Agriculture and Agri-Food Canada Agriculture et Agroalimentaire Canada

Wild oat herbicide resistance: Few active groups left

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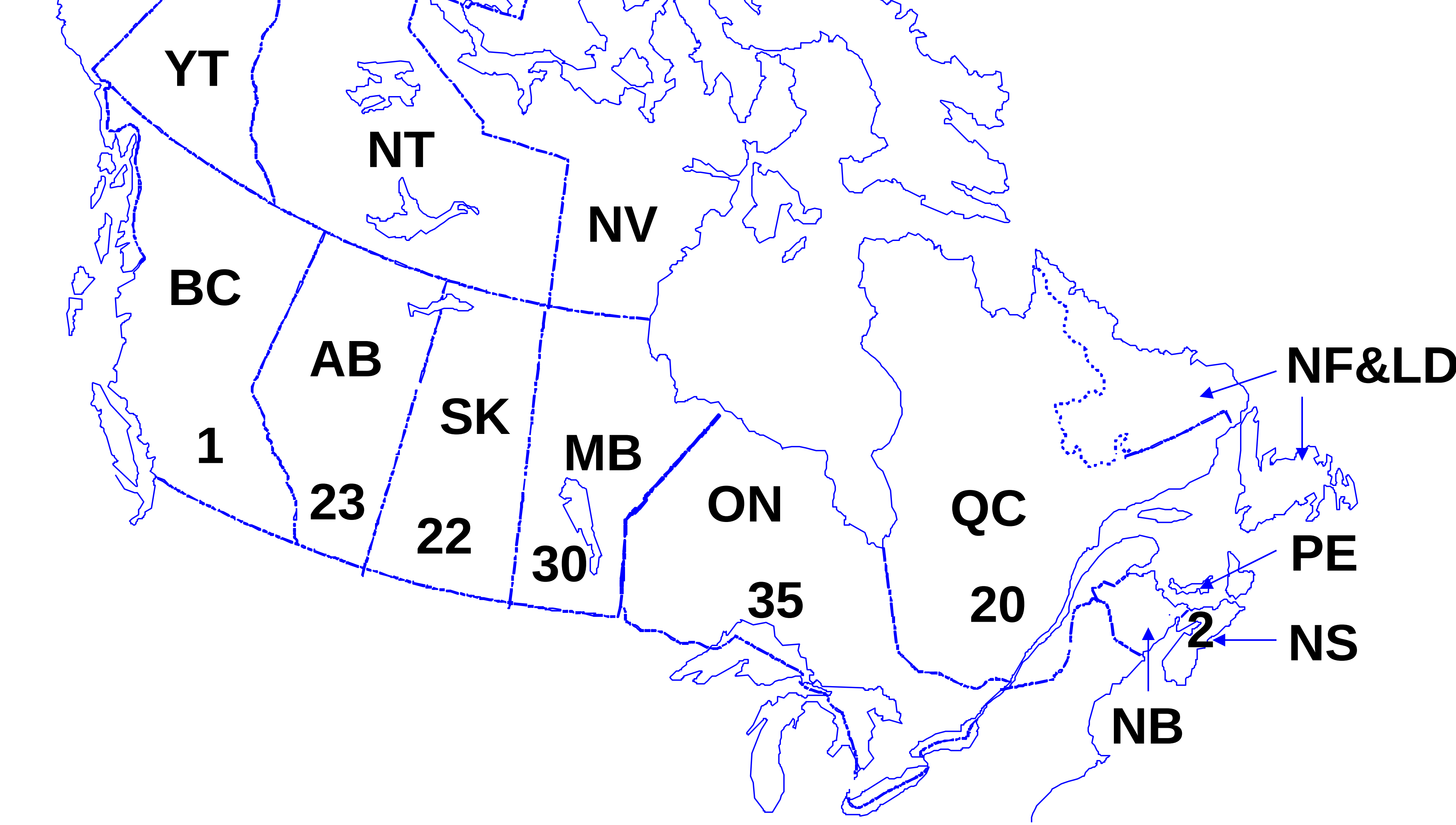
Top 10 weeds in Alberta: 2010 survey (pre-harvest, 986 fields)

- 10: *Crepis tectorum* (narrow-leaved hawk's-beard) ↑ (17th in 2001)
- 9: *Sonchus asper (*spiny annual sow thistle) ↑ (41th in 2001)
- 8: *Chenopodium album* (lambsquarters) ↓ (7th in 2001)
- 7: *Stellaria media* (chickweed) ↓ (3rd in 2001)
- 6: Volunteer canola ↑ (16th in 2001)
- 5: *Taraxacum officinale* (dandelion) ↑ (10th in 2001)
- 4: *Cirsium arvense* (Canada thistle) (no change)
- 3: *Galium* spp. (cleavers) ↑ (6th in 2001)
- 2: *Avena fatua* (wild oat) (no change)
- 1: *Polygonum convolvulus* (wild buckwheat) (no change)

Unique HR weed cases (biotypes) = 76



The rising incidence of HR weeds in western Canada

M ha / M ac

2001 - 2003 surveys: 4.4 / 10.9

2007 - 2009 surveys: 9.9 / 24.4

2014 - 2017 surveys: 15.4 / 38.0? (*2015 SK = 21.5 M ac; 2016 MB = 6.8 M ac; 2007 AB=7.7 M ac +?*)

Weed Technology 2008 22:530–543

Education/Extension

Weed Resistance Monitoring in the Canadian Prairies

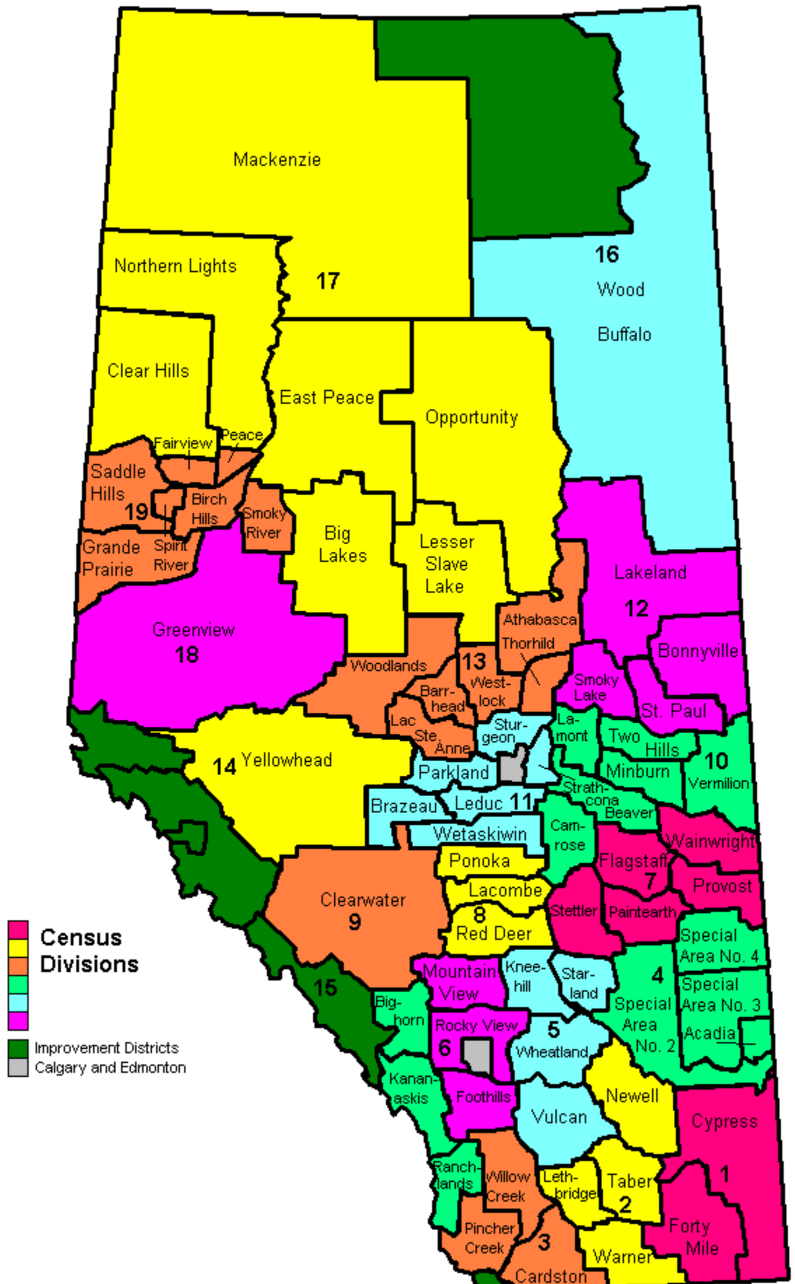
Hugh J. Beckie, Julia Y. Leeson, A. Gordon Thomas, Clark A. Brenzil, Linda M. Hall, Grant Holzgang, Chris Lozinski, and Scott Shirriff*

2017 Alberta weed resistance (pre-harvest) survey

- 250 fields across Alberta
- Last survey in 2007
- Beckie, Shirriff, Leeson, Hall, Harker
- Funded ($240 K) by:

-Western Grains Research Foundation
-Alberta Wheat Commission
-Alberta Pulse Growers Commission
-Alberta Canola Producers Commission

2017 Alberta kochia / R. thistle post-harvest survey



Wheatland (36)
Foothills (15)
Vulcan (51)
Kneehill (9)
Starland (8)
Rocky View (8)
Lethbridge (27)
Cardston (18)
Pincher Creek (9)
Willow Creek (21)
Taber (18)
Acadia (5)
Cypress (21)
Forty Mile (39)
Warner (33)
Newell (12)

Total: 330 sites

- Beckie, Shirriff, Hall
- Funded by ACIDF

Wild Oat Resistance

Mechanisms of Resistance:

Group 1 + 2:

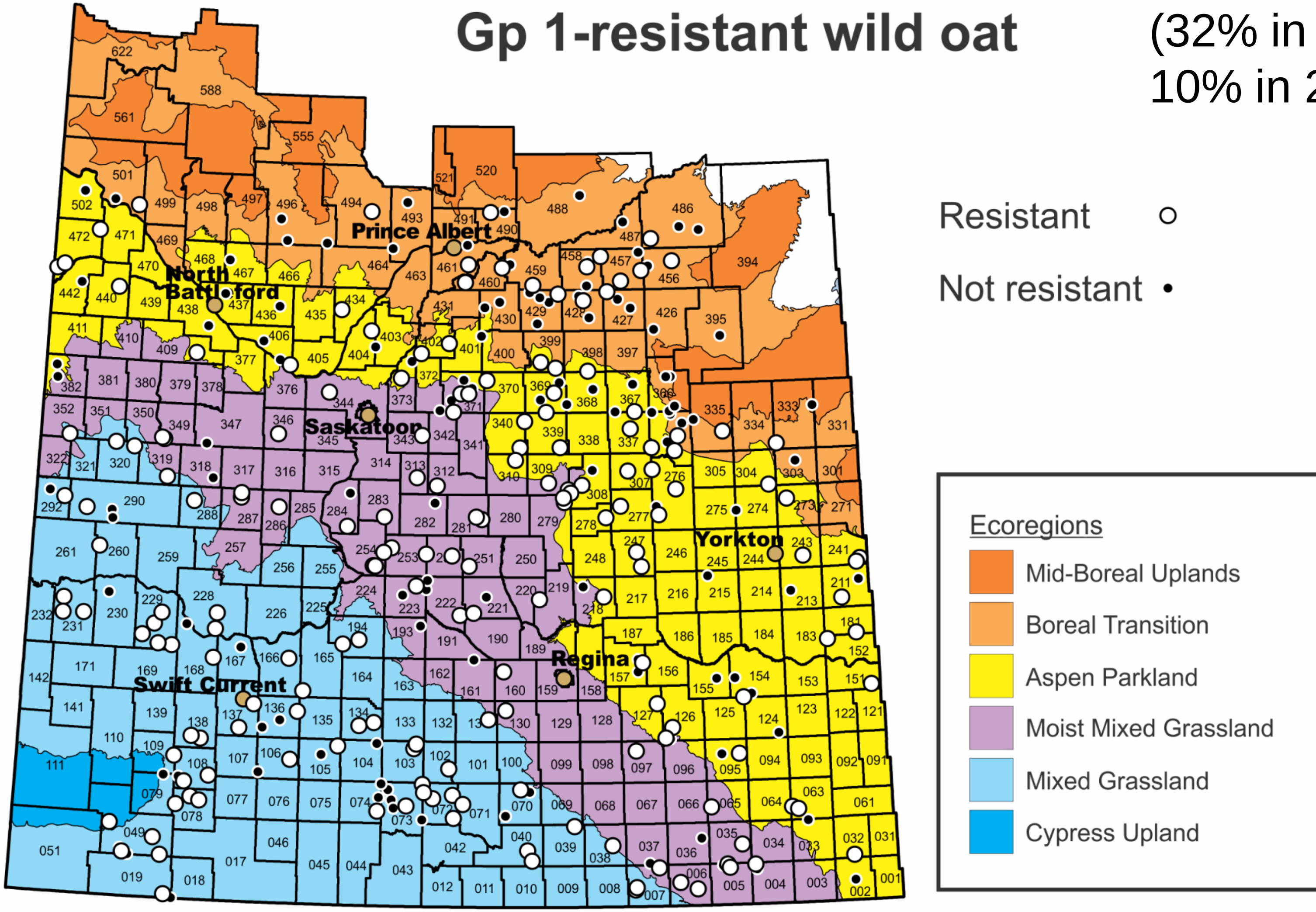
- Target-site mutations
- Enhanced metabolism

Group 8:

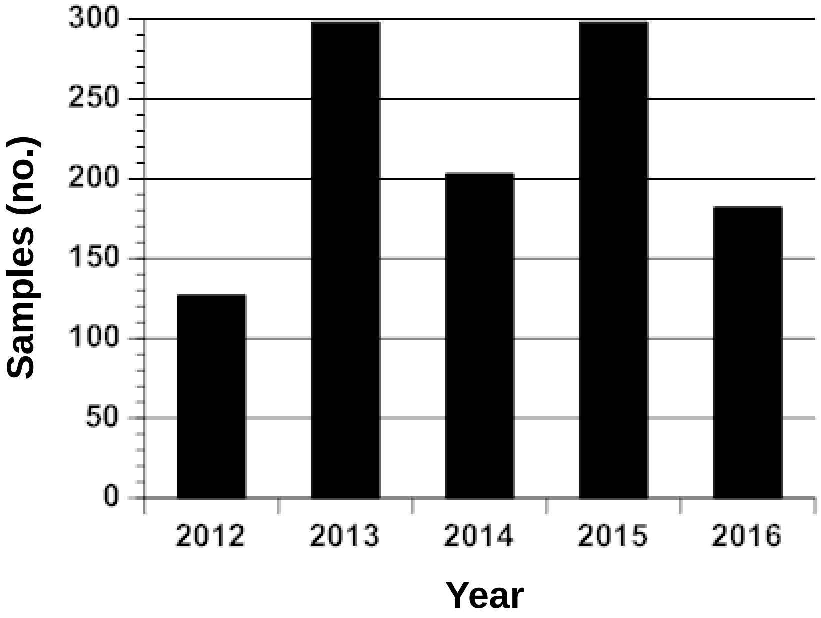
- Increased levels on endogenous gibberellin
- Enhanced metabolism

Gp 1-resistant wild oat

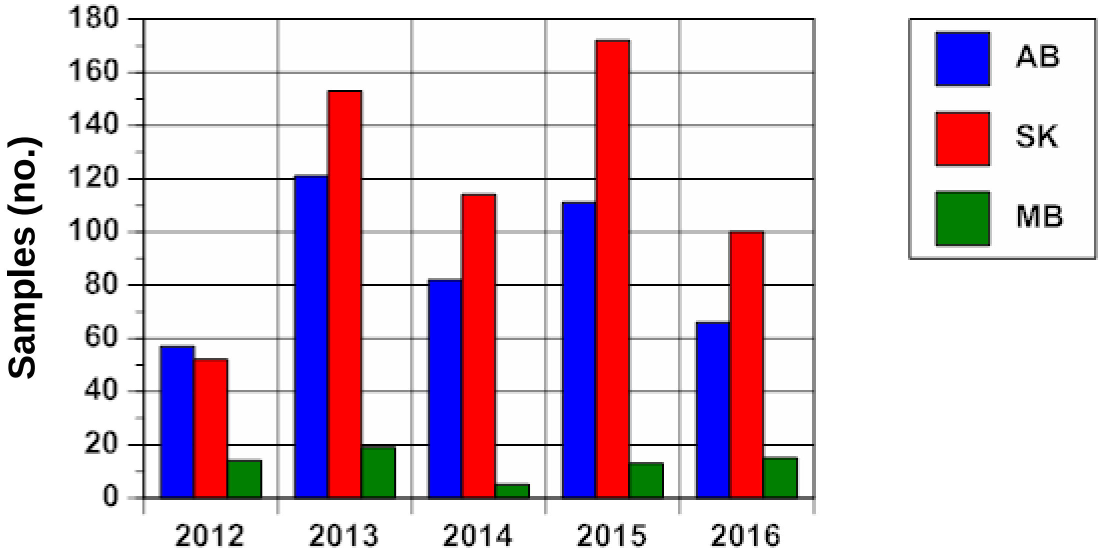
59% of fields where sampled; (32% in 2009, 10% in 2003)



Submissions to the CPL

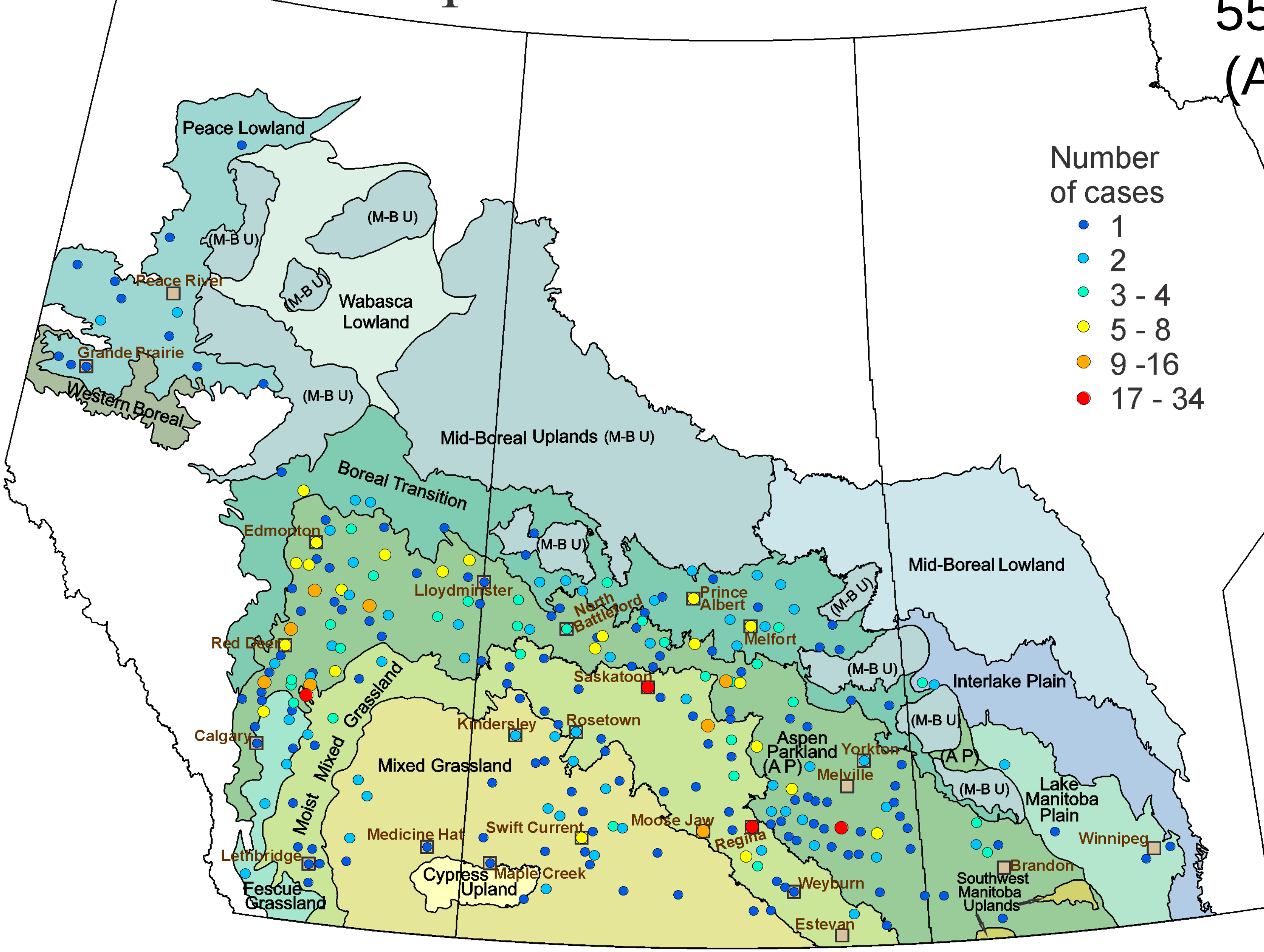


Submissions to the CPL: by province

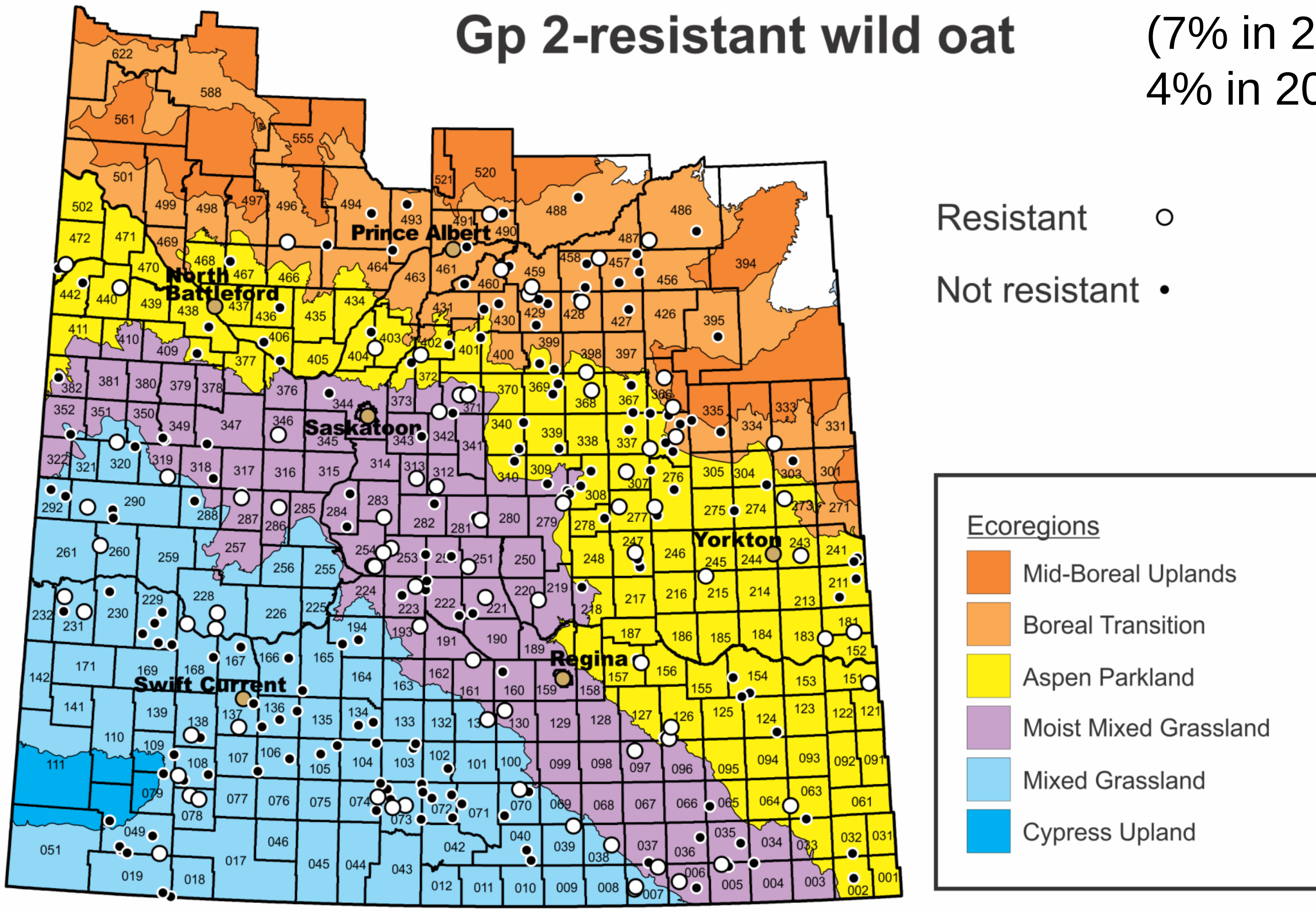


Submissions
2012-2016:
550 cases
(AB=195)

Gp 1-resistant wild oat



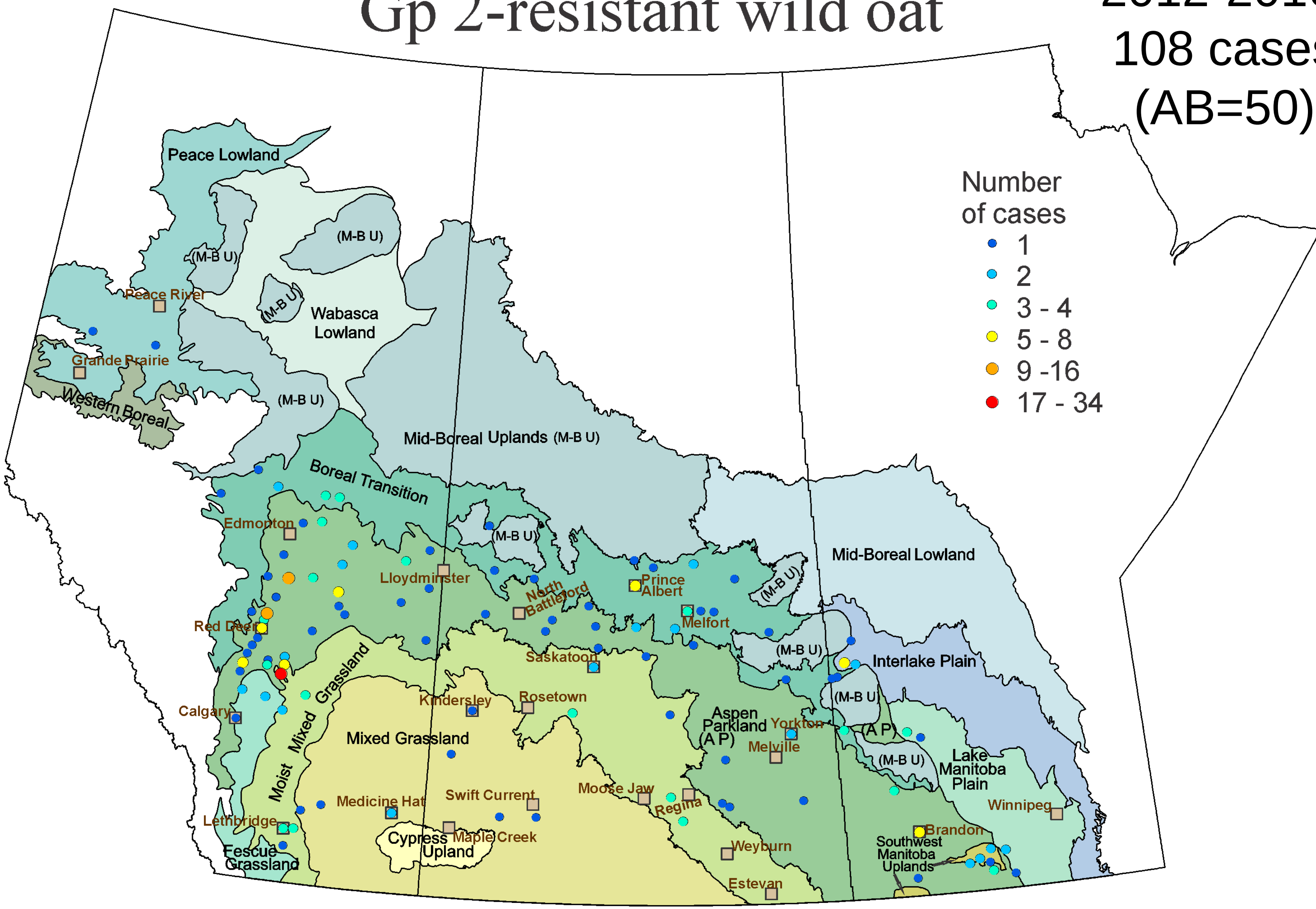
32% of fields where sampled; (7% in 2009, 4% in 2003)



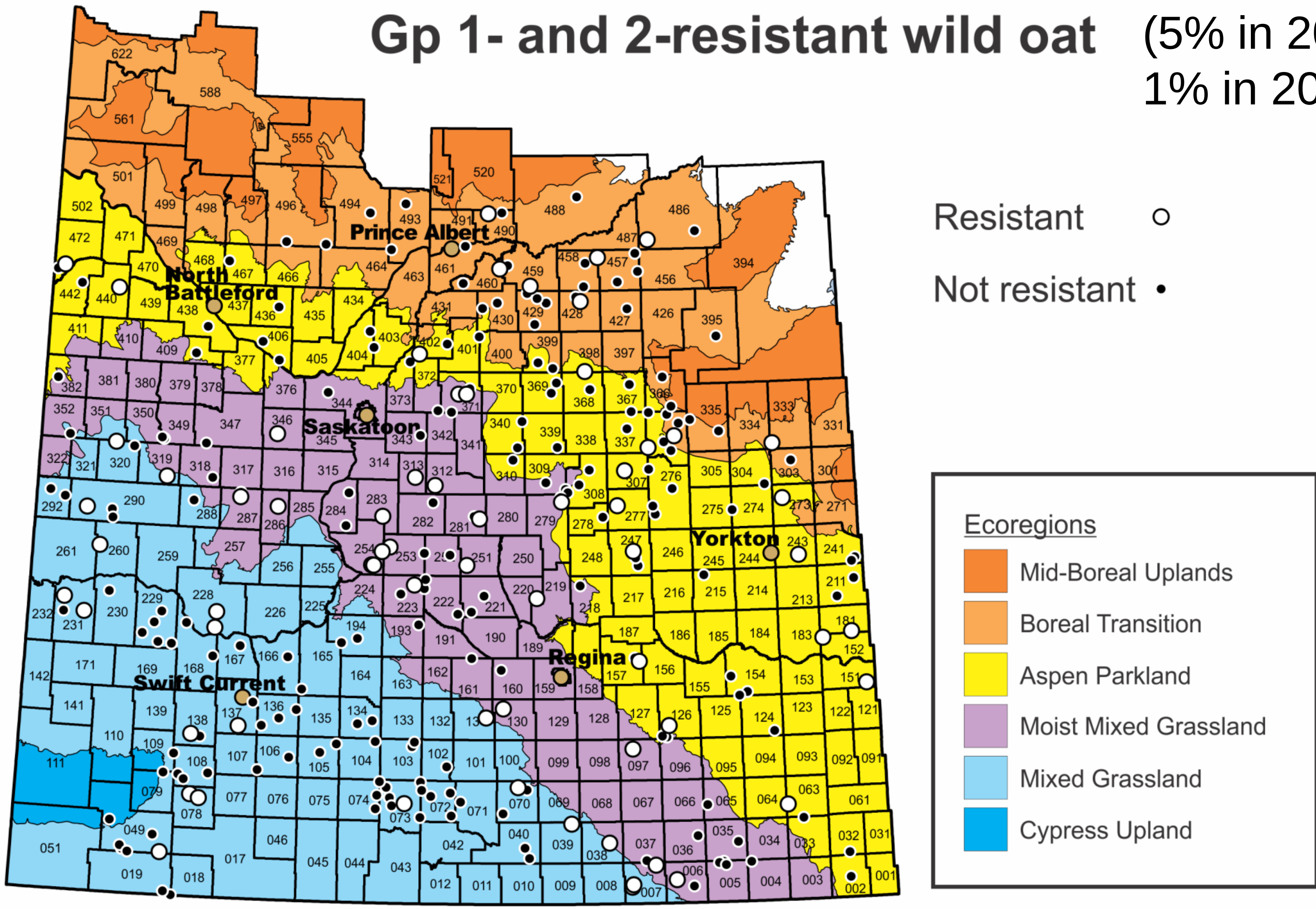
Gp 2-resistant wild oat

Submissions

2012-2016:
108 cases
(AB=50)



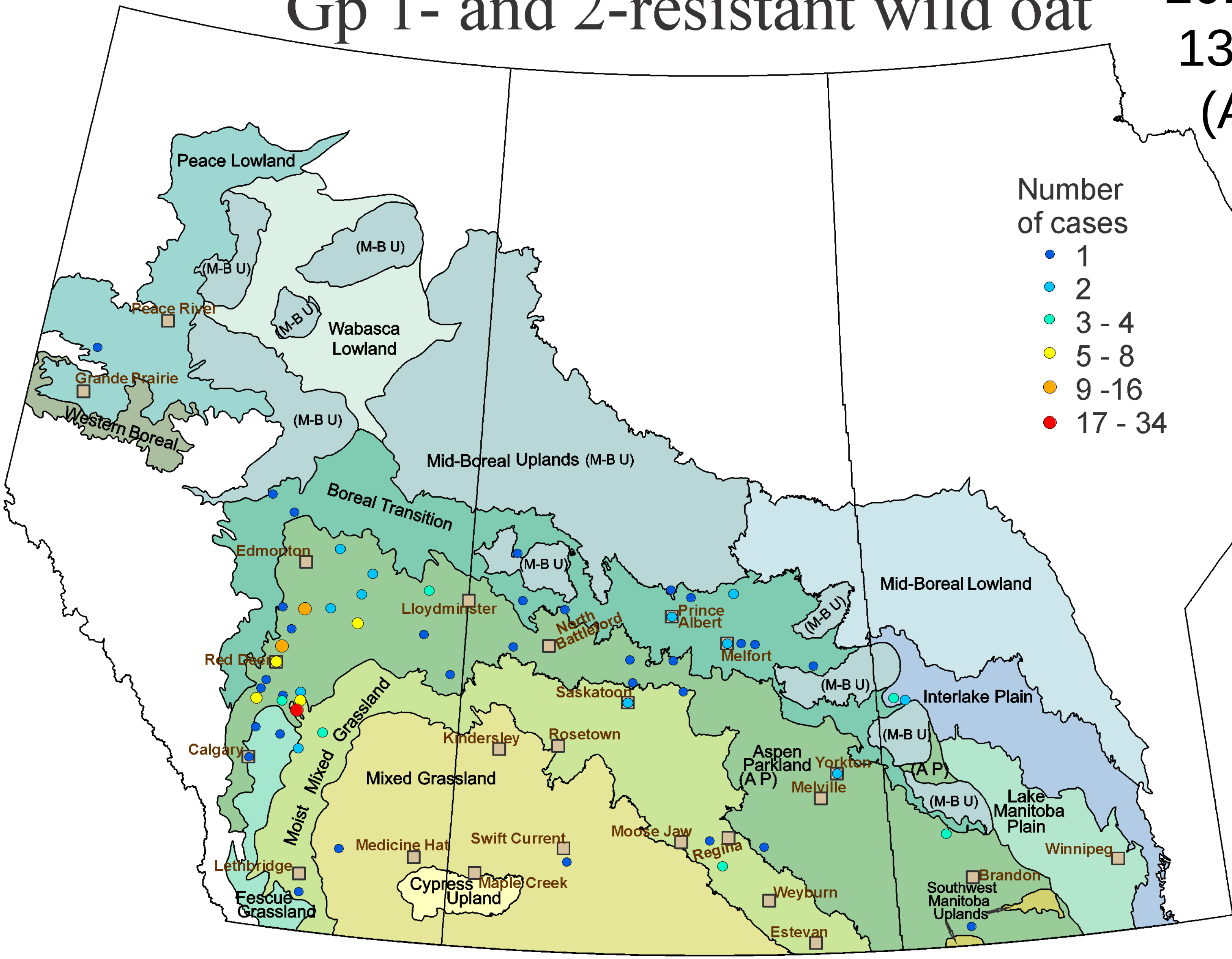
25% of fields where sampled; (5% in 2009, 1% in 2003)



Submissions

2012-2016:
135 cases
(AB=98)

Gp 1- and 2-resistant wild oat

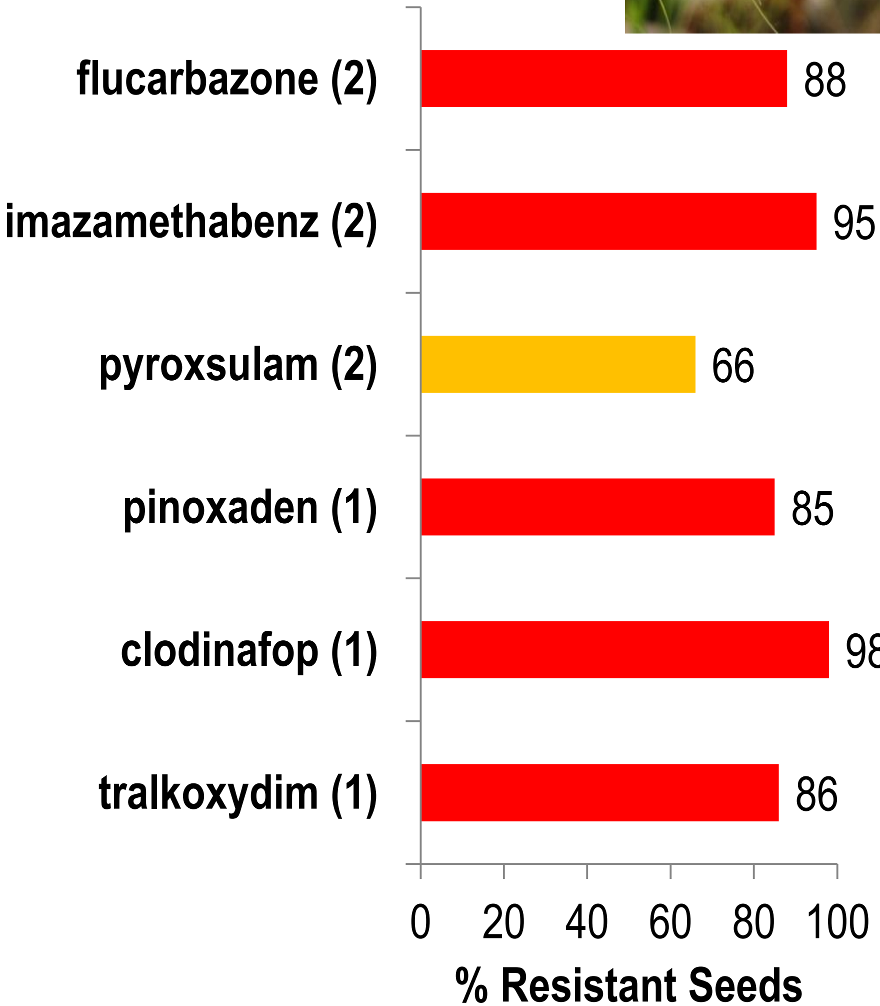


MB 2016 HR weed survey: grass weed resistance

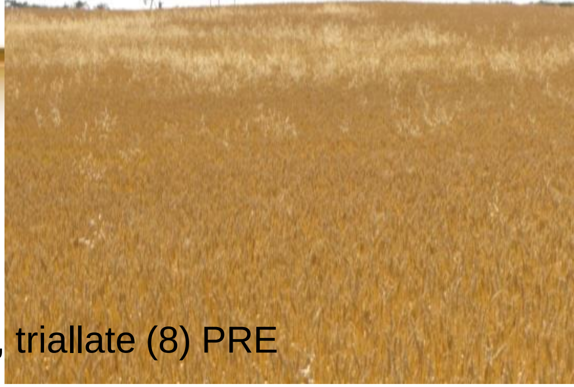
HR biotype	# fields	total fields sampled	%	# municipalities (74)
Gp 1 wild oat	**79**	**101**	**78**	**51**
Gp 2 wild oat	**43**	**101**	**43**	**34**
Gp 1+2 wild oat	**42**	**101**	**42**	**33**
Gp 1 green foxtail	22	50	44	18
Gp 2 green foxtail	3	50	6	3
Gp 1+2 green foxtail	1	50	2	1
Gp 1 yellow foxtail	19	60	32	16
Gp 2 yellow foxtail	10	60	17	8
Gp 1+2 yellow foxtail	4	60	7	4
Gp 2 barnyard grass	3	11	27	3

Multiple-resistant wild oat

Year	Crop	Wild oat herbicides
2004	Wheat	clodinafop
2005	Wheat	fenoxaprop
2006	LL Canola	glufosinate/clethodim + clethodim
2007	Barley	pinoxaden + tralkoxydim
2008	Barley	imazamethabenz
2009	RR Canola	glyphosate + glyphosate
2010	Wheat	triallate/trifluralin + clodinafop
2011	Field pea	ethalfluralin + quizalofop
2012	Wheat	pyroxsulam
2013	LL Canola	Glufosinate/clethodim



Wheat &/or barley herbicide options: Gp 1+2-resistant wild oat



~~Altitude FX (FX2) (CL) – imazamox (2)~~
~~Assert – imazamethabenz (2)~~
~~Aurora – clodinafop (1)~~
Avadex – triallate (8) PRE
~~Avert – imazamethabenz (2)~~
~~Axial (iPak, Xtreme) – pinoxaden (1)~~
~~Bengal WB – fenoxaprop (1)~~
~~Bison – tralkoxydim (1)~~
~~Broadband – pinoxaden (1)~~
~~Bullwhip – clodinafop (1)~~
~~Cordon – fenoxaprop (1)~~
~~Cougar – fenoxaprop (1)~~
~~Everest 2.0 – flucarbazone (2)~~
~~HellCat – fenoxaprop (1)~~
~~Harmony Grass – clodinafop (1)~~
~~Ladder – clodinafop (1)~~
~~Foax – clodinafop (1)~~
~~Foothills NG – clodinafop (1)~~

Suppression:
Focus – pyroxasulfone (15) PRE
Trifluralin (3) PRE

Fortress MicroActiv – trifluralin (3), triallate (8) PRE
~~Inferno Duo – fluracarbazone (2)~~
~~Liquid achieve – tralkoxydim (1)~~
~~Marengo – tralkoxydim (1)~~
~~NextStep NG – clodinafop (1)~~
~~Nufarm Tralkoxydim Liquid – tralkoxydim (1)~~
~~Predicade – thiencarbazone (2)~~
~~Puma Advance – fenoxaprop (1)~~
~~Sierra 2.0 – flucarbazone (2)~~
~~Signal (FSU) – clodinafop (1)~~
~~Simplicity 30 OD (GoDRI) – pyroxsulam (2)~~
~~Slam'R – clodinafop (1)~~
~~Tandem – pyroxsulam (2)~~
~~Traxos (Two) – pinoxaden + clodinafop (1)~~
~~Tundra – fenoxaprop (1)~~
~~Varro – thiencarbazone (2)~~
~~Velocity m3 – thiencarbazone (2)~~
~~Vigil WB – fenoxaprop (1)~~
~~WildCat – fenoxaprop (1)~~

Multiple group-HR wild oat

- Resistance to groups
  1 + 2 + 8+ 25
- Metabolic resistance

Symposium

Nature, Occurrence, and Cost of Herbicide-Resistant Wild Oat (*Avena fatua*) in Small-Grain Production Areas[1]

HUGH J. BECKIE, A. GORDON THOMAS, ANNE LÉGÈRE, DAVID J. KELNER, RENE C. VAN ACKER, and SCOTT MEERS[2]

NRC Research Press

ARTICLE

Triallate-resistant wild oat (*Avena fatua* L.): unexpected resistance to pyroxasulfone and sulfentrazone

Amy R. Mangin, Linda M. Hall, and Hugh J. Beckie

Abstract: Wild oat is the most economically detrimental weed species in the Canadian Prairies and effective herbicidal control options are limited due to widespread resistance to ACCase inhibitors, ALS inhibitors, and lipid biosynthesis inhibitors; therefore, evaluation of new herbicidal modes of action such as pyroxasulfone and sulfentrazone for control is critical. Two wild oat populations (HR08-210 and HR11-151) were first subjected to a discriminating dose screen to characterize resistance to ACCase and ALS inhibiting herbicides in comparison with a susceptible population (S1988). Dose-response experiments with triallate, pyroxasulfone, and sulfentrazone were then conducted to evaluate potential cross-resistance. Screening indicated both herbicide-resistant (HR) populations were resistant to ACCase- and ALS inhibiting herbicides, most likely due to enhanced metabolism and an ACCase mutation. HR08-210 and HR11-151 were resistant to triallate (resistance ratios of 2.53 and 3.39, respectively), but cross-resistance to pyroxasulfone (2.78) and sulfentrazone (2.0) was only observed in HR11-151. Results indicate previously selected resistance to ACCase and ALS inhibitors (enhanced metabolism and ACCase mutation) or triallate (enhanced endogenous gibberellins) could limit the utility of new herbicide modes of action for control of wild oat.

Key words: cross-resistance, multiple resistance.

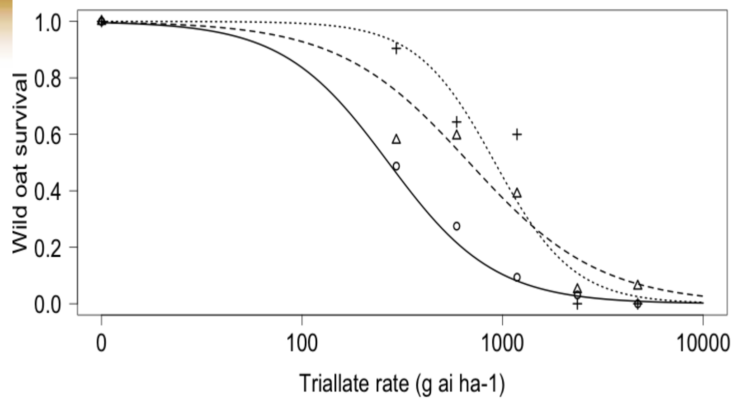
Résumé : La folle avoine est la mauvaise herbe économiquement la plus nuisible dans les Prairies canadiennes et les herbicides permettant de lutter contre elle sont peu nombreux en raison de la résistance très répandue aux

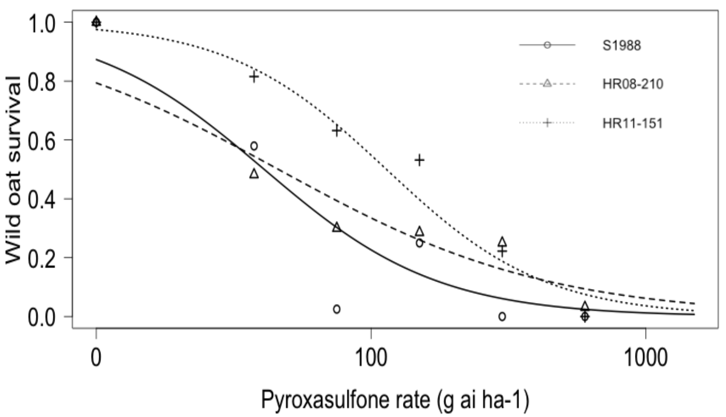
Results: Dose-Response

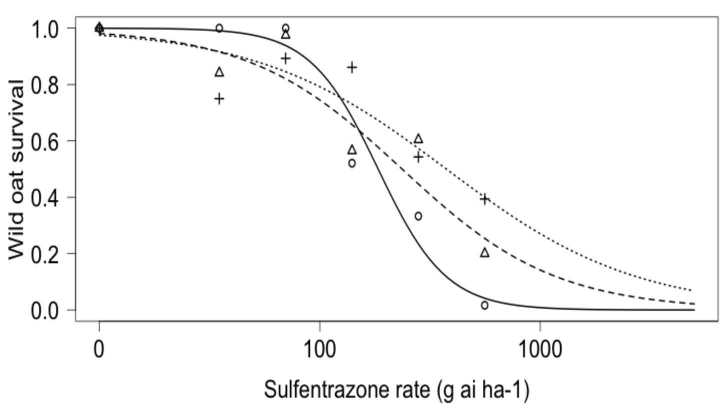
Estimated LD_{50} values and R/S ratios for wild oat populations S1988, HR08-210 and HR11-151 in a dose response study with triallate, pyroxasulfone and sulfentrazone

Biotype	LD_{50} ($\pm$SE)^z	R/S^y	P-value
	-------- g ai ha^{-1} --------		
Triallate			
S1988	270 (50)	-	
HR08-210	681 (95)	2.53	0.0088
HR11-151	915 (81)	3.39	0.0006
Pyroxasulfone			
S1988	41 (8)	-	
HR08-210	46 (13)	1.13	0.7429
HR11-151	114 (13)	2.78	0.0063
Sulfentrazone			
S1988	183 (13)	-	
HR08-210	236 (34)	1.28	0.1740
HR11-151	375 (83)	2.0	0.0290

$^z LD_{50}$, lethal dose to required for 50% survivorship of wild oat biotypes. The values in parentheses are standard errors.
^{y}R/S, ratio (resistant/susceptible) referred to the standard susceptible population S1988.







Herbicide options in field pea

	Wild oat	*Gp 1+2 wild oat*
Clethodim (1)	x	
Sethoxydim (1)	x	
Quizalofop (1)	x	
Sethoxydim + Imazethapyr/imazamox (1+2)	x	
Imazethapyr/imazamox (2)	x	
Imazethapyr (2)	x	
Imazamox+bentazon (2+6)	x	
Ethafluralin (3: PRE)	S	S
Trifluralin (3; PRE)	x	x
Triallate (8; PRE)	x	x

Top 10 HRWM practices


Perspective

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Our top 10 herbicide-resistant weed management practices

Hugh J Beckie[a*] and K Neil Harker[b]

Abstract

Although proactive or reactive herbicide-resistant weed management (HRWM) practices have been recommended to growers in different agroecoregions globally, there is a need to identify and prioritise those having the most impact in mitigating or managing herbicide selection pressure in the northern Great Plains of North America. Our perspective on this issue is based on collaborative research, extension activities and dialogue with growers or farming experience (cereal, oilseed and pulse crop production) during the past 30 years. We list our top 10 HRWM practices, concluding with the number 1 practice which is the foundation of the other nine practices: crop diversity. Although our top 10 HRWM practices have broad applicability across agroecoregions, their ranking may vary widely.

Keywords: best management practices; herbicide resistance; multiple resistance; integrated weed management; resistance management

1 INTRODUCTION

Proactive or reactive herbicide-resistant weed management (HRWM) practices have long been recommended to growers in different agroecoregions. For example, 12 best management practices (BMPs) to reduce the risk of herbicide resistance were published in 2012.[1] However, HRWM practices must be customised to each agroecoregion, which vary by climate, soils and cropping systems. There is a need to identify and prioritise those HRWM practices having the most impact in mitigating or managing herbicide selection pressure in the northern Great Plains of North America.

Our perspective is based on research across western Canada (with numerous collaborators), extension activities (with valuable feedback from growers or others involved in agribusiness) or farming experience (cereal, oilseed and pulse crop production) during the past 30 years. Thus, the content of this perspective article represents our expert opinion and is not meant as a full-length critical review of the subject matter. Although our top 10 HRWM practices outlined below have broad applicability across other agroecoregions in the Americas or overseas, their ranking will likely vary. Further, the relative importance of these practices may differ by weed species, each with their unique biological and ecological characteristics that may affect the relevance or efficacy of a particular practice.

2 OUR TOP 10 HRWM PRACTICES

2.1 Number 10: Maintaining a database: an invaluable reference guide

The starting point for HRWM is maintaining and updating a database each year that chronicles agronomic practices or management operations, particularly those that vary from field to field or from year to year. These agronomic practices could be grouped into cultural (e.g. crop species and cultivar, seeding date and rate), mechanical (tillage operations) and herbicidal weed management variables (pre- and post-emergence herbicides, application parameters and environmental conditions). Because most prairie growers (>85%) have home computers with internet access,[2] spreadsheets can easily be produced and customised. Additionally, software packages of crop and herbicide rotation planners are available in many jurisdictions, which facilitate record-keeping and can flag up high-risk herbicide practices, such as repeated use of products with the same site of action. As detailed later, the database should also contain records of weed species occurrence or abundance and herbicide treatment efficacy, either generally across the field or for specific sites within the field using global positioning system (GPS) coordinates. Overall, maintaining a database of key parameters and constantly reviewing records are a prerequisite for making informed agronomic decisions and especially pesticide decisions for each field or even specific areas of a field. Because about 40% of prairie agricultural land is rented or leased,[3] it would benefit both landowners and renters to have a continuous historical record of past crop management practices that could be included in a land rental agreement.

2.2 Number 9: Strategic tillage: if, where or when needed

Physical or mechanical weed control has traditionally occupied one corner of the integrated weed management (IWM) triangle.

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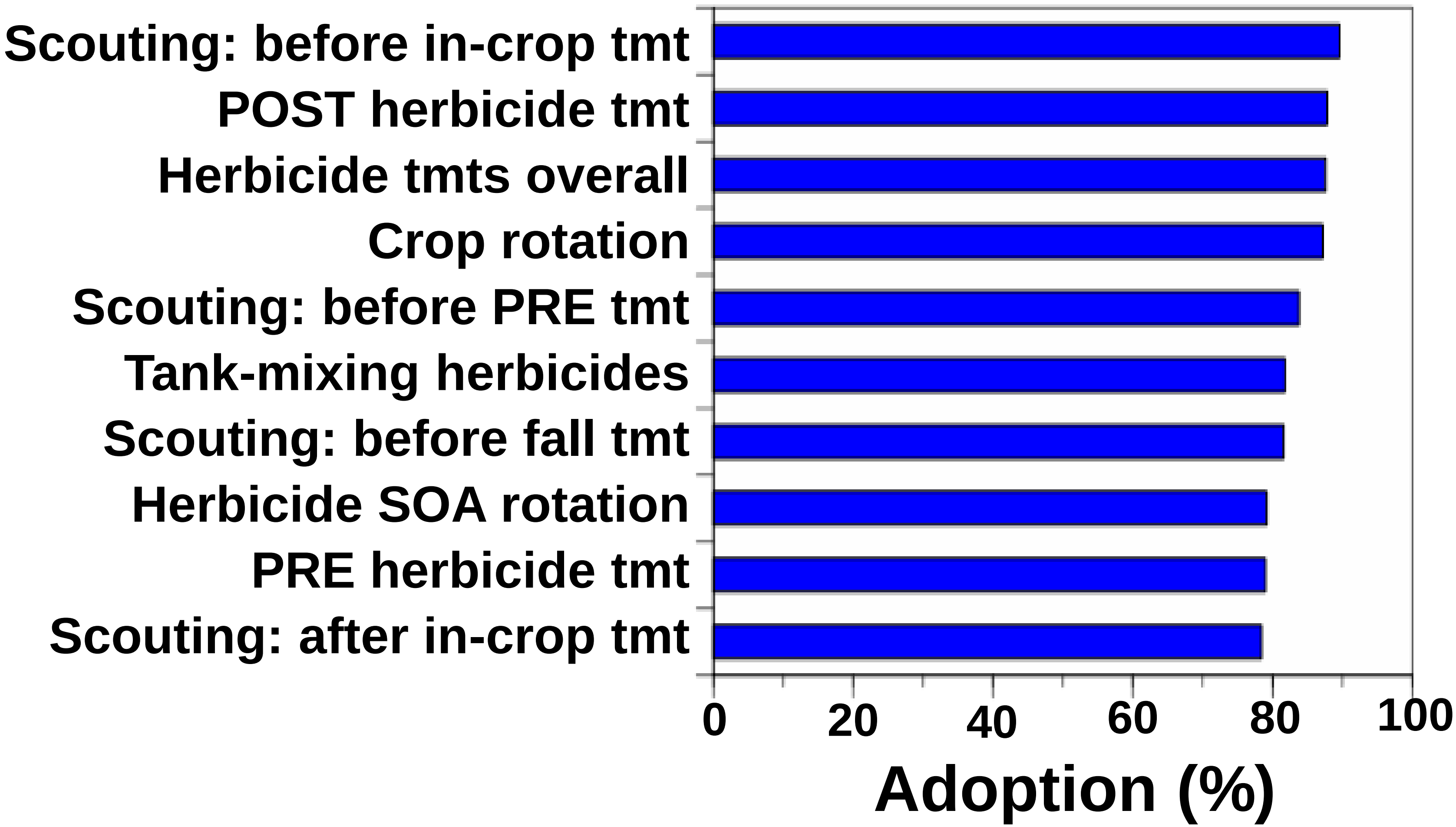
- 10: Maintaining a database: invaluable reference
- 9: Strategic tillage: if, where, or when needed
- 8: Field & site-specific weed mgmt: 1 size may not fit all
- 7: Weed sanitation:border control and slowing HR dispersal
- 6: In-crop wheat-selective herbicide rotation: combating NTSR
- 5: Herbicide gp rotation: avoid back-to-back in-crop gp 1 or 2
- 4: Herbicide mixtures/sequences: better than rotations
- 3: Pre- and post-herbicide scouting: know your enemy
- 2: Competitive crops & practices that promote competitiveness: natural biological control
- 1: Crop diversity

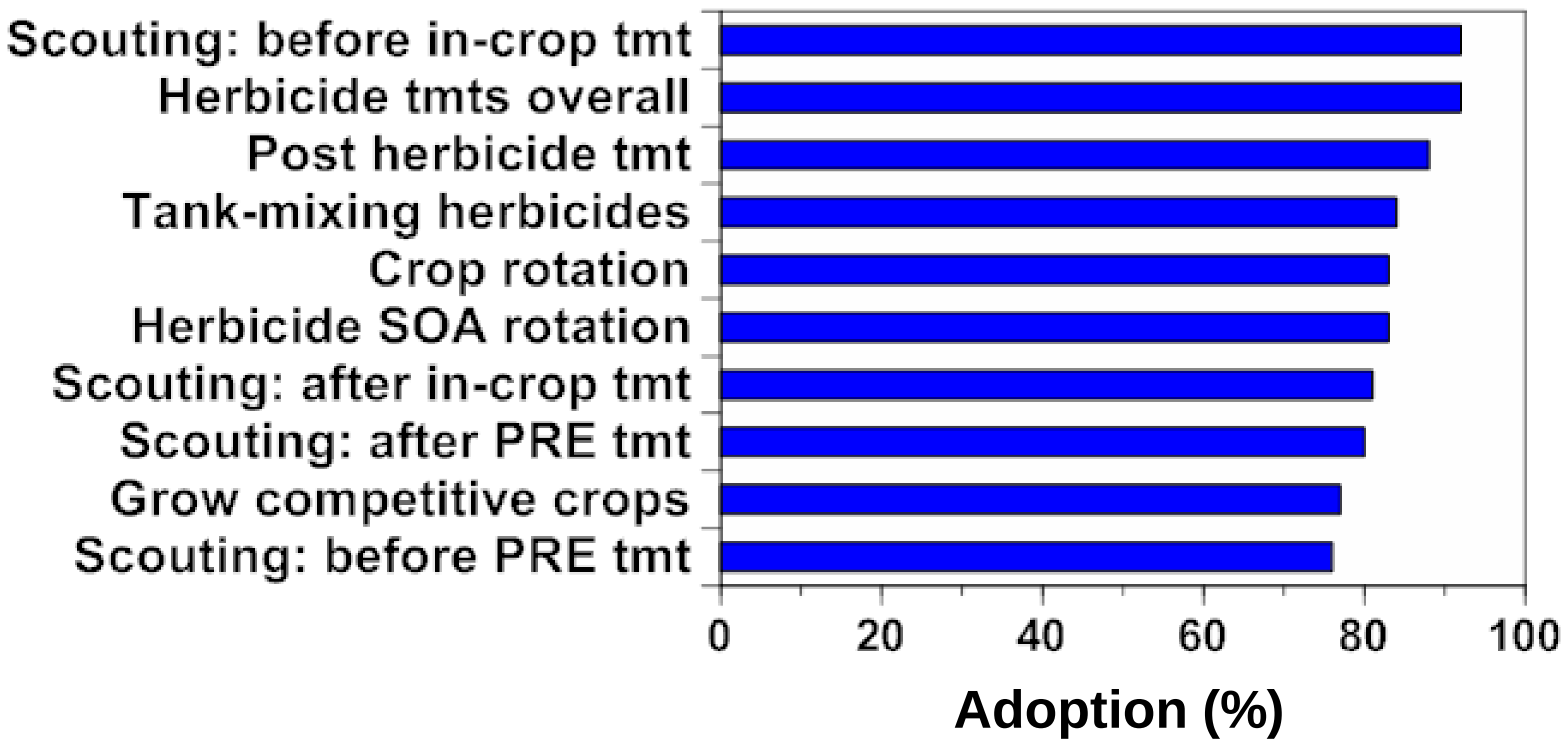
Top 10 weed management practices

2015 SK grower questionnaire (n = 600 respondents)



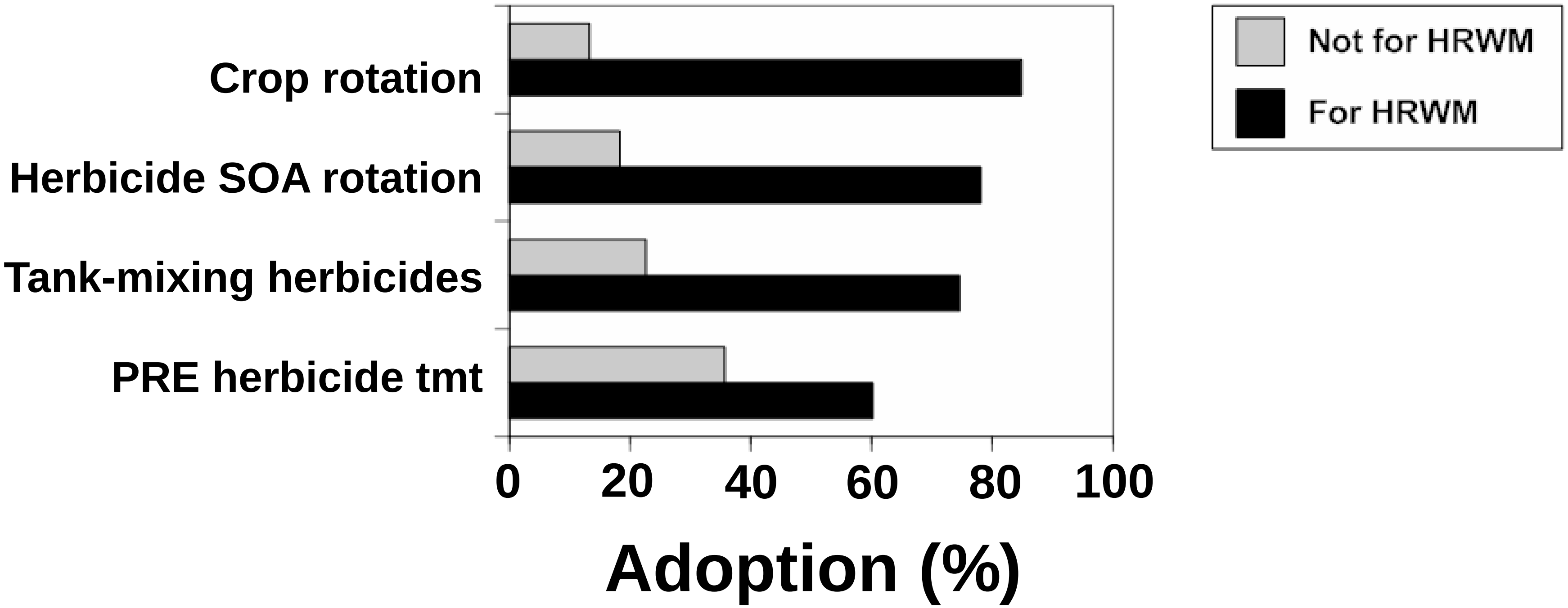
Top 10 weed management practices

2016 MB grower questionnaire (n = 108 respondents)



HRWM practices

2015 SK grower questionnaire (n = 250 respondents)

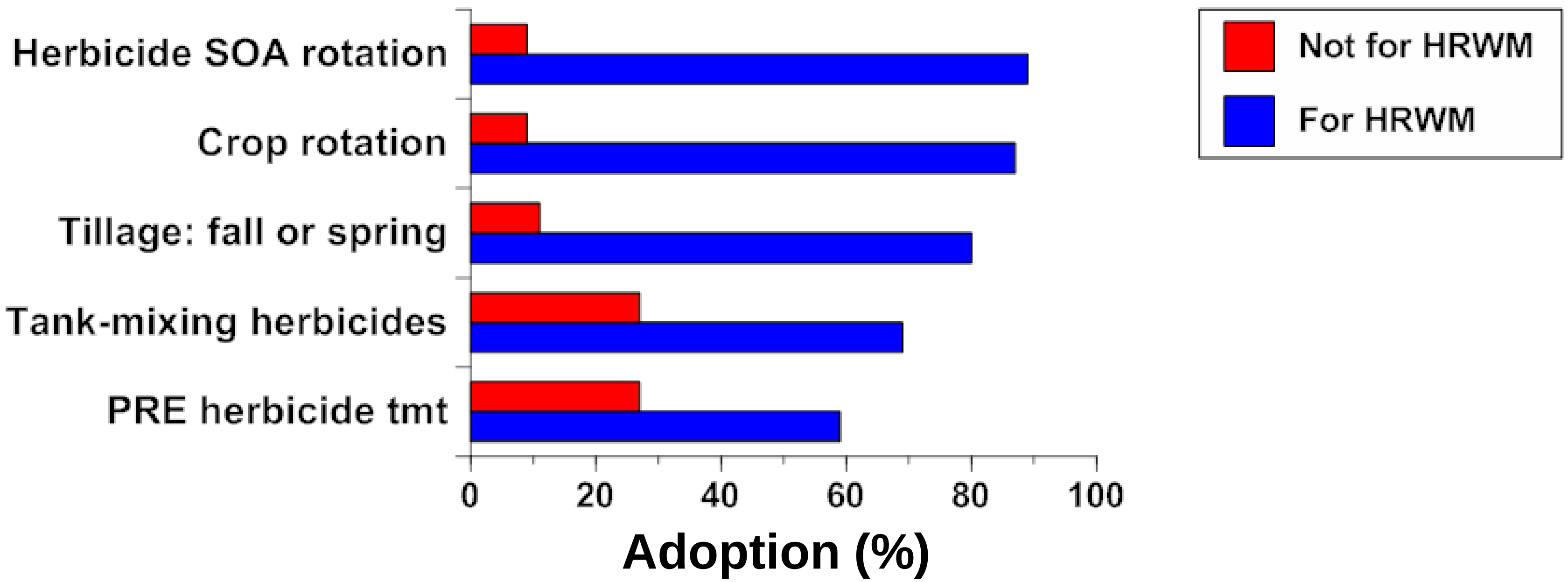


Overall, those with HR weeds rely more on herbicides at all application windows, and have *greater adoption of:*

- scouting before in-crop herbicide treatment
- tank-mixing herbicides
- herbicide SOA rotation
- growing weed-competitive crops
- increasing crop seeding rates *vs. those without resistance*

HRWM practices

2016 MB grower questionnaire (n = 48 respondents)



Overall, those with HR weeds rely more on herbicides at all application windows, and have *greater adoption of:*

- scouting before in-crop herbicide treatment
- tank-mixing herbicides
- herbicide SOA rotation
- growing weed-competitive crops
- tillage
- *vs. those without resistance*

The cost of weed resistance in Saskatchewan: 2015

	% of respondents (250)	
No additional cost	7	
$10/ac or less	41	($24.70/ha or less)
$11 - $20/ac	23	(- $49.40/ha)
$21 - $30/ac	11	(- $74.10/ha)
$31 - $40/ac	6	(- $98.80/ha)
$41 – 50 /ac	4	(- $123.50/ha)
Unknown cost	8	

Mean cost = $12 per acre or $30 per hectare

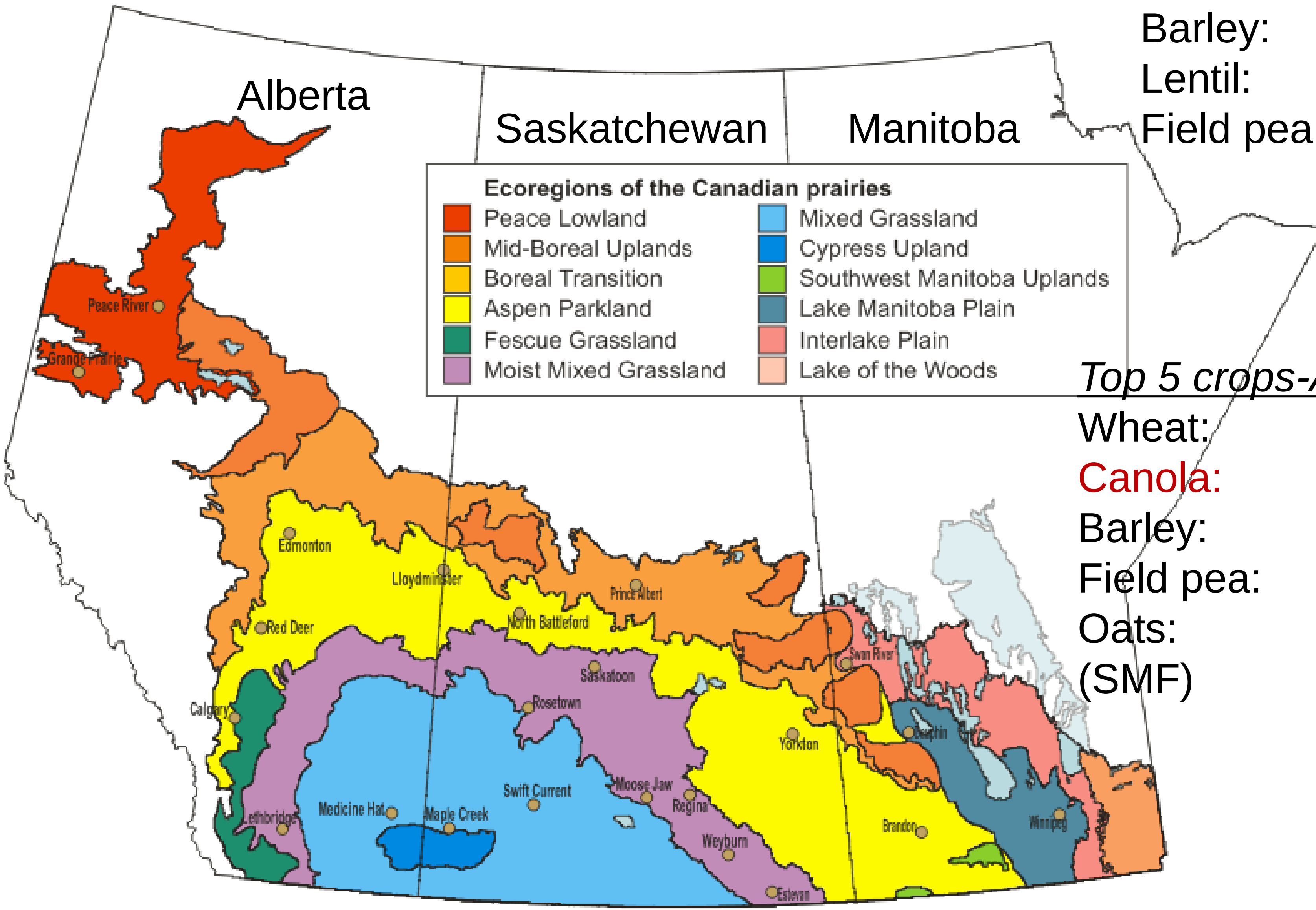
The cost of weed resistance in Manitoba: 2016

	% of respondents (50)	
No additional cost	5	
$10/ac or less	56	($24.70/ha or less)
$11 - $20/ac	23	(- $49.40/ha)
$21 - $30/ac	9	(- $74.10/ha)
$31 - $40/ac	7	(- $98.80/ha)
$41 – 50 /ac	0	(- $123.50/ha)
Unknown cost	0	

Mean cost = $11 per acre or $27 per hectare

Annual crop area: 70 M ac

Top 5 crops (M ac)	
Canola:	22.9
Wheat:	21.2
Barley:	5.5
Lentil:	4.4
Field pea:	4.1

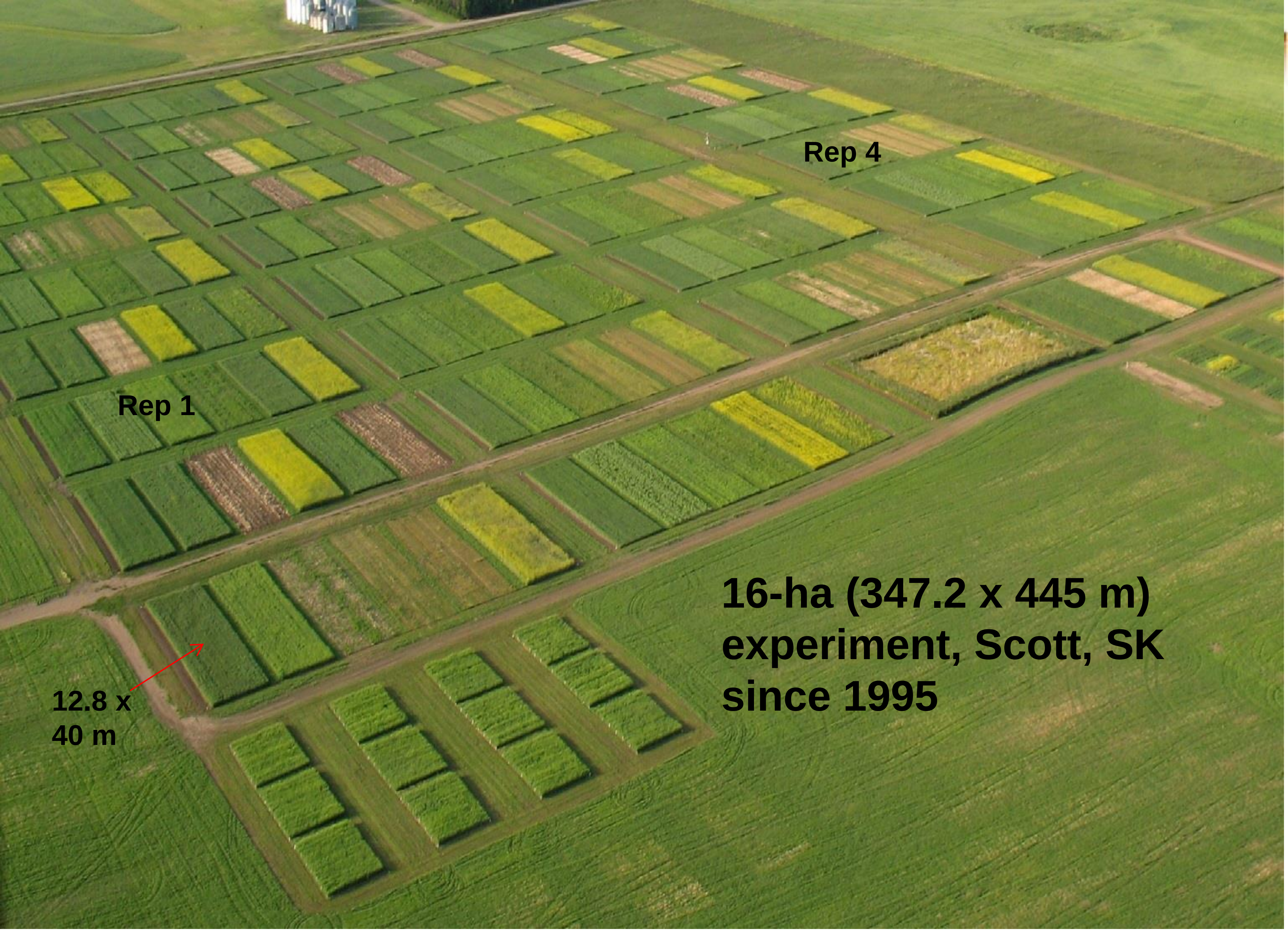


Top 5 crops-AB (M ac)	
Wheat:	7.1
Canola:	6.9
Barley:	2.8
Field pea:	1.8
Oats:	0.7
(SMF)	(0.8)

HR canola in rotation:
- ca. ½ RR; ½ LL
(2012-2014 crop years)

(220 respondents)	*%*
Canola 1 in 2 yr	46
Canola 1 in 3 yr	23
Canola 1 in 4 yr or less	17
Continuous canola	4
No canola	10

Net return: $/ac (2017):	
Wheat:	95
Canola:	178
Barley (malt):	69
Lentil:	275
Field pea:	103


Rep 4
Rep 1
12.8 x
40 m
16-ha (347.2 x 445 m)
experiment, Scott, SK
since 1995

Nine alternative cropping systems

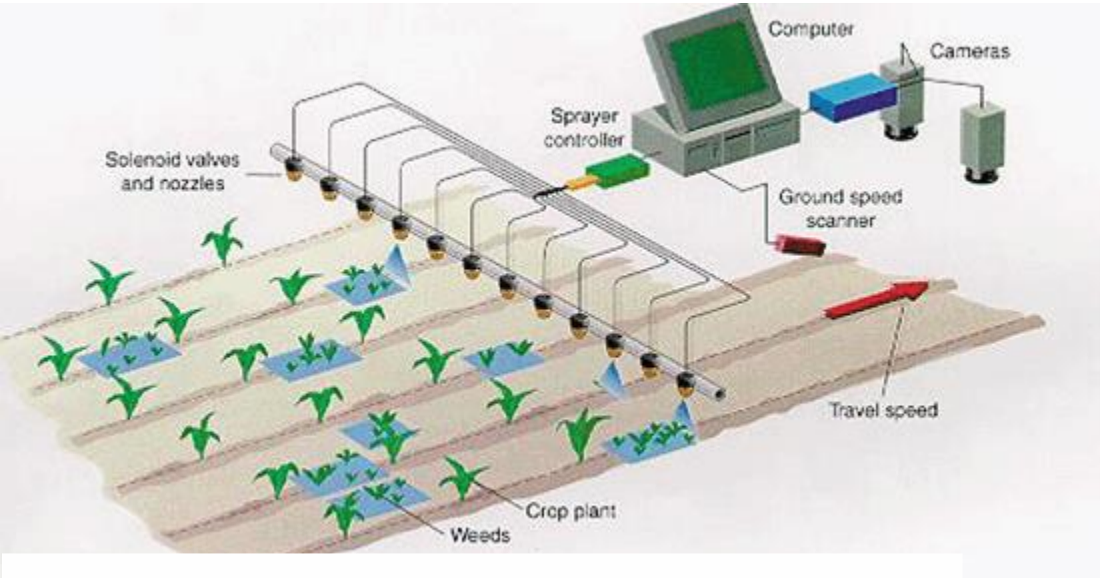
Input level	Diversity level	Crop sequence
HIGH	DAG	Can-rye-pea-bar-flx-whe
	DAP	Bar-alf-alf-alf-can-whe
	LOW	TF-can-whe-TF-whe-whe
RED	DAG	Can-rye-pea-bar-flx-whe
	DAP	Bar-alf-alf-alf-can-whe
	LOW	CF-can-whe-GM-whe-whe
ORG	DAG	GM-whe-pea-bar-GM-mus
	DAP	Bar-alf-alf-alf-mus-whe
	LOW	GM-mus-whe-GM-whe-whe

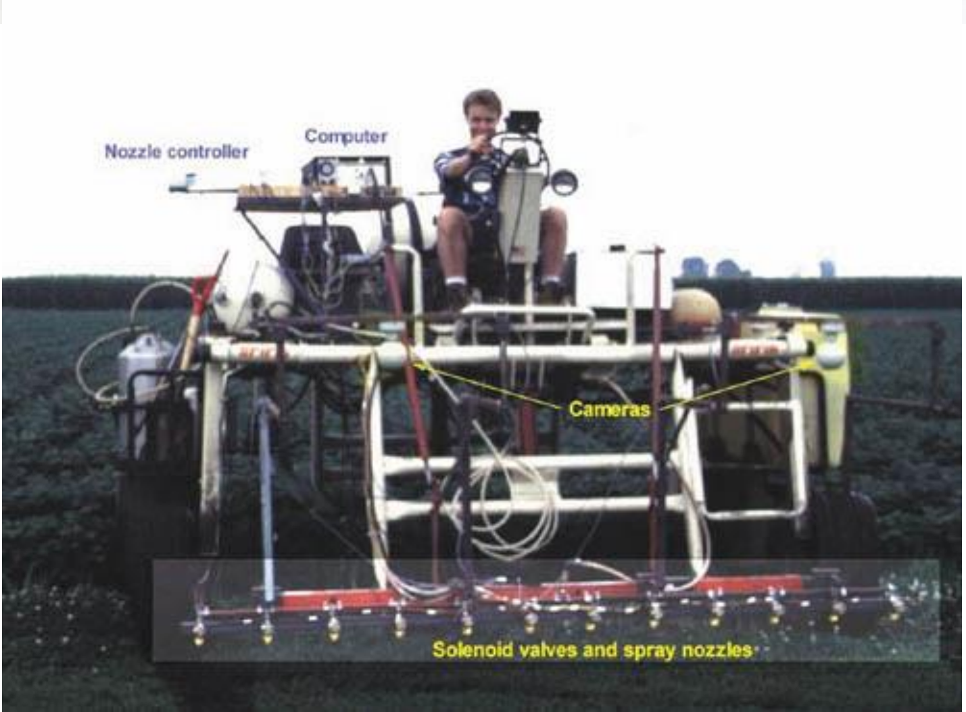
Gp 1-resistant wild oat population frequency

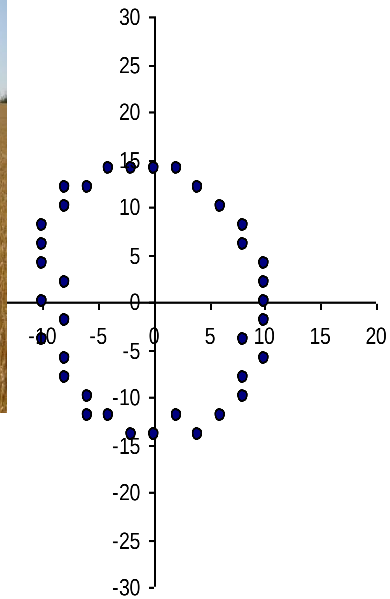
Cropping system	Gp 1 appl. **(no.)**	WO panicles **(no. m^{-2})**	WO resistance **(%)**
HIGH-DAG	10	6.8 *c*	42.3 *b*
HIGH-DAP	6	0.7 *d*	2.7 *d*
HIGH-LOW	4	13.4 *b*	12.3 *c*
RED-DAG	7	7.4 *c*	60.0 *a*
RED-DAP	4	2.8 *d*	0 *d*
RED-LOW	5	18.0 *a*	14.9 *c*
ORG-LOW	0	11.1 *b*	0 *d*

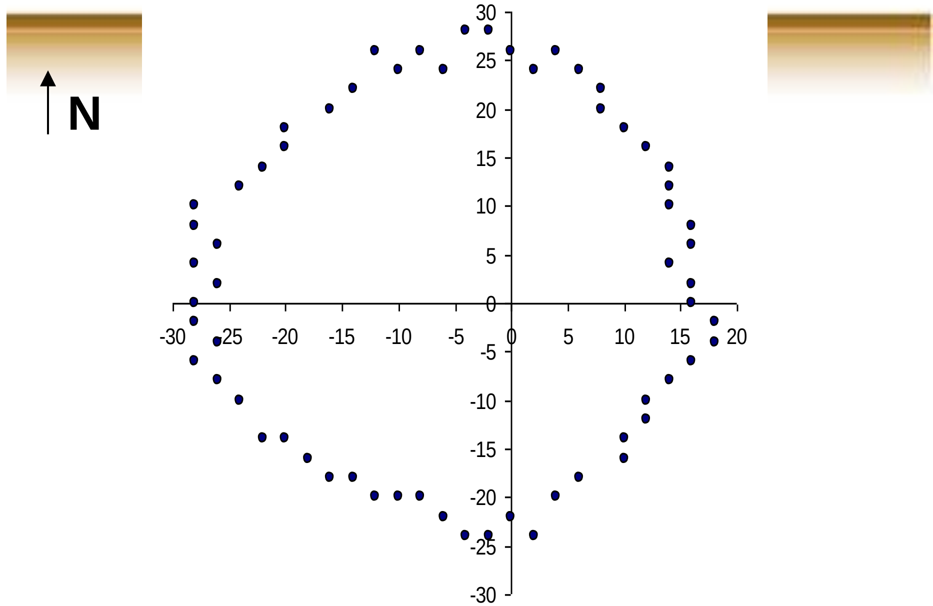
a-*d*: LSD test

Site-specific weed management



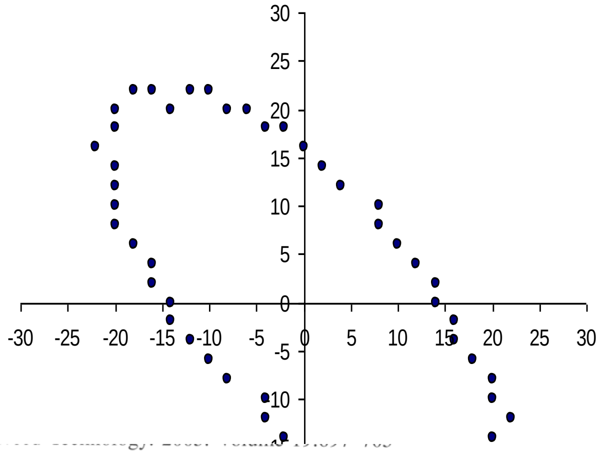


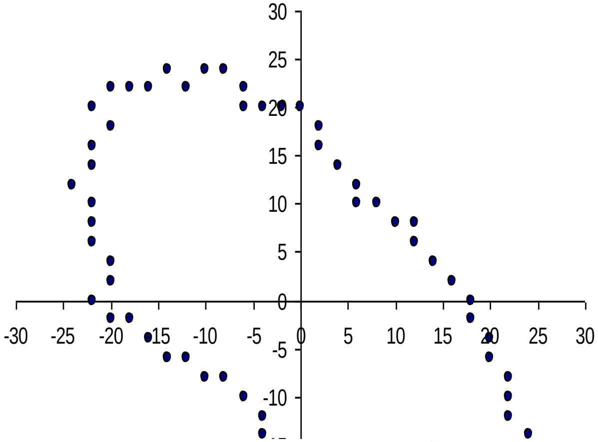




Nontreated

1997 → **2002**





Treated

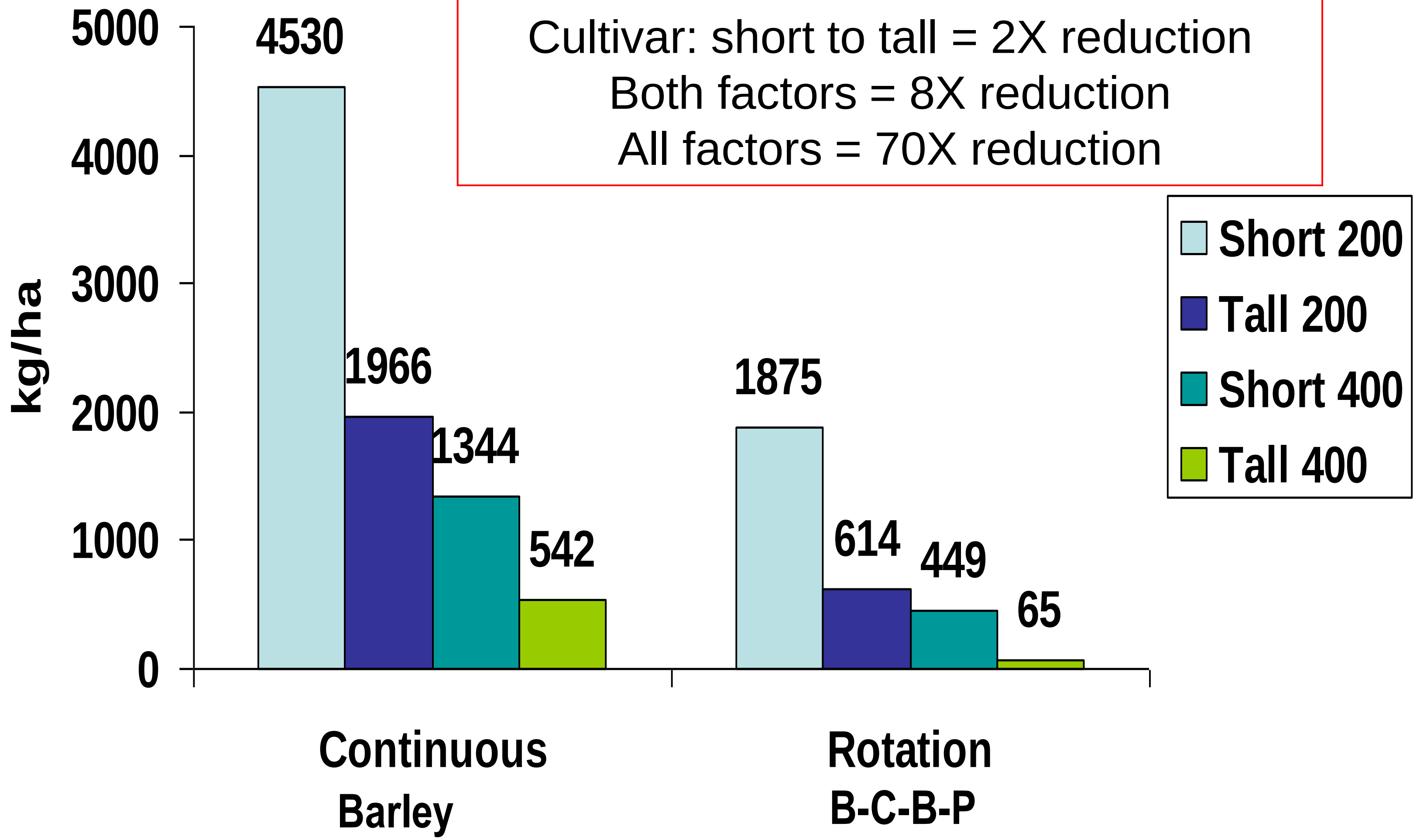
Patch Management of Herbicide-Resistant Wild Oat (*Avena fatua*)[1]

HUGH J. BECKIE, LINDA M. HALL, and BARCLAY SCHUBA[2]

Panicle Clipping

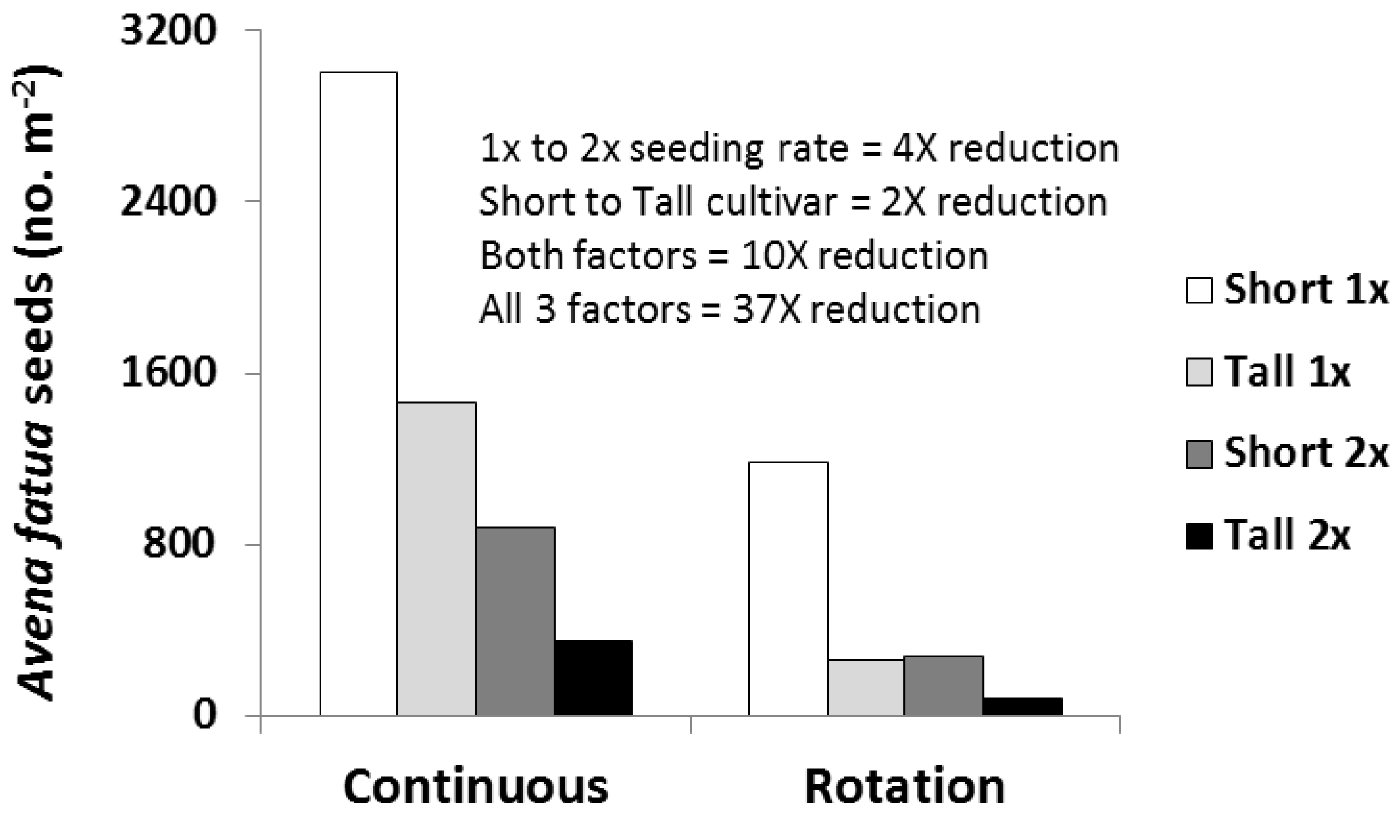
Wild oat biomass at maturity

Seed rate: 200 to 400/m^2 = 3X reduction
Cultivar: short to tall = 2X reduction
Both factors = 8X reduction
All factors = 70X reduction



(Harker et al.)

Wild oat seed production



Weed Science 2016 64:673–682

Evaluating Seed Shatter of Economically Important Weed Species

Nikki R. Burton, Hugh J. Beckie, Christian J. Willenborg, Steven J. Shirtliffe, Jeff J. Schoenau, and Eric N. Johnson*

The increasing occurrence of herbicide resist
developed in over 30 yr, have increased the ne
tactics. Harvest weed seed control (HWSC) p
manage problematic weeds. For HWSC to b
retained on the plant at crop maturity. This 2
oat, green foxtail, wild mustard, and cleavers
maturity crop in field experiments at Scott, S
trays collected once a week during crop ripeni
stages (swathing, direct-combining). Seed sh
between crops at maturity: ca. 30% for wild oa
for green foxtail. Overall, seed shatter of wilc

Weed Science 2017 65:650–658

Factors Affecting Weed Seed Devitalization with the Harrington Seed Destructor

Breanne D. Tidemann, Linda M. Hall, K. Neil Harker, and Hugh J. Beckie*

The Harrington Seed Destructor (HSD), a novel weed control technology, has been highly

Conclusions

- Continual weed resistance surveillance via field surveys and submission sample testing is a continuing high priority
- Present and future weeds (?) with glyphosate resistance is and will be an important focal point of research
- BUT…. overall, wild oat (multiple) resistance will continue to be the #1 HR weed problem across western Canada
- Consistent application of BMPs is the best long-term strategy (tortoise vs. hare fable)
- W. Canada producers are now using a number of these BMPs – but we need new tools soon!