Preventing Herbicide Resistance

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Introduction

Herbicide resistant weeds can "arrive" on a farm in a number of different ways: 1) you can select resistant weeds through repeated use of one herbicide group; 2) resistant weed seeds may be contained in seedlots or in farm machinery; 3) resistant weed seeds may be delivered to your farm fields by nature (birds, water, wind, etc.). Of these three avenues, the first is by far the most important. Therefore, strategies to prevent herbicide resistance must involve reducing selection pressure on weeds.

In the first truly random weed resistance survey in Manitoba (2004), 40% of wild oats in farm fields were found to be resistant to group 1 herbicide and 13% were resistant to group 2 herbicides (Murray, 2004). Over one-half of wild oats resistant to group 2 were also resistant to group 1. Clearly, conventional farming systems have failed to prevent herbicide resistant weeds entering the farm. The problem of herbicide resistance in conventional farming systems will undoubtedly be aggravated as more field crops are made resistant to only a few herbicide groups. One thing is clear, farmers who do not change their farming systems will have to deal with more herbicide resistant weeds in the future.

During the past 10 years, extension workers have advised farmers to rotate herbicide groups in order to avoid selection of resistant weeds. Unfortunately, this strategy has had limited success due to lack of herbicide diversity. It appears, therefore, that the best way to avoid herbicide resistant weeds is to reduce herbicide use.

Strategies for herbicide use reduction in specific rotation types

Low farm diversity. Opportunities to reduce herbicide use in farming systems characterized by simple crop rotations are low. These farming systems tend to be dominated by a few weeds, such as wild oat and Canada thistle. Skipping herbicides is possible in certain years, however predictability of herbicide reduction is low. Skipping herbicides in simple rotations often results in a weed outbreak, increasing the weed seedbank. These higher weed populations may actually increase the chances of selecting for herbicide resistance in future. Options for herbicide reduction in simple rotations include: timing pre-emergence glyphosate application to maximize crop advantage over weeds; fertilizer placement and application timing that favours crop growth over weed growth; reducing N fertilizer rates; choosing competitive crop types (oats, fall rye); introducing fallow periods into the rotation. Seeding date is also a very powerful weed management tool, especially for wild oat (Figure 1).

Figure 1. The effect of four different six-year rotations on wild oat populations, based on research conducted by Agriculture and Agri-Food Canada in northern Alberta.

Rotation	% decrease in wild oat
Delayed-seeded crops (3 years out of 6)	86.7
Fall rye (2 years out of 6)	66.2
Sod crops (Brome) (3 years out of 6)	46.7
Alternate wheat-fallow	3.7

From *Principles and Practices of Commercial Farming*, University of Manitoba (1968).

Diversified annual grain crop rotations.
Opportunities to reduce herbicide use in farming systems characterized by diverse grain rotations are actually quite good. The PFP (Pesticide-Free Production) research and on-farm trials in Manitoba and eastern Saskatchewan clearly show that herbicides can be eliminated in certain years without threatening crop yield or the bottom line. A number of examples of herbicide reduction on farm are given on our website (www.umanitoba.ca/outreach/fewerchemicals).

Five years of trials at Carman, and Brandon, MB, showed that oat yields were never affected by skipping in-crop herbicide use when a diverse rotation was used. The rotation at Carman was wheat-linola-oat-canola while the rotation at Brandon was wheat-canola-oat-pea. Both systems are under no-till management. Crops following PFP oat did have significantly higher weed populations (Table 2), which may increase selection pressure for resistant weeds. However, yields of crops following PFP crops (canola at Carman; pea at Brandon) were never negatively affected by having a preceeding PFP oat crop (Table 3 and Figure 1, respectively). In fact, in one year (2003 at Carman), the yield of canola following PFP was oat was actually significantly higher than canola after sprayed oat.

Skipping in-crop herbicide use in linola (done at Carman only) was less successful than skipping herbicides in oat. Eliminating in-crop herbicide use in linola dramatically increased future weed problems. Although unsprayed linola (PFP) yielded 30 to 50% less than where an in-crop herbicide was used (Table 3), yields of crops following PFP linola were also not affected by having a preceeding PFP linola crop. These studies (Schoofs et al., 2005; Renewable Ag and Food Systems) clearly point out that herbicide use can be reduced in no-till annual crop rotations, however weed populations did increase. Anytime weed populations increase, the risk of future resistance selection also increases.
Chaff collection is known to remove weeds from farmland. However, in the Brandon trial, chaff collection every year made no difference to the success of herbicide use reduction (Figure 1).

Table 2. Total weed seedling density (seedlings m^{-2}) as influenced by PFP and crop rotation at Carman, MB. Means with different letters are considered to be significantly different (p<0.05).

Rotation	2000	2001	2002	2003	2004
	--------Linola--------				
pfp linola[1]-pfp oat-canola-wheat	-	42	11	97	309*bc*
linola-pfp oat-canola-wheat	-	24	7	100	162*cd*
linola-oat-canola-wheat	18	8	77	170	87*d*
pfp linola-pfp oat-alfalfa-alfalfa	-	7	40	248	593*a*
linola-pfp oat-alfalfa-alfalfa	19	9	29	269	548*ab*
linola-oat-alfalfa-alfalfa	-	18	23	174	456*ab*
	--------Oat--------				
pfp linola-**pfp oat**-canola-wheat	-	-	852*a*	4040	552*c*
linola-**pfp oat**-canola-wheat	-	24	368*b*	2068	470*c*
linola-**oat**-canola-wheat	20	32	195*b*	2897	1330*b*
pfp linola-**pfp oat**-alfalfa-alfalfa	-	-	813*a*	2056	2772*a*
linola-**pfp oat**-alfalfa-alfalfa	-	17	184*b*	1064	707*c*
linola-**oat**-alfalfa-alfalfa	23	37	183*b*	972	571*c*
	--------Canola--------				
pfp linola-pfp oat-**canola**-wheat	-	-	-	777	1300*a*
linola-pfp oat-**canola**-wheat	-	39	152	485	1179*a*
linola-oat-**canola**-wheat	14	26	10	259	324*b*
	-------- Wheat --------				
pfp linola-pfp oat-canola-**wheat**				-	490*b*
linola-pfp oat-canola-**wheat**	-	-	18	622	584*b*
linola-oat-canola-**wheat**	14	14	16	522	1074*a*
	--------Alfalfa--------				
pfp linola-pfp oat-**alfalfa**-alfalfa	-	-	-	1199	611*a*
linola-pfp oat-**alfalfa**-alfalfa	-	16	44	1165	1412*a*
linola-oat-**alfalfa**-alfalfa	12	19	6	1091	130*b*

[1] weed seedling density is for the bolded and underlined crop

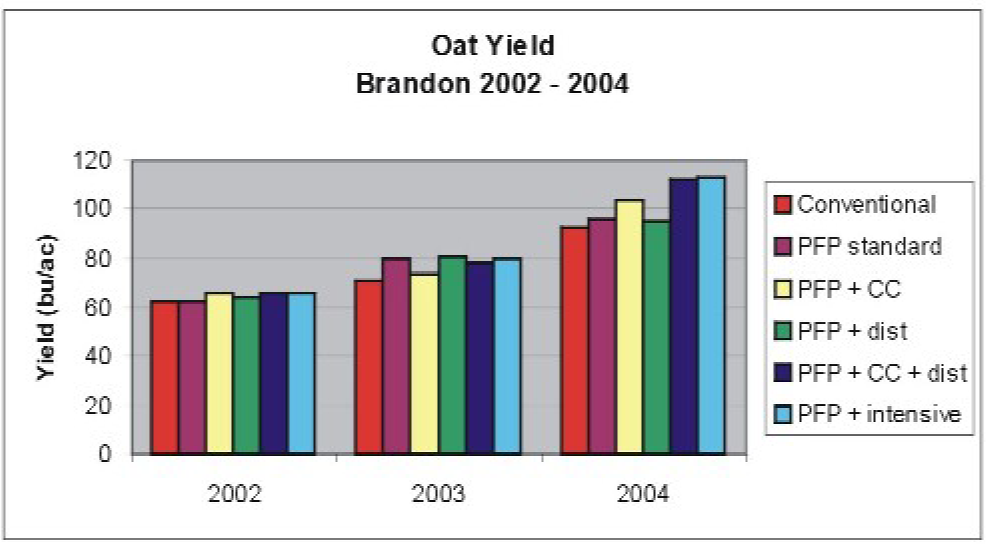
Table 3. Grain and forage yield (kg ha^{-1}) for the for the Pesticide Free Production crop rotation study 2000-2004. Means with different letters are considered to be significantly different (p<0.05).

Rotation	2000	2001	2002	2003	2004
	--------Linola--------				
pfp linola[1]-pfp oat-canola-wheat	-	672*b*	1139*bc*	1250*cd*	1134*bc*
linola-pfp oat-canola-wheat	-	1106*a*	3378*a*	1700*a*	1557*a*
linola-oat-canola-wheat	-	1026*a*	2440*ab*	1629*ab*	1299*ab*
pfp linola-pfp oat-alfalfa-alfalfa	-	1030*a*	1461*bc*	1040*d*	781*c*
linola-pfp oat-alfalfa-alfalfa	-	1130*a*	2831*a*	1430*abc*	1192*abc*
linola-oat-alfalfa-alfalfa	-	1284*a*	3180*a*	1347*bc*	1199*ab*
	--------Oat--------				
pfp linola-**pfp oat**-canola-wheat	-	-	4277	4962*a*	4894
linola-**pfp oat**-canola-wheat	5241	3306	4287	4974*a*	5103
linola-**oat**-canola-wheat	5017	3007	3389	4951*a*	4253
pfp linola-**pfp oat**-alfalfa-alfalfa	-	-	3781	3794*b*	4622
linola-**pfp oat**-alfalfa-alfalfa	4948	2851	3376	4186*b*	4499
linola-**oat**-alfalfa-alfalfa	4709	3196	3601	4149*b*	4933
	--------Canola--------				
pfp linola-pfp oat-**canola**-wheat	-	-	-	2552*a*	3288

linola-pfp oat-**canola**-wheat	-	1957	1843	2494*a*	3537
linola-oat-**canola**-wheat	-	2390	1615	1745*b*	3316
	-----------------------------------Wheat-----------------------------------				
pfp linola-pfp oat-canola-**wheat**	-	-	-	-	4787
linola-pfp oat-canola-**wheat**	-	-	3010	4454	4735
linola-oat-canola-**wheat**	3566	2271	2998	4580	4535
	------------------------------Alfalfa (year 1)------------------------------				
pfp linola-pfp oat-**alfalfa**-alfalfa	-	-	-	6189	3746
linola-pfp oat-**alfalfa**-alfalfa	-	12241	5130*a*	6418	3967
linola-oat-**alfalfa**-alfalfa	5804	10155	4513*b*	5932	5435
	------------------------------Alfalfa (year 2)------------------------------				
pfp linola-pfp oat-alfalfa-**alfalfa**	-	-	-	-	9557
linola-pfp oat-alfalfa-**alfalfa**	-	-	11394	11988	9667
linola-oat-alfalfa-**alfalfa**	5589	8925	12189	13516	9260

[1] grain or forage yield is for the bolded and underlined crop

Figure 1. Oat yield at Brandon, MB grown in a wheat-canola-oat-pea rotation under different herbicide intensities. PFP=Pesticide-Free Production; CC=chaff collection every year; Dist=soil disturbance with rotary harrow in autumn before oat production; Intensive=additional herbicide application on peas following oat.



Annual rotations with silage crops

Inserting silage crops into annual rotations provides additional opportunities to reduce herbicide use. First, silage crops often do not require herbicides to maximize silage yield and quality. This provides the opportunity to skip herbicides within one production year. Second, silage crops are an effective way to manage weeds without the use of herbicides. A Manitoba study (Schoofs and Entz, 2000; Can J Plant Science) showed that silage crops were as effective as a herbicide-treated wheat grain crop in controlling future wild oat problems (Table 4). Annual forage crops were less effective at controlling small-seeded broadleaved weed species such as red root pigweed and lamb's quarters, however. It was interesting to note that for many weeds, spring-sown cereal silage alone was less effective at controlling weeds than where a winter-habit cereal was included (eg. Winter triticale). The spring-sown winter cereal appeared to give better season-long weed suppression than spring-sown spring type.

Table 4. Density of weeds emerged in a pea crop following various annual forage treatments. Note that the first three treatments were wheat grain crops with different herbicide regimes. From Schoofs and Entz (2000) Can. J Plant Science.

Treatment in year prior to field pea crop	Wild oat (per m^2)		Green foxtail (per m^2)		Redroot pigweed (per m^2)		Lamb's quarters (per m^2)		Wild buckwheat (per m^2)	
	1995	1996	1995	1996	1995	1996	1995	1996	1995	1996
Wheat grain with grass and broadleaved herbicides	29	1461	42	962	50	20	12	1	11	1
Wheat grain with broadleaved herbicide only	283	2426	290	316	3	2	8	0	10	1
Wheat grain minus in-crop herbicide	283	2144	333	461	88	1	318	3	9	1
Winter triticale. Simulated grazing 4 times during growth season.	4	369	91	669	4	13	2	6	2	16
Spring/winter triticale silage intercrop. Silage and simulated late-season grazing.	10	421	18	490	327	24	15	7	5	4
Spring triticale silage	31	773	60	1338	611	79	9	51	9	41
Sorghum sudangrass silage	12	1001	30	103	8	12	25	4	2	5
Alfalfa silage	30	662	460	1205	406	19	11	7	2	17
Weed fallow	20	667	8	1712	1096	35	7	16	5	55

Rotations that include perennial forage crops

Adding perennial hay phases to crop rotations significantly reduces populations of many problem weeds. A survey of cereal fields that either followed alfalfa or grains in a "straight-grain" rotation clearly showed that alfalfa hay significantly reduced densities of wild oat, green foxtail, cleavers, and Canada thistle in following grain crops (Table 5). Alfalfa hay phases do not effectively control many of the small-seeded broadleaved weeds (eg. Wild mustard) and dandelion populations tend to increase after an alfalfa phase.

Table 5. Weed populations dynamics in commercial fields after alfalfa compared with after cereals. For results of all weeds measured in the study, from Ominski et al. (1999). Weed Science.

Species name	Relative abundance		Density (plants/m2)		Frequency (%)		Uniformity (%)	
	Grain rotation	After alfalfa	Grain rotation	After alfalfa	Grain rotation	After alfalfa	Grain rotation	After alfalfa
Wild oat	43	9	20	1	85	43	55	9
C. thistle	13	7	3	1	58	35	17	7
lambsquarters	19	29	6	7	65	67	27	32
Quackgrass	14	15	5	3	42	39	15	13
Cleavers	12	4	7	1	20	11	13	4
Wild mustard	36	27	18	8	80	70	44	26
Dandelion	2	24	0.5	4	16	65	3	26

Cover crops

Two cover crop systems can be effectively used in prairie cropping systems. The first involves growing a crop on land that is fallowed for one season. These are often called "summerfallow substitutes". Research at the AAFC Lethbridge Research Centre has shown that sweet clover and fall rye provide excellent weed control when these crops are used as summerfallow substitutes. Sweetclover controlled perennial weeds dandelion and perennial sowthistle. Sweetclover also suppressed kochia, flixweed, russian thistle and downy brome (Blackshaw et al., 2001; Weed Science 49:406-413). Mowing and undercutting the sweet clover instead of full plant incorporation has been found to sometimes enhance weed suppression by sweet clover.

A second cover crop system adapted to wetter areas involves seeding fall rye in autumn and killing it mechanically or chemically prior to or after seeding a crop the following spring. One Manitoba study showed that dry edible beans grown in the presence of such a fall rye mulch yielded 5% more than where no rye cover crop was used, plus one fewer in-crop herbicide applications was required (see http://www.umanitoba.ca/outreach/fewerchemicals/research/ryecover.html).

Summary and Conclusions

This presentation argued that in order to reduce the threat of herbicide resistant weeds, herbicide use must decrease. Rampant spread of herbicide resistance today tells us that what we are currently doing is not working.

This presentation provides some strategies for herbicide use reduction.

Results of this analysis suggest that farming systems must include more crop diversity and employ higher levels of crop husbandry if meaningful levels of herbicide reduction are to be achieved.

Farmers cannot make all necessary changes alone. Industry and government must take herbicide resistance more seriously. For example, continual approval of crops resistant to the same herbicide groups by federal government regulators must be reconsidered.