop Protection for classification of herbicide by group number) occurred most frequently relative to other herbicide groups. Group 1-R wild oat occurred in over one-half of fields surveyed in each of the provinces and in over one-half of Saskatchewan elevators. Group 2-R and 8-R wild oat each occurred in about 20% of fields surveyed in the three provinces and elevators surveyed in Saskatchewan; Group 25-R wild oat occurred in about 20% of Manitoba fields. Of particular concern was the relatively high incidence of multiple group resistance in wild oat in Saskatchewan and Manitoba. In Saskatchewan, 18% of Group 1-R populations were also resistant to Group-2 herbicides (imidazolinones), even though these herbicides were not frequently used. In Manitoba, 27% of fields surveyed had wild oat resistant to herbicides from more than one group. Four populations were resistant to all herbicides registered for use in wheat. Twenty-eight percent of fields surveyed in Saskatchewan have Group 1- or 3-R green foxtail. The objective of this paper is to determine the cost to the producer in managing R wild oat and green foxtail in annual crops.

Cost of Managing Herbicide-Resistant Wild Oat and Green Foxtail

In estimating the cost of managing R wild oat or green foxtail populations, it was assumed that once resistance developed to one or more herbicides in a group, the producer would discontinue use of all herbicides in that group because of the likelihood of cross resistance. It was further assumed that the producer would use a substitute product that would provide the most cost-effective control of the R population. The cost of application of preemergence (PRE) and postemergence (POST) herbicides was assumed to be similar, since equipment varies between producers. Cost estimates of using these alternative herbicides were calculated for the most frequent-occurring biotypes of wild oat or green foxtail resistant to a single herbicide group or to multiple herbicide groups. Cost scenarios were developed for production of the top five crops grown in the prairies (in decreasing order, oats excluded): spring wheat, barley, canola, flax, and field pea. Cultural weed control practices used by the

producer prior to resistance development and post-resistance management were fixed, because of difficulty in estimating the economic impact of one or more of these practices on weed control efficacy in the different crops. In managing R weed populations, producers usually seek alternative herbicides before changing their cultural practices, which by themselves may not provide consistently effective weed management (Kirkland and Beckie 1998).

Alternative herbicides and associated costs for controlling R biotypes of wild oat and green foxtail in the top five crops grown in the prairies are listed in Table 1. Of the 70 M acres planted to annual crops in the prairies in 1996, 42% were sown to wheat, 17% to barley, 12% to canola, and 2% to flax and field pea each (Anonymous 1997a,1997b, 1997c). In total, 75% of cropped land was sown to these five crops that year. For control of Group 1-R wild oat in cereals, Assert or Avadex would not increase the cost to the producer; Avenge would increase costs by $1.43/ac compared to the average cost of Group-1 products (Mataven is currently not available to producers). Trifluralin would increase costs to barley producers by $0.81/ac. This product, like Edge, is not registered for use in minimum- or zero-till systems, which comprise 32 and 16%, respectively, of cropped land in the prairies (Anonymous 1997a, 1997b, 1997c). For canola producers, all alternative options would increase costs in controlling Group 1-R wild oat, with trifluralin as the least expensive PRE product (+$1.95/ac) and Liberty as the least expensive POST product (+$4.44/ac). Herbicide-resistant (HR) canola varieties currently occupy about 50% of the total canola acreage in the prairies, with Group 2-HR canola comprising 50% of that (K. Downey, per. comm.). Seed costs of HR varieties are similar or higher than non-HR varieties, depending on type and seed availability. The PRE herbicides trifluralin and Avadex would cost flax producers with Group 1-R wild oat an extra $1.95 and $3.28/ac, respectively. In field pea, all alternative herbicides would increase costs, with Avadex as the least expensive PRE herbicide and Pursuit as the least expensive alternative POST herbicide. However, some of the alternative herbicides for control of Group 1-R wild oat, such as Edge and Pursuit, have activity on one or more broadleaf weed species. Thus, the product's spectrum of weed control must be considered by the producer in comparing total weed control costs. The alternative herbicide chosen by the producer may not be the least expensive in controlling R wild oat, but rather one that also controls those broadleaf weed species present in the particular field. Based on occurrence of Group 1-R wild oat in Saskatchewan (6 M ac), which has one-half of all cultivated land in the prairies, the cost of managing these populations with the least expensive alternative herbicide in canola, flax, and field pea is estimated to be $1.8 M annually. In Manitoba where 3 M ac are estimated to have Group 1-R wild oat based on the survey detailed herein and past surveys (Bourgeois and Morrison 1997, Bourgeois et al. 1997), the annual cost of managing these populations is estimated at $1.1 M.

For producers with Group 8-R wild oat, cost of many alternative herbicides, particularly those used in broadleaf crops, would not be higher than Avadex (least expensive ineffective herbicide). For producers with wild oat resistant to Group-1 and -2 herbicides or Group-1, -2, and -25 herbicides, all alternative herbicides would cost more than the least expensive ineffective herbicide. Avadex would be the least expensive option in cereal crops and field pea, whereas trifluralin would be the least expensive option in canola and flax. Based on occurrence of Group 1- and 2-R wild oat in Saskatchewan (1.1 M ac), the cost of managing these populations with the least expensive alternative herbicide in these five crops grown in

the province is estimated to be $0.9 M annually. For producers with wild oat populations resistant to Groups 1, 2, 8, and 25, no options are available in wheat. A wild oat density of 10 per m^2, which is the mean density in occurrence fields in the prairies, can reduce wheat yields by 10% (Anonymous 1998). All alternative herbicides available for use in the other crops would cost significantly more than the least expensive ineffective herbicide.

Control of Group 1-R green foxtail in wheat, barley, and flax, using the least expensive alternative herbicide, would not increase costs to the producer (Table 1). However, control of Group 1-R populations in canola and field pea would cost an additional $1.95/ac using trifluralin. Based on occurrence of Group 1-R green foxtail in Saskatchewan (2.5 M ac), the cost of managing these populations with the least expensive alternative herbicide in canola and field pea in the province is estimated to be $0.7 M annually. Control of Group 3-R green foxtail in wheat would markedly increase costs compared to trifluralin, although lower cost options are available in the other crops. Control of multiple-R green foxtail (Groups 1 and 3) would increase costs in wheat, canola, and field pea. Using Stampede would not increase costs to barley or flax producers with these multiple-R populations. Fortunately, the incidence of multiple-R green foxtail in Saskatchewan is low. However, based on the frequency of occurrence of Group 3-R green foxtail in Manitoba (Goodwin 1994) and the prominent use of Group-1 products to control these populations, occurrence of multiple-R green foxtail in Manitoba is likely higher than in Saskatchewan.

The number of alternative herbicide groups available to manage R biotypes is equally as important as the relative cost of alternative herbicides. Stampede for use in barley and flax and Group-2 products for use in field pea are the only remaining alternative herbicides for control of Group 1- and 3-R green foxtail. Only Group-8 products remain effective for control of wild oat resistant to herbicides from Groups 1, 2, and 25 in wheat. Similarly dinitroanilines (Group 3) are the only herbicide group remaining for control of Group 1-, 2-, 8-, and 25-R wild oat in barley, flax, and field pea. The occurrence of wild oat biotypes resistant to herbicides from four groups indicates that multiple resistance in wild oat can restrict crop rotations, which may impact on the sustainability of these cropping systems. Producers having zero-till cropping systems with populations with this pattern of multiple resistance would not be able to use dinitroanilines, since they are not registered for use in this tillage regime. In zero-till systems, Roundup- or Liberty-HR canola is the only annual crop in which a herbicide is available to control these R populations. Because of disease incidence and severity, the recommended cropping frequency of canola in the rotation is once every four years. Producers with wild oat resistant to these four herbicide groups have been forced to change their cropping systems. For example, they have increased the frequency of Roundup- or Liberty-HR canola and forages in their rotations and have increased the use of glyphosate for non-selective weed control prior to spring planting. Future introduction of other HR crops will assist these producers in sustaining the productivity of their cropping systems, provided that the herbicides used in these crops are managed judiciously to maintain their effectiveness.

Integration of cultural practices with judicious herbicide use to manage R wild oat or green foxtail populations offers producers the greatest potential to sustain their cropping systems. An important cultural weed management tool is crop rotation, such as alternating broadleaf and cereal annual crops or including perennial crops. However, crop rotation must be accompanied by proper herbicide-group rotation. In the Saskatchewan field survey in 1996,

the level of diversity of cereal and broadleaf annual crops in the rotation did not reduce the producer's risk of having Group 1-R wild oat, because Group-1 herbicides were frequently used in both types of crops (Beckie et al. 1998b). Other tools to favor the crop at the expense of R weeds include precision fertilizer placement (e.g. banding), increased crop seeding rates (particularly cereals), and varied seeding dates. Rather than increasing production costs for the producer, these practices can increase net returns and income stability (Campbell et al. 1990; Blackshaw 1997). The greatest obstacle to adoption of these cultural practices, however, remains the consistency of their effectiveness in reducing the impact of weeds on crop yield and quality (Kirkland and Beckie 1998). By using as many of these cultural weed management practices in the cropping system as possible, the producer has the best chance of being able to capitalize on potential synergies among them and may be able to reduce the total amount of herbicide inputs over a period of time without adversely affecting crop yield and quality and without replenishing the seed bank. In addition to using cultural practices at the time of seeding to help manage R-weed infestations over large areas of the field, producers should scout their fields during the growing season for suspicious R weed patches at early stages of development. Over 90% of Saskatchewan producers do not realize they have R weeds in their fields (Beckie et al. 1998b). If an R patch can be detected early, the area can be managed separately from other areas of the field. Preventing seed production within these patches by application of non-selective herbicides, mowing, or tillage may contain the spread of seed throughout the field, primarily by harvesting or tillage equipment. Containing and managing an R patch at an early stage of development when it occupies a small area may be more economical than managing an R weed infestation across an entire field or farm.

Conclusion

Depending on the type of resistance in grass weeds, alternative herbicides available for their control may substantially increase costs to the producer. The cost to producers of managing R wild oat and green foxtail in annual crops in Saskatchewan and Manitoba using alternative herbicides is estimated at over $4 M annually. For some R biotypes, alternative herbicides either are not available or all have the same mode of action, which restricts crop or herbicide rotation options and threatens the future sustainability of annual cropping systems where these infestations occur.

Acknowledgments

The 1996 Saskatchewan field survey was made possible through financial support by the Innovative Partnerships Program of the Canada-Saskatchewan Agriculture Green Plan Agreement and the Matching Investment Initiative (MII) of Agriculture and Agri-Food Canada (AAFC). The grain elevator survey was conducted with the cooperation and assistance of the Saskatchewan Wheat Pool (SWP) and Cargill. The individual contributions of Daryl Kratchmer (SWP) and John Waterer (Cargill), as well as those of the elevator agents, are gratefully acknowledged. Direct financial assistance was provided by MII-AAFC, and by the following herbicide manufacturers and distributors: AgrEvo Canada, BASF Canada, Bayer Canada, Cyanamid Crop Protection, Dow AgroSciences Canada, DuPont Canada, Monsanto Canada, and Zeneca Canada. The County of Wheatland survey in Alberta was supported by Alberta Agriculture, Food and Rural Development and the County of Wheatland. The Manitoba survey was implemented by the Soils and Crops Branch of Manitoba Agriculture, in

conjunction with Westco and the Manitoba Weed Supervisors Association. Additional financial support was provided by Westco and the Sustainable Development Innovations Fund of Manitoba Agriculture. Technical assistance by the following Saskatoon Research Centre staff is gratefully acknowledged: Scott Shirriff, Carma Wooff, Zenon Bainas, Debbie Nordstrom, and Brad Thompson for conducting one or more surveys or performing resistance tests. Special thanks are extended to those growers who participated in these surveys.

References Cited

Anonymous. 1997a. 1996 Census: Agricultural Profile of Manitoba. Catalogue 95-178-XPR, Ottawa, ON. 215 p.

Anonymous. 1997b. 1996 Census: Agricultural Profile of Saskatchewan. Catalogue 95-179-XPR, Ottawa, ON. 219 p.

Anonymous. 1997c. 1996 Census: Agricultural Profile of Alberta. Catalogue 95-180-XPR, Ottawa, ON. 113 p.

Anonymous. 1998. Guide to Crop Protection. Saskatchewan Agriculture and Food, Regina, SK. 268 p.

Beckie, H. J. and L. T. Juras. 1998. Saskatchewan grain elevator weed survey: herbicide-resistant wild oat and green foxtail 1997. Agriculture and Agri-Food Canada Weed Survey Ser. Publ. No. 98-4, Saskatoon, SK. 23 p.

Beckie, H. J., D. J. Kelner, R. C. Van Acker, and A. G. Thomas. 1998a. Manitoba weed survey: herbicide resistant wild oat 1997. Agriculture and Agri-Food Canada Weed Survey Ser. Publ. No. 98-5, Saskatoon, SK. 36 p.

Beckie, H. J., A. Légère, A. G. Thomas, F. C. Stevenson, J. Y. Leeson, L. T. Juras, and M. D. Devine. 1998b. Saskatchewan weed survey: herbicide-resistant wild oat and green foxtail 1996. Agriculture and Agri-Food Canada Weed Survey Ser. Ext. Publ. 98-3, Saskatoon, SK. 77 p.

Blackshaw, R. E. 1997. A review of integrated weed management systems for cereal crops. *In* P. Comeau and G. Harper, eds. Expert Committee on Weeds. Proc. 1996 National Mtg., Victoria, BC. pp. 11-16.

Bourgeois, L. and I. N. Morrison. 1997. Mapping risk areas for resistance to ACCase inhibitor herbicides in Manitoba. Can. J. Plant Sci. 77:173-179.

Bourgeois, L., I. N. Morrison, and D. Kelner. 1997. Field and grower survey of ACCase resistant wild oat in Manitoba. Can. J. Plant Sci. 77:709-715.

Campbell, C. A., R. P. Zentner, H. H. Janzen, and K. E. Borwen. 1990. Crop rotation studies on the Canadian prairies. Agriculture and Agri-Food Canada Publ. 1841/E, Ottawa, ON. 133 p.

Goodwin, M. 1994. An extension program for ACCase inhibitor resistance in Manitoba: A case study. Phytoprotection 75 (Suppl.):97-102.

Kirkland, K. J. and H. J. Beckie. 1998. Contribution of nitrogen fertilizer placement to weed management in spring wheat (*Triticum aestivum*). Weed Technol. 12:507-514.

Table 1. The additional cost ($/ac)[a] of managing resistant wild oat and green foxtail in the top five annual crops grown in the prairies

Group resistance	Cereal crops		Broadleaf crops		
	Wheat	Barley	Canola	Flax	Field pea
Wild oat					
1	Assert:2 Avenge:8 (1.43) Avadex:8 Mataven:25	Assert:2 trifluralin:3 (0.81) Avenge:8 (1.43) Avadex:8	Edge:3 (5.53) trifluralin:3 (1.95) Avadex:8 (3.28) Pursuit:2[b] (5.38) Odyssey:2[b] (10.94) Roundup:9[b] (5.74) Liberty:10[b] (4.44)	trifluralin:3 (1.95) Avadex:8 (3.28)	Pursuit:2 (5.38) Odyssey:2 (10.94) Edge:3 (5.53) trifluralin:3 (1.95) Avadex:8 (1.62)
8	Horizon:1 (0.51) Hoe-grass:1 (0.54) Puma:1 (1.06) Achieve:1 (1.31) Assert:2 Mataven:25 (0.16)	Hoe-grass:1 (0.54) Achieve:1 (1.31) Assert:2 trifluralin:3 (1.67)	Select:1 Hoe-grass:1 Fusion:1 Venture:1 Assure:1 Poast:1 Edge:3 (2.25) trifluralin:3 Pursuit:2[b] (2.10) Odyssey:2[b] (7.66) Roundup:9[b] (2.46) Liberty:10[b] (1.16)	Select:1 Hoe-grass:1 Fusion:1 Venture:1 Assure:1 Poast:1 trifluralin:3	Select:1 Hoe-grass:1 Fusion:1 Venture:1 Assure:1 Poast:1 Pursuit:2 (3.76) Odyssey:2 (9.32) Edge:3 (3.91) trifluralin:3 (0.33)
1,2,[25][c]	Avenge:8 (3.22) Avadex:8 (0.93) [Mataven:25 (1.09)][c]	trifluralin:3 (2.60) Avenge:8 (3.22) Avadex:8 (0.93)	Edge:3 (5.53) trifluralin:3 (1.95) Avadex:8 (3.28) Roundup:9[b] (5.74) Liberty:10[b] (4.44)	trifluralin:3 (1.95) Avadex:8 (3.28)	Edge:3 (5.53) trifluralin:3 (1.95) Avadex:8 (1.62)
1,2,8,25	No options	trifluralin:3 (2.60)	Edge:3 (5.53) trifluralin:3 (1.95) Roundup:9[b] (5.74) Liberty:10[b] (4.44)	trifluralin:3 (1.95)	Edge:3 (5.53) trifluralin:3 (1.95)

(Table 1-continued)

Green foxtail					
1	trifluralin:3 Accord:4 Stampede:7	trifluralin:3 (0.81) Stampede:7	Edge:3 (5.53) trifluralin:3 (1.95) Pursuit:2[b] (5.38) Odyssey:2[b] (10.94) Roundup:9[b] (5.74) Liberty:10[b] (4.44)	trifluralin:3 (1.95) Stampede:7	Edge:3 (5.53) trifluralin:3 (1.95) Pursuit:2 (5.38) Odyssey:2 (10.94)
3	Horizon:1 (7.57) Hoe-grass:1 (7.60) Puma:1 (8.12) Achieve:1 (8.37) Accord:4 (2.34) Stampede:7 (1.12)	Hoe-grass:1 Achieve:1 Stampede:7	Select:1 Hoe-grass:1 Venture:1 Assure:1 Poast:1 Pursuit:2[b] (3.43) Odyssey:2[b] (8.99) Roundup:9[b] (3.79) Liberty:10[b] (2.49)	Select:1 Hoe-grass:1 Venture:1 Assure:1 Poast:1 Stampede:7	Select:1 Hoe-grass:1 Venture:1 Assure:1 Poast:1 Pursuit:2 (3.43) Odyssey:2 (8.99)
1,3	Accord:4 (2.34) Stampede:7 (1.12)	Stampede:7	Pursuit:2[b] (5.38) Odyssey:2[b] (10.94) Roundup:9[b] (5.74) Liberty:10[b] (4.44)	Stampede:7	Pursuit:2 (5.38) Odyssey:2 (10.94)

aGroup number listed after each herbicide. Herbicide costs ($/ac) shown in brackets are relative to the least expensive herbicide in R group(s) listed. If no cost is indicated, the herbicide is less expensive than the ineffective herbicide(s). Suggested 1997 retail herbicide prices ($/ac) are (Anonymous 1998): Accord=9.32; Assert=13.11; Avadex=14.04 (fall granular, cereals), 17.04 (fall granular, canola and flax), 15.38 (spring liquid, field pea); Avenge=16.33; Edge=19.29 (fall-applied, granular formulation); Group-1 products (average)=14.90 (cereals), 13.76 (broadleaf crops): Achieve=15.35, Assure =14.44, Fusion=12.95, Hoe-grass=14.58, Horizon=14.55, Poast=14.51, Puma=15.10, Select=14.99, Venture =11.07; Liberty=18.20; Mataven=14.20; Odyssey=24.70; Pursuit=19.14; Stampede=8.10; Roundup=19.50 (herbicide+seed technology fee); trifluralin=15.71 (fall granular), 6.98 (fall granular, for green foxtail control only in wheat). Notes: 1) Accord, Assert, Edge, Liberty, Odyssey, Pursuit, Roundup, and trifluralin also control one or more broadleaf weeds, which the producer must consider in comparing total weed control costs; 2) efficacy of the herbicides for control of wild oat or green foxtail are assumed to be equal; 3) when a range of rates are listed (Anonymous 1988), the mean rate is used and 4) rates of herbicides that control both wild oat and green foxtail are those listed for wild oat control, which may be the same or higher than those listed for green foxtail control, since most fields that have green foxtail also have wild oat present.

bHerbicide-resistant canola only.

cFor Group 1, 2, and 25 resistance in wild oat, Mataven (Group 25) would not be an option in wheat.