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Long-term Pesticide Free Production Study at Carman, MB (2000)

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Summary
A long-term rotation was started in 2000 at the University of Manitoba to investigate the effects of Pesticide Free Production (PFP), a production system where in-crop herbicides were omitted from certain crops in rotation, on weed populations and crop performance in two crop rotations (flax-oat-canola-wheat and flax-oat-alfalfa-alfalfa). Over the long-term, weed seedbank populations were greater in rotations where in-crop herbicides were omitted, but significant yield reductions were only observed in some crops when omitting herbicides in both, the flax and oat crops. Over the 10 years, a crude economic analysis suggests that occasional in-crop herbicide omissions, particularly in competitive crops, may increase net revenues by saving the costs of herbicide while having no major impact on weed populations and crop grain yield.

Introduction
The long-term rotation study at Carman, MB, was started in 2000 and is among the youngest of the studies that comprise this volume of Prairie Soils and Crops. As such, its beginnings and inception are still in recent memory. In the winter of 1999, the Pesticide Free Production (PFP) principle that is being tested with this study was conceived during a road-trip from Winnipeg to Minnesota to visit Frank Forcella, a prominent weed scientist with expertise on modelling weed seedling emergence. On the way, the travelers were brainstorming about how to mitigate herbicide-resistance in weeds and how to increase the use of integrated pest management practices by farmers with the intent to decrease dependence on pesticides, lower input costs, reduce selection for herbicide-resistant weed biotypes and possibly create new marketing opportunities for prairie grain producers. Collectively, this discussion spawned the principle of Pesticide Free Production systems (PFP) (later renamed Farming with Fewer Chemicals) and this long-term rotation study, initiated in 2000, was designed to test this potential production system at the research level.

In PFP, weed management avoids the use of in-crop herbicides and pre-seeding or pre-emergence soil-residual herbicides, but allows weed management using non-residual, pre-emergent and post-harvest applications of herbicides such as glyphosate. PFP encourages the adherence to weed control thresholds and allows for the flexibility to decide on the additional use of an in-crop herbicide when deemed necessary and opt out of participating in PFP for that growing season. This contrasts organic production systems, for example, where producers have to adhere to stringent regulations with limited flexibility. Branding of PFP-produced crops was intended with the hope that producers could gather a premium for crops that were certified as being produced without the use of in-crop pesticides. Thus, the goal was to maintain productivity and allow producers to reduce pesticide applications with the potential for increased revenues through savings on input costs and eventually also possibly collect a premium for reducing the pesticide load on the environment and reduce the risk of human exposure to pesticides while maintaining productivity of their cropping system.

The study was designed to test the following short-term objectives[6]:
(1) Determine the effect of including one or two PFP crops in a 4-year crop rotation on weed populations within the PFP and post-PFP crops;
(2) Determine the effect of including one or two PFP crops in a 4-year crop rotation on crop yield in the PFP and post-PFP crops;
(3) Determine the effect of including a perennial crop on weed populations and productivity of PFP crops (oat and flax) when the non-PFP crops (wheat and canola) are replaced with perennial alfalfa.
In brief, the study was fully-phased, where all crops are present each year. The study consisted of an annual crop rotation (flax-oats-canola-wheat) and an annual crop-alfalfa rotation (flax-oats-alfalfa-alfalfa) arranged as an RCBD with 3 replicates. In each replicate, each

rotation was subjected to one of three treatments; (i) the control rotation, where selective in-crop herbicides were applied on all annual crops, (ii) the same rotation where in-crop herbicides were not applied to the oat crops (PFP1) and (iii) the same rotation where in-crop herbicides were omitted from each oat and flax crop (PFP2). A tall-grass native prairie and a continuous chemical fallow treatment were included as reference treatments giving a total of 26 independent treatments (Table 1). The study was managed using no-till and non-selective, non-residual herbicides have been used to manage weeds in all crops before seeding and in the chemical fallow treatment. Glyphosate was used to terminate the alfalfa stand in late summer/early fall the fall of the second year about one month after the second cut of hay for that season. The specific herbicide programs are listed in Table 2. The canola varieties grown throughout the study were resistant to glufosinate and canola seed was treated with fungicide (trifloxystrobin, metalaxyl) and insecticide (clothianidin, carbathiin) throughout. No additional fungicides and insecticides were used or needed between 2005 and 2008. From 2000 to 2004, canola was regularly treated with benomyl and vinclozolin to limit infections from the disease sclerotinia (*Sclerotinia sclerotium)*.

During the first four years of the study, measurements to address the initial objectives were taken and weed populations, weed biomass and crop biomass and grain and hay yield were monitored intensely[6]. Between 2005 and 2009, only crop yield was measured in this study. In the spring of 2009, a comprehensive evaluation of the weed seedbank was undertaken and we are continuing crop yield and other measurements as outlined under future work.

For this chapter, a simple economic analysis was conducted for crop yields from 2000 to 2008 (Fig. 1). Herbicide costs, determined from the retail prices suggested in the Guide to Crop protection for each respective year for Manitoba were subtracted from gross return (crop yield * average price per unit for each year). Adjusted gross returns were calculated by subtracting the cost of all herbicides plus application ($5 per herbicide application) costs from the total gross revenue. A figure showing the average adjusted gross return for each annual crop in each rotation and PFP system was generated.

Major findings from study

Weed Populations

In general, total weed seedling populations increased when in-crop herbicides were omitted in the PFP years in the short-term[6] and weed seedbank densities were greater in these treatments in all crops over the long-term (Table 3)[4]. Not surprisingly, weed seedling and weed seedbank densities were greatest when in-crop herbicides were omitted in flax and the following oat crop. The poor competitive ability of flax when weeds were not managed with in-crop herbicides contributed to a general 2-fold increase in the weed seedlings after four years and a 2.5-fold increase in the weed seedbank populations after 10 years of the study. In the early years, weed data was not collected by individual weed species[6] and consequently, early species dynamics information is not available. After 10 years, however, the most dominant species in the seedbank were the foxail species, which were comprised of green and yellow foxtail (*Setaria* spp) and barnyard grass (*Echinochloa crus-galli* L.), redroot pigweed (*Amaranthus retroflexus* L.) and yellow woodsorrel (*Oxalis stricta* L.). Wild oat (*Avena fatua* L.), one of the most competitive and dominant grassy weeds in western Canada[7], was not present at the site when this study was initiated and has never been present in this study. Wild oat continues to be rare at the Ian Morrison Research Farm.

Weed seedbanks can be considered the memory of the system and are influenced by previous management practices and environmental conditions[1]. After 10 years, the weed community composition in the seedbank was similar in the control and the PFP1 rotation, but differed in flax, wheat, and canola when herbicides were omitted from flax and oats (PFP2). PFP2 resulted in a species shift toward more lambsquarters (*Chenopodium album* L.), Canada thistle (*Crisum arvense* L.), buckwheat (*Polygonum convolvulus* L.), and foxtail species and a shift away from redroot pigweed and yellow woodsorrel. In some crops, the change in dominance among the weed species from broadleaf (redroot pigweed) to grassy (i.e. foxtail) species in response to these in-crop herbicide omissions may warrant the use of a different herbicide program to manage the weed community more effectively. This supports the common observation that selective in-crop herbicides are one of the most important factors driving the species composition of the weed community[2,3]. Dandelion (*Taraxacum officinale* G.H. Weber ex Wiggers) was a common weed in these rotations as well, but low seed persistence resulted in a small seedbank population for this weed. Although there also were significantly more weed seeds in the seedbank in alfalfa under PFP2 management, the composition of the weed seedbank community was not different among the alfalfa crops[4].

The weed seedbank density in the tall grass prairie was about 7-fold lower than that found in the annual control rotations and was dominated by lambsquarters and foxtail species. The weed seedbank density was lowest in the continuous chemical fallow treatment (almost 40-fold lower than the control annual rotations) and was dominated by redroot pigweed and yellow woodsorrel. Interestingly, the progressive loss of top soil in chemical fallow plots (4 x 10 m) is now clearly visible after 10 years.

Crop yield

Crop yields from 2005-2008 were compared and in a combined statistical analysis, yields of the all annual crops only were reduced in the PFP2 rotation (Table 4). The higher weed seedbank densities (about 40%) in the PFP1 rotations compared to the control rotations did not affect crop yield in any annual crop in the annual and perennial rotation. In fact, a subsequent analysis of grain yield for each crop showed that even by doubling the seedbank populations in the PFP2 annual rotation, no effect was observed on the yield of wheat and canola. Both are competitive crops in which effective in-crop herbicides are available to manage weeds. The use of highly efficacious herbicides has resulted in a steady decline in weed populations in western Canada over the past 40 years[7] and the results from this study showed that highly efficacious herbicides manage weeds even at higher seedbank densities such that crop yield is not jeopardized. These results also suggest that pre-harvest herbicide applications to target weed seedbank additions may be unnecessary when a competitive crop is planted in the year following an efficacious in-crop herbicide program.

Economics

Overall, adjusted gross returns mirrored grain yields (Fig. 1). However, in canola and oat in the annual rotation, the mean adjusted gross returns tended to be slightly greater in the PFP1 rotation than in the control rotation where in-crop herbicides were used each year. The higher returns in oat reflects savings for in-crop herbicides and associated application costs while the tendency for increased returns in canola following PFP oat was caused by slightly higher yields in canola. The trend for slightly higher canola yields in PFP1 after oats in which in-crop herbicides were not used has been consistent throughout this study[6,4] and is very interesting as it suggests that the slight increase in weed populations in the PFP1 rotation somehow seem be associated with a benefit to productivity of canola in that system. This raises the question of whether the extensive use of highly efficacious weed management tools might be reducing weed populations and perhaps biological diversity so much that we are reaching the biological limitations of strict monoculture crop production in these systems.

Summary and Future

Herbicide applications are often justified to reduce seed return to the seedbank and thereby reduce future weed populations. Over ten years, this study has clearly demonstrated that increases in the densities of weed seeds in the seedbank have none to only small negative impacts on grain yields of competitive crops. In fact, in-crop herbicide omissions in highly competitive crops resulted in slightly higher economic returns on average over the long-term.

The study is an excellent platform for future work on understanding the detriments and benefits of different levels of weed infestations in cropping systems using current agronomic practices over the short- and long-term. The study is also currently being used to evaluate the persistence of free plant DNA of alfalfa and canola in rotation. Both of these crops are platforms for genetic-engineering and understanding the dynamics of free DNA from these plants in the soil environment[5] is important to mitigate the risk of horizontal gene transfer via natural transformation of plant DNA into soil microbes.

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Table 1. Rotation structure in the long-term PFP study at Carman, MB.

Rotation[a]	**Treatment**	**Crop Sequence**			
Annual	Control	canola	wheat	flax	oat
Annual	1 PFP crop	canola	wheat	flax	PFP oat
Annual	2 PFP crops	canola	wheat	PFP flax	PFP oat
Perennial	Control	alfalfa	alfalfa	flax	oat
Perennial	1 PFP crop	alfalfa	alfalfa	flax	PFP oat
Perennial	2 PFP crop	alfalfa	alfalfa	PFP flax	PFP oat
	Control	Chem. Fallow			
	Control	Native Prairie			

[a] The experiment is a fully-phased rotation (each crop is present each year) that investigates all combinations of rotation type and PFP treatment plus two additional control treatments (chemical fallow and native prairie) and consists of a total of 26 treatments. The study is located at the Ian Morrison Research Farm at Carman, MB (49°29'48"N, 98° 2'26"W, 267 m above sea level) on an Orthic Black Hochfeld fine loam soil. In PFP treatments, only the in-crop herbicide applications from that crop in the rotation.

Table 2. Herbicide active ingredients, formulations and dose for each crop to which post-emergence herbicides were applied. Pre-plant glyphosate was applied to all crops and second-year alfalfa was terminated with the use of glyphosate.

Crop	**Trade Name**	**Active Ingredient**	**Formulation**	**Dose** (kg ai ha^{-1})
Wheat	Refine SG	Thifensulfuron–methyl	33.5%	0.010
		Tribenuron–methyl	16.65%	0.005
	Horizon 240EC	Clodinafop–propargyl	240 g L^{-1}	0.056
Flax	Poast Ultra	Sethoxydim	450 g L^{-1}	0.500
	Buctril M	Bromoxynil	280 g L^{-1}	0.280
		MCPA	280 g L^{-1}	0.280
Canola	Liberty	Glufosinate ammonium	150 g L^{-1}	0.500
Oat	Refine SG	Thifensulfuron–methyl	33.5%	0.010
		Tribenuron–methyl	16.65%	0.005
Alfalfa year 1	Poast Ultra	Sethoxydim	450 g L^{-1}	0.500

Table 3. Average seedbank density in each crop and rotation as influenced by omitting in-crop herbicide applications in the oat crop only (PFP1) or in both, the flax and oat crops (PFP2) in rotation after ten years. Standard errors of the means are indicated in parentheses. (Adapted from Gulden et al. 2011).

Rotation	**Treatment**	**Crop**			
		canola	wheat	flax	oat
		Seedbank density (seed m^{-2})			
Annual	Control	3710 (654)	3870 (1210)	6240 (1980)	4780 (1090)
Annual	PFP 1	5520 (1150)	4820 (250)	10000 (413)	5520 (917)
Annual	PFP 2	11400 (1320)	9050 (1140)	13500 (1510)	12500 (2460)
Perennial	Control	5620 (862)	2290 (800)	3630 (1310)	4720 (1650)
Perennial	PFP 1	7270 (2190)	3230 (609)	3060 (251)	5940 (2090)
Perennial	PFP 2	9590 (3030)	5590 (1910)	14000 (3300)	13000 (441)
Control	Chem. Fallow	190 (73)			
Control	Native Prairie	1010 (304)			

Table 4. Average seed yield (2005-2008) for each grain crop and the annual and perennial rotations as influenced by omitting in-crop herbicide applications in the oat crop only (PFP1) or in both, the flax and oat crops (PFP2). Standard errors of the means are indicated in parentheses. (Adapted from Gulden et al. 2011).

Rotation	**Treatment**	**Crop**			
		canola	wheat	flax	oat
		Grain yield (kg ha^{-1})			
Annual	Control	1914 (158)	2407 (260)	1092 (113)	2749 (475)
Annual	1 PFP crop	2128 (109)	2348 (299)	1132 (91)	2551 (391)
Annual	2 PFP crops	1939 (121)	2510 (280)	487 (124)	1989 (208)
Perennial	Control			1106 (142)	2258 (323)
Perennial	1 PFP crop			974 (131)	2112 (286)
Perennial	2 PFP crop			240 (88)	2072 (269)

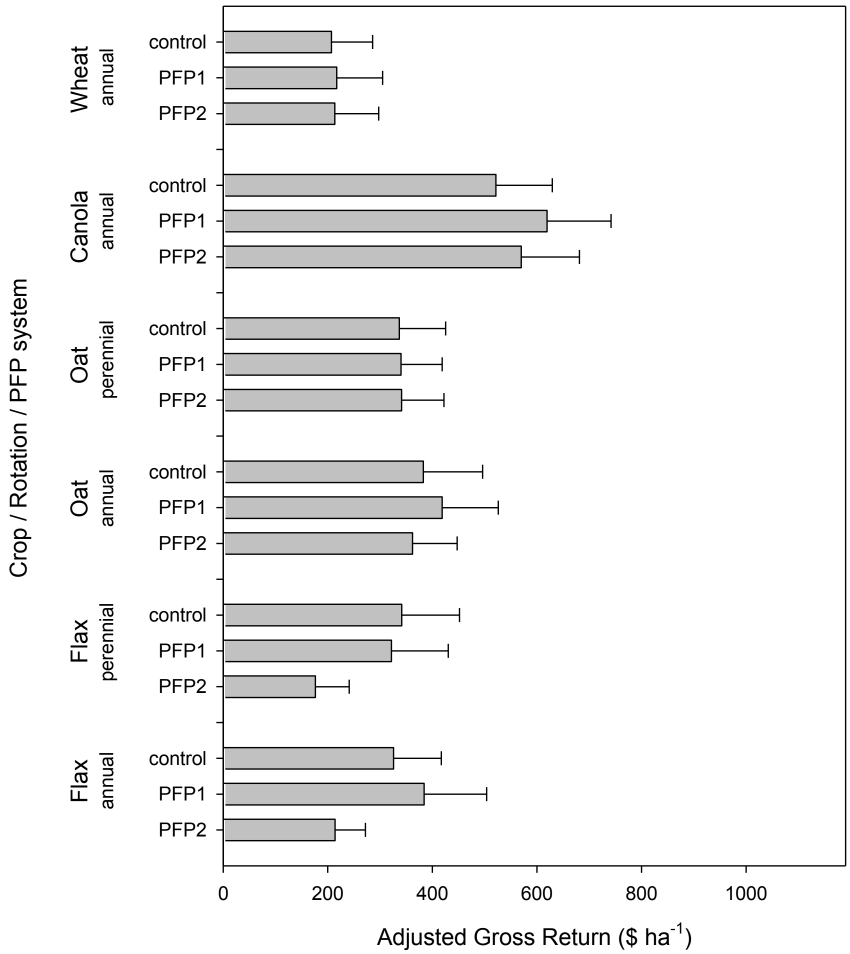

Figure 1. Adjusted gross return in annual crops in rotation with annual crops or alfalfa as influenced by omitting in-crop herbicide applications in the oat crop only (PFP1) or in both, the flax and oat crops (PFP2) in rotation. Average adjusted gross return (Net return minus herbicide plus cost of application) from 2000-2008 and the standard errors of the means are shown.

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