Management Practices Influencing Herbicide Resistance in Wild Oat (*Avena fatua*)

H. J. Beckie[1], L. M. Hall[2], S. Meers[2], J. J. Laslo[3], and F. C. Stevenson[4]

[1]Agriculture and Agri-Food Canada, Saskatoon, SK, S7N 0X2; [2]Alberta Agriculture, Food and Rural Development, Edmonton, AB, T6G 2P5; [3]Wheatland County Agricultural Service Board, Strathmore, AB, T1P 1J6; [4]Saskatoon, SK, S7N 3T6

Key words: *Avena fatua*, herbicide resistance, integrated weed management, survey, wild oat

Abstract

A 3-year study was conducted in Wheatland County, Alberta to determine if agronomic practices of growers influenced the occurrence of herbicide resistance in wild oat. Wild oat seeds were collected in 33 fields in 1997, and in 31 fields in each of 1998 and 1999 (one field per grower). Seedlings were screened for resistance to two acetyl-CoA carboxylase (ACCase) inhibitors (Group 1), imazamethabenz, an acetolactate synthase (ALS) inhibitor (Group 2), and triallate, a thiocarbamate herbicide (Group 8). A questionnaire on herbicide resistance awareness and management practices was completed by each grower. Both ACCase and ALS inhibitor resistance in wild oat were linked to a lack of crop rotation diversity. In addition, ALS inhibitor-resistant wild oat was associated with conservation-tillage systems and recent use of herbicides with that mode of action. Results of this study suggest that timely tillage and inclusion of fall-seeded and perennial forage crops in rotations will effectively slow the selection of resistance in this grass species.

Introduction

Wild oat is the most abundant annual grass weed in the prairies, and the increasing incidence of herbicide resistance in this species is compounding management difficulties. Field and grain elevator surveys conducted in the region indicated that resistance in wild oat to ACCase inhibitors (Group 1, Retzinger and Mallory-Smith 1997) occurred most frequently, followed by resistance to ALS inhibitors (Group 2) and to triallate (Group 8) (Beckie et al. 1999, 2001). In a survey of two randomly selected townships (each 10-km square) located in different agricultural regions of Saskatchewan, nearly 50% of fields had wild oat populations with ACCase inhibitor resistance, 20 to 30% with ALS inhibitor resistance, and about 15% with triallate resistance (Beckie et al. 2002). Thirty to 40% of the populations were resistant to multiple modes of action.

Since resistance in wild oat in Canada was first discovered in 1990 (Heap et al. 1993), information from all levels of government and from agri-business has been targeted at growers to convey the importance of integrated weed management and to increase their awareness of herbicide resistance in wild oat. Initial recommendations in the early 1990s for delaying selection for wild oat resistance focused on herbicide group rotation. Further recommendations included enhanced crop competitiveness against wild oat by choice of crops and cultivars, increased seeding rates, varied seeding dates, and appropriate fertilization. These recommendations were within the context of diverse cropping systems, particularly those that include annual or perennial forages which effectively reduce wild oat abundance and herbicide use (Harker et al. 2003). From 1992 to 2001, postemergence herbicide (ACCase inhibitor, ALS inhibitor, glyphosate, glufosinate) use for wild oat control increased markedly in Alberta, whereas preemergence herbicide use gradually declined (dinitroanilines, thiocarbamates) (Thomas et al. 2003a). That survey also found that in 2001, herbicide group rotation was not practiced in 22% of fields and only 12% of growers suspected or were aware of herbicide-resistant weeds on their farm. Wild oat resistance was suspected by the majority of those growers. The perception among most growers that herbicide-resistant wild oat was not a problem on their farm, the popularity of postemergence-applied wild oat herbicides with limited modes of action, and a lack of information on the impact of management practices on selection of herbicide resistance in wild oat may have limited their ability to implement proactive resistance management practices during the 1990s.

Two studies in western Canada in the late 1990s examined linkages between management practices and risk of ACCase inhibitor resistance in wild oat. Growers from Manitoba townships considered at low risk (based on previous herbicide usage) for the occurrence of ACCase inhibitor resistance in wild oat had more diversified crop rotations than those from medium- to high-risk townships (Bourgeois et al. 1997). Based on results of a field and grower survey in Saskatchewan, Légère et al. (2000) reported that the occurrence of ACCase inhibitor resistance in wild oat was associated primarily with the frequency of ACCase inhibitor use and extent of implementation of weed sanitation practices. Such practices included cleaning equipment when moving between fields, tarping grain trucks, mowing or spraying ditches or uncontrolled weed patches, and applying composted vs. fresh manure. In that study, few of the agronomic practices widely recommended for delaying and managing resistance, including crop rotation and competition, delayed seeding, and tillage, had a significant effect on the frequency of ACCase inhibitor resistance in wild oat. Crop rotations were not conducive to the rotation of herbicides with different modes of action because ACCase inhibitors can be used in all of the major crops in the region. In addition, Thomas et al. (1999) found no association between the frequency of ACCase inhibitor resistance in wild oat and farming systems in Saskatchewan, further confirming that frequency of herbicide group use was the dominant factor in explaining the presence of ACCase inhibitor resistance in this grass weed.

In accordance with the findings of Légère et al. (2000), occurrence of triazine resistance in common waterhemp (*Amaranthus rudis* Sauer) populations in Nebraska was not associated with crop rotation, but with movement of resistant seeds among fields within farms via field equipment (Anderson et al. 1996). The occurrence of resistance was the same in fields of continuous corn (*Zea mays* L.) or grain sorghum [*Sorghum bicolor* (L.) Moench] compared with fields with a 2- or 3-year crop rotation with corn or sorghum grown once during the rotation. In contrast, triazine resistance in broadleaf weed biotypes in eastern Ontario was associated with crop monoculture; additional factors favoring triazine resistance were manure application and infrequent use of postemergence herbicides or tillage (Stephenson et al. 1990). Although the aforementioned studies cannot support causal relationships, they do suggest that diversified cropping practices and systems which include weed sanitation measures can lessen or delay weed resistance selection or spread. These practices may reduce the intensity of use of a single herbicide or herbicide mode of action on weed populations.

The objective of this study was to investigate how chemical, mechanical, or cultural practices of growers may influence the occurrence of herbicide-resistant wild oat in western Canada, by conducting a multi-year (1997-1999) field and grower survey in Wheatland County, Alberta. This project supported an extension program to enhance awareness of growers and agri-business of the occurrence of herbicide-resistant weeds, and increase grower adoption of herbicide rotation and integrated weed management practices.

Materials and Methods

Wild Oat Field Survey

Wheatland County is located is southern Alberta, primarily in the Fescue Grassland ecoregion (Figure 1) (Leeson et al. 2002). An ecoregion is an area of similar climate, natural vegetation, and soils (Ecological Stratification Working Group 1995). One hundred growers from across the County were contacted randomly each year and interviewed on their weed management practices in three fields. High-risk growers, those who repeatedly used the same herbicide mode of action for wild oat control, were selected from this group. Different growers were selected each year. Thirty-three growers in 1997, 31 growers in 1998, and 31 growers in 1999 (total of 95 growers) agreed to have their fields surveyed for wild oat resistance. One cropped field per grower was selected and surveyed in August or September, immediately before crop harvest. Field size averaged 68 ha, and ranged from 16 to 280 ha. The crops grown in the surveyed fields (one crop per field) are listed in Table 1.

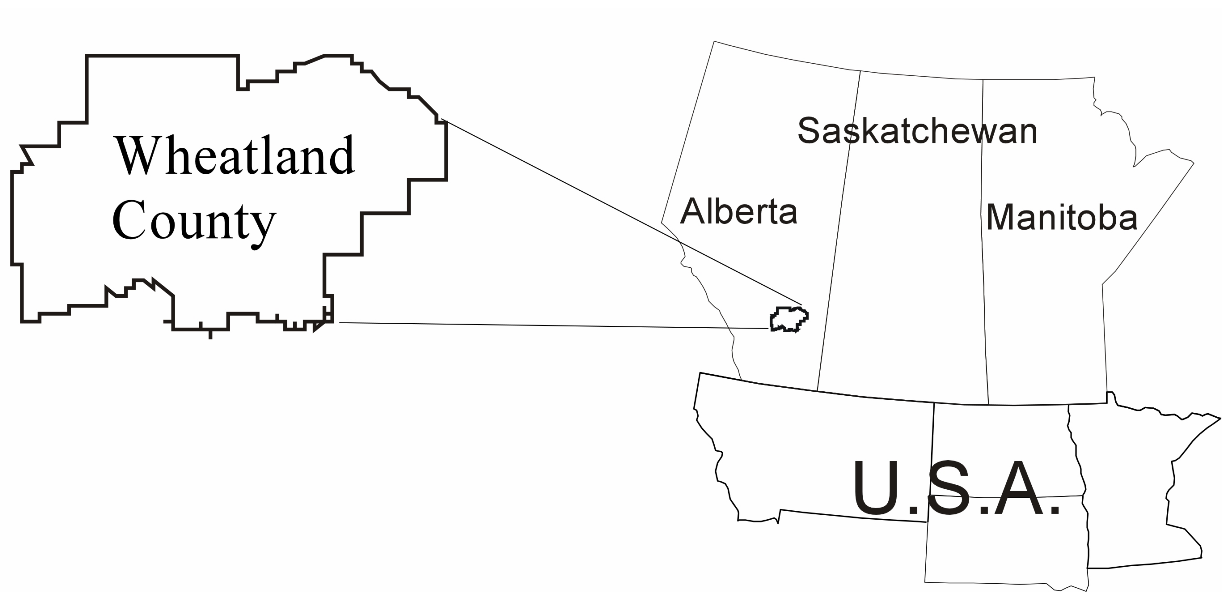

Figure 1. Location of Wheatland County, Alberta.

Table 1. Crops Grown in the Surveyed Fields (1997 to 1999) in Wheatland County, Alberta.

Crop	1997	1998	1999	*Total*
Spring wheat[a]	19	13	20	52
Barley	8	9	6	23
Canola	4	9	5	18
Mustard	1	0	0	1
Field pea	1	0	0	1
Total	*33*	*31*	*31*	*95*

[a]Spring wheat, *Triticum aestivum* L.; barley, *Hordeum vulgare* L.; canola, *Brassica napus* L.; mustard, *Sinapis alba* L. or *Brassica juncea* L.; field pea, *Pisum sativum* L.

Fields were surveyed using the inverted 'W' pattern (Thomas 1985). More than 1,000 viable seeds of wild oat were collected from approximately 40 mature plants per patch (each patch sampled separately) and placed in an unsealed paper bag (Beckie et al. 2000). The shape of a patch was categorized as linear (a sprayer miss) or irregular. In addition, the area of wild oat infestation was estimated as less than 0.4 ha (a single patch); greater than 0.4 ha (either few patches or many patches); or 'other' (with description provided, e.g., individual plants dispersed widely). If the weed population was widely disseminated across the field with no visible patchiness (i.e., single plants), at least 100 plants were sampled to obtain an estimate of the level of resistance in the population. Samples were dried and stored at room temperature before conducting the resistance tests.

Resistance Tests

Resistance tests were initiated 4 months after seeds were collected to reduce the level of innate dormancy. Wild oat accessions were screened for ACCase inhibitor, ALS inhibitor, or triallate resistance. Resistance to ACCase inhibitor herbicides was determined using the procedure developed by Murray et al. (1996) and modified by Bourgeois and Morrison (1997). Seedlings were grown on agar media treated with either fenoxaprop-P (without safener), an aryloxyphenoxypropionate (APP) herbicide, or sethoxydim, a cyclohexanedione (CHD) herbicide. To screen populations for ALS inhibitor resistance, imazamethabenz was applied at the maximum recommended rate of 500 g ai/ha to plants at the two- to three-leaf stage (Beckie et al. 2000). Thirty-six plants were grown in flats measuring 52 by 26 by 5 cm that were filled with a commercial potting mixture amended with a slow-release fertilizer. Plants were visually assessed as herbicide-resistant or -susceptible at 21 to 28 days after treatment. Wild oat resistance to triallate was detected with a discriminating dose of 0.7 νM using a procedure similar to the ACCase inhibitor dish bioassay (Beckie et al. 2000). A minimum of 100 viable seeds from each sample were screened in each resistance test. Treatments (and untreated controls) were replicated three times and the tests were repeated. Known herbicide-resistant and -susceptible biotypes were included in all tests (Beckie et al. 2000).

Grower Survey

Each grower was interviewed to determine their herbicide resistance awareness and management practices using a standard questionnaire, after herbicide treatments had been applied to the surveyed field but before harvest. Management questions assessed herbicide group rotation; cultural weed control practices; problem weeds prior to herbicide application; cropping, tillage, and manure practices; and herbicides applied in the current and past 2 years (Table 2).

Data Analysis
Multiple correspondence analysis was conducted to explore coincidences between different practices associated with each survey question, and grower awareness/suspicion or the presence/absence of wild oat resistance. The analysis was conducted using the PROC CORRESP procedure of SAS (SAS 1999). Correspondence analysis finds a multi-dimensional representation that maximizes the association (chi-square) between the row and column categories of a two-way contingency table (Greenacre 1984, 1993). Multiple correspondence analysis extends this technique to a joint analysis of all two-way tables among the different variables. Scores calculated from the analysis are plotted in two-dimensional Euclidean space. Close correspondence between ordination points for awareness or occurrence of resistance and management practices (particular response to the various questions) indicates potentially important relationships requiring further investigation.

Chi-square analysis was subsequently conducted to more quantitatively assess if awareness/suspicion or occurrence of resistance in wild oat differed among particular attributes of specific management practices. Chi-square analysis associations were deemed significant at $P<0.10$. For most agriculture research, the 0.10 level of significance would detect trends; further research to explore such trends may be warranted (T. Entz, personal communication). Data were consolidated (rare levels combined with other levels or omitted) prior to the analyses to simplify interpretations for multiple correspondence analysis and ensure adequate group representation for the chi-square analysis while maintaining the practical integrity.

Results and Discussion

One-third (31) of the 95 growers suspected or were aware of herbicide-resistant weeds on their farm (Table 2, question 2a). Most of these growers (26) suspected or were aware of resistance in wild oat (question 2b). Of these 26 growers, 15 specified wild oat resistance to Group 8 herbicides (triallate, difenzoquat), 11 to ACCase inhibitor herbicides, and 3 to ALS inhibitor herbicides (question 2c; some growers listed more than one group). Tests indicated that wild oat populations were resistant to an ACCase inhibitor, imazamethabenz, or triallate in 27 of the 95 fields (29%). This proportion of fields with herbicide-resistant populations is lower than that found in a township in the Grassland region of Saskatchewan surveyed in 1997 (59%) (Beckie et al. 2002). In this study, 16% of growers had populations with ACCase inhibitor (APP) resistance, 10% with imazamethabenz resistance, and 6% with triallate resistance. Three of the fields had populations with multiple group resistance (ACCase inhibitor plus imazamethabenz in one field; ACCase inhibitor plus triallate in two fields). Resistance in wild oat was confirmed for only three growers who suspected or were aware of wild oat resistance. Growers may be confusing late-emerging wild oat or spray misses for resistant weeds. Alternatively, the information campaign may have increased grower awareness of herbicide-resistant wild oat to a point where resistance was accepted as inevitable. A 1996 field survey in Saskatchewan found that only 5% of growers suspected ACCase inhibitor resistance in wild oat, two-thirds of whom were correct (Beckie et al. 1999). In this survey, 12% of growers suspected ACCase inhibitor resistance in wild oat, but verified for only 20% of these respondents.

Multiple correspondence analysis of the data (Figure 2) indicated that ALS inhibitor resistance (GR2R) in wild oat coincided with (1) ALS inhibitor use in the current (GR2) and previous year (Y-1GR2); (2) lack of crop rotation (NoCrpRot) or absence of fall-seeded crops or perennial forages in the rotation (NoFSFor); and (3) a mixture of patch sizes or 'other' (CoOtPatch; fields that the surveyor made more than one choice or response 4 for question 1b). ALS inhibitor resistance was also associated, albeit to a lesser extent, with continuous cereal crop production (ContCer) and seeding systems less reliant on tillage (RT). There is a clear relationship between recent ALS inhibitor herbicide use and ALS inhibitor resistance in wild oat. Besides selection pressure, detecting resistance in weeds in a field to a particular herbicide group is more likely when sampled plants have been treated with a herbicide from that group (Beckie et al. 2000). The soil residual properties of many ALS inhibitor products in this arid environment will contribute to both selection pressure and detection of biotypes in the field. Lack of crop rotation (i.e., continuous spring cereal crop production; lack of fall-seeded or perennial forage crops) can increase abundance of this grass weed and necessitate greater herbicide use (Thill and Lemerle 2001; Thill et al. 1994). Moreover, wild oat is more abundant in conservation- than intensive-tillage systems (Watson et al. 2001). Reduced-tillage systems may also increase the proportion of the wild oat population selected with an in-crop ALS inhibitor herbicide because of greater proportional recruitment from a shallower seedbank as compared with intensive-tillage systems.

Grower awareness/suspicion of resistance in wild oat was proportionally greater when field records were kept (question 3c, Table 2; P=0.068) and when they were used to plan herbicide use (question 3d; 'yes' and 'sometimes' vs. 'no', P=0.081). For question 3c, 20 respondents who were aware of resistance kept field records compared with six respondents who also were aware of resistance but did not keep records. For question 3d, 19 respondents who were aware of resistance used field records to plan their herbicide usage (answered 'yes' or 'sometimes') compared with seven respondents who also were aware of resistance but did not use records to plan herbicide usage. Records of previous crops grown or herbicides used would increase awareness of frequency of use of products with the same mode of action, which, in turn, could increase grower awareness of the risk of resistance. Conversely, growers who suspect or are aware of weed resistance in their fields may be more likely to keep field records to guide future herbicide use. Grower awareness or suspicion of resistance was not associated with patch shape or size as documented by the surveyor or other management practices.

There was proportionally more ACCase inhibitor (APP) resistance in wild oat when fall-seeded or perennial forage crops were not grown in the rotation (question 3a, Table 2; P=0.031). Twelve growers with ACCase inhibitor-resistant wild oat did not grow such crops in rotations compared with three growers who also had ACCase inhibitor-resistant wild oat but did include these crops in rotations. Inclusion of such crops is recommended to break the life cycle of wild oat and reduce population abundance. These crops also facilitate less frequent herbicide use, thus reducing the selection pressure for resistance. Interestingly, those growers who kept field records were more likely to have ACCase inhibitor-resistant wild oat (question 3c; P=0.033). This documentation by these growers was usually not a reaction to greater awareness/suspicion of

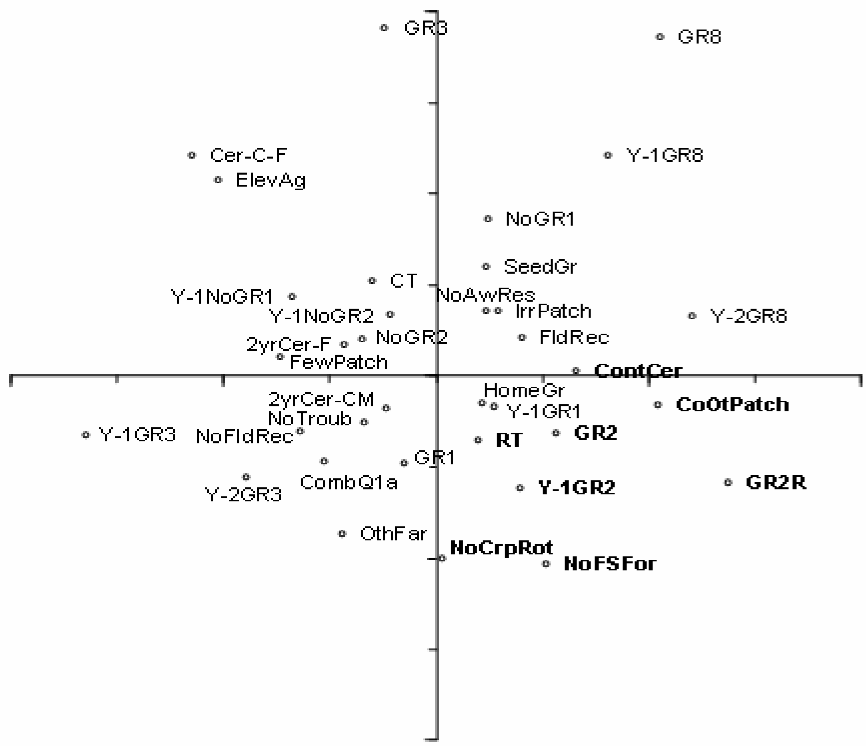

Figure 2. Multiple correspondence analysis ordination of coincidences between grower awareness/suspicion of wild oat resistance or presence/absence of resistance *and* patch shape/size or management practices. Associations considered statistically important are indicated in bold font: ContCer, continuous cereals (questions 5a, 10a, 11a in Table 2); CoOtPatch, 'other' wild oat patch category (response 4 of question 1b) or a mixture of patch sizes; GR2, Group 2 (ALS inhibitor) herbicide used in current year (question 9a); GR2R, Group 2 resistance; NoCrpRot, crop rotation not utilized (response 2 of question 3e); NoFSFor, fall-seeded or forage crops not utilized (response 2 of question 3a); RT, reduced tillage (responses 2 or 3 of question 6); Y-1GR2, Group 2 herbicide used 1 year previous (question 10b). Variables in close proximity to the centroid of the ordination are not shown and those indicated in non-bolded font are not deemed important and therefore not defined.

ACCase inhibitor-resistant wild oat, because most growers with this biotype were unaware of its presence.

Occurrence of ALS inhibitor resistance was proportionally greater when irregular-shaped patches were observed by the surveyor (question 1a, Table 2; P=0.044), when ALS inhibitor herbicides were used in the previous year (question 10b; P=0.034), and in reduced-tillage systems (minimum tillage or direct-seeding systems) (question 6: P=0.078). These results are similar to those derived from multiple correspondence analysis (Figure 2). Although resistant weeds are likely to occur in patches, a linear resistant weed distribution may result from seed movement by a harvester or a spray miss of a herbicide that controls the biotype.

Occurrence of triallate resistance was linked to many patches greater than 0.4 ha observed by the surveyor (question 1b, Table 2; P=0.001). There also was proportionally more triallate resistance when ACCase inhibitor herbicides were used in the previous year (question 10b; P=0.093), although the reason for this association is unclear. The ACCase inhibitors are the most popular wild oat herbicides among growers in western Canada. Those growers experiencing poor control with a Group 8 product, such as triallate, would most often use an ACCase inhibitor.

This study furthers our knowledge of the influence of grower management practices on occurrence of wild oat resistance. Incidence of ACCase or ALS inhibitor resistance in wild oat, which is most prevalent, was linked to a lack of diversity in crop rotations, i.e., no fall-seeded or perennial forage crops, or cereal monoculture. The relationship between ACCase inhibitor resistance in wild oat and crop rotation diversity was not evident in a previous study in Saskatchewan (Légère et al. 2000). ALS inhibitor resistance in wild oat was also associated with conservation-tillage systems, which can favor wild oat abundance and consequently greater herbicide use. Seedbank dynamics, such as greater concentration of seeds near the soil surface in conservation- than intensive-tillage systems, may also influence the rate of resistance evolution (Gressel and Segel 1982). In the absence of tillage, weed seedlings may be derived largely from seeds shed in the previous crop. Consequently, there will be little buffering against resistance evolution from old seeds which may have greater percentage susceptibility (Moss 2002). The relationship between ALS inhibitor resistance and ALS inhibitor herbicide use in the survey year and in the previous year suggests strong selection pressure and frequent use of these products in cropping systems, possibly to reduce the selection pressure for ACCase inhibitor-resistant wild oat or to manage such infestations. Indeed, both ACCase and ALS inhibitor use in this ecoregion in 2001 was high. Herbicides of each mode of action were applied to more than 40% of fields in the ecoregion, whereas Group 8 herbicides (triallate, difenzoquat) were not used (Thomas et al. 2003b).

A multi-faceted technology transfer approach supported by all levels of government and the agriculture industry has increased awareness of herbicide resistance by growers since the initial reports of herbicide-resistant wild oat. Although management practices vary considerably from grower to grower, this study and others (Bourgeois et al. 1997; Légère et al. 2000) show that few non-herbicide practices effectively influence the occurrence of herbicide-resistant wild oat. The abundance of wild oat and the lack of effective alternative herbicides and alternative crops to permit diversification in farming systems continues the selection for herbicide resistance. In the future, growers will rely increasingly on herbicide-resistant crops, such as glyphosate- and glufosinate-resistant canola, that permit use of herbicides that have a low propensity to select for wild oat resistance. To date, there are no reports of glyphosate or glufosinate resistance in weeds in Canada. The elimination of subsidies for grain transportation by rail in 1995 in Canada has led to an expansion of the livestock industry and increased forage production. This trend should have a positive impact on managing for wild oat resistance.

Acknowledgements

We acknowledge Wheatland County for their enthusiasm during the planning and execution of the project and especially the participating growers. Funding for the extension of this information was provided by Alberta Environmentally Sustainable Agriculture Program, Agricore, Cargill, CJS Agro, Dynagra, Pioneer, United Farmers of Alberta, and United Grain Growers.

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Table 2. Questions Listed in the Grower Questionnaire (Sections I-VI) and Chi-square Analysis of Associations Between Grower Awareness/Suspicion of Resistance or ACCase Inhibitor (Group 1), ALS Inhibitor (Group 2), or Triallate (Group 8) Resistance in Wild Oat *and* Patch Shape/Size or Management Practices.

Grower awareness or wild oat resistance [R][a]				Chi-square (P<0.10)[b]
	no. of responses (yes/no)[c]			
Surveyor: patch shape/size				
1. (a) Shape of weed patches?				
[R] Group 2	(1) linear (sprayer miss): 0/13	(2) irregular: 7/36		0.044
(b) Approximate size of patches?				
[R] Group 8	(1) <0.4 ha-single patch: 2/25	(2) >0.4 ha-few patches: 0/31	(3) > 0.4 ha-many patches: 4/8 (4) other: 0/22	0.001
Grower: herbicide resistance awareness and management practices				
I. Herbicide resistance awareness:				
2. (a) Are you aware of or do you suspect the presence of herbicide-resistant weeds on your farm?				
	(1) yes: 31	(2) no: 64		NA
(b) If "yes", which weeds are involved?				
	(1) wild oat: 26	(2) other: 5		NA
(c) If "yes", which herbicide is involved?				
	(1) Group 1: 11	(2) Group 2: 3	(3) Group 8: 15	NA
II. Herbicide group rotation:				
(d) Do you rotate herbicide groups? [(1) yes; (2) no; (3) unsure]				NS
III. Cultural weed control practices:				
3. (a) Do you plant fall-seeded crops or perennial forages as a weed control measure?				
[R] Group 1	(1) yes: 3/3	(2) no: 12/67		0.031
(b) Does weed competition influence your crop seeding rate or seed placement? [(1) yes; (2) no; (3) sometimes]				NS
(c) Do you keep field records?				
[R] Awareness	(1) yes: 20/39	(2) no: 6/30		0.068
[R] Group 1	(1) yes: 13/46	(2) no: 2/34		0.033
(d) Do you use field records to plan your herbicide usage?				
[R] Awareness	(1) yes: 14/29	(2) no: 7/33	(3) sometimes: 5/5	0.081
(e) Do you use crop rotation to help control weeds, i.e., to what extent do weeds influence				

the type of rotations you use? [(1) yes; (2) no; (3) sometimes]	NS
IV. Assessment of problem weeds prior to herbicide application:	
4. (a-e) List what you consider your five most troublesome weeds in the field in order of importance (a=first rank).	NS
(f) Overall, how would you rate the weed pressure in the field? [(1) none; (2) light; (3) moderate; (4) serious; (5) very serious]	NA
V. Cropping, tillage, and manure practices:	
5. (a) Crop/variety?	NA
(b) Number of acres in field?	NA
(c) Indicate the source of the seed in this field: [(1) home grown; (2) other farmer; (3) elevator agent; (4) seed grower]	NS
6. Indicate the type of tillage operation used on this field:	
[R] Group 2 (1) conventional tillage: 1/35 (2) minimum tillage or direct seeding – high disturbance (>30% disturbance); (3) direct seeding – low disturbance (<30% disturbance): (2 or 3): 8/50	0.078
7. Did you apply manure in the surveyed field this year or in the previous 2 years? [(1) yes; (2) no]	NS
VI. Herbicide usage:	
8. Current year: preseeding burnoff or preemergence herbicides (includes fall-applied) [(a) product; (b) rate; (c) area treated; (d) effectiveness (1=none, 10=excellent)]	NS
9. Current year: in-crop herbicides [a-d, as above]	NS
10. Weed control in the previous year: [list (a) crop, (b) products applied, (c) control (1 to 10)]	
[R] Group 2 (10b-2)[d] (0) yes: 6/27 (1) no: 3/59	0.034
[R] Group 8 (10b-1)[d] (0) yes: 6/60 (1) no: 0/29	0.093
11. Weed control 2 years previous: [a-c, as for question 10]	NS

[a]Statistical results [R], i.e., number of responses, of the chi-square analysis (where NA, not applicable, is not listed under the chi-square heading) are presented only when the chi-square statistic is significant (NS, not significant, listed where no associations are deemed significant at $P \geq 0.10$).

[b]Test that grower awareness/suspicion of resistance or occurrence of Group 1, 2, or 8 resistance differ among levels of the survey questions; levels with poor representation were combined with better represented groups.

[c]Occurrence of grower awareness/suspicion of wild oat resistance or occurrence of Group 1, 2, or 8 resistance (yes/no, only where [R] is indicated) for different levels (indicated in parentheses: 0, 1, 2, 3, or 4) of the survey questions. To aid interpretation of the results, compare the number of ‘yes’ responses, i.e., positive association, among the different levels. *Example 1*: for Question 1a, Group 2 resistance was significantly (P=0.044) associated with irregular-shaped patches, not linear-shaped patches (7 ‘yes’ responses for irregular-shaped vs. 0 ‘yes’ responses for linear-shaped patches); no other associations between grower awareness or

wild oat resistance *and* patch shape were significant and therefore data are not presented. *Example 2*: for Question 6, Group 2 resistance was significantly (P=0.078) associated with conservation tillage (8 'yes' responses for minimum tillage or low- or high-disturbance direct seeding vs. 1 'yes' response for conventional tillage).

[d]Results for question 10b refer to the usage (0=yes and 1=no) of different herbicide groups (number after hyphen indicates the herbicide group) in the year immediately preceding the field survey.