Evolving on-farm weed management systems: the Canadian experience

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Summary Farmers must continuously deal with weed infestations in crops. Herbicides are very effective tools to control weeds yet there has been an over reliance on their use at the expense of other useful methods of weed management. Successful long-term weed management requires a shift away from simply controlling problem weeds to implementing cropping systems that prevent weed reproduction, reduce weed emergence, and minimise weed competition with crops. Agricultural systems that utilise diverse crop rotations, competitive crops, higher crop seed rates, specific fertiliser management, crop mulches, and cover crops can effectively manage weed populations, especially when used in conjunction with limited but targeted use of herbicides. Farmers in Canada are slowly, but surely, adopting these more sustainable weed management systems. Further research and extension efforts are required to ensure that these integrated weed management systems are consistently effective and economically viable to ensure more universal adoption at the farm level.

Keywords Conservation tillage, competitive crops, crop rotation, integrated weed management, herbicide resistant canola.

INTRODUCTION

Farmers have been controlling weeds for centuries with varying levels of success. The advent of herbicides has been hailed as one of the most important advances in agriculture and herbicides now typically comprise 20 to 30% of input costs in North American cropping systems (Derksen *et al.* 2002). Despite widespread adoption of herbicide technology, there is ever increasing interest in reducing herbicide use. Farmers cite low commodity prices, crop injury and herbicide carryover concerns, the increasing incidence of herbicide resistant weeds, and public concern about the environmental and human health effects of pesticides as issues forcing them to reconsider how they manage weeds.

Successful long-term weed management requires a change in mindset from simply controlling problem weeds with herbicides to one where cropping systems are redesigned to minimise the need for herbicides. Such systems would restrict weed reproduction, reduce weed emergence, and minimise weed competition with crops. Research has shown that competitive crop production practices can contribute to development of more sustainable weed management systems. This paper will report on changing weed management practices at the farm level in Canada.

PRODUCTION CHANGES OVER THE LAST DECADE

Changes in weed management practices need to be discussed in the context of overall changes in agricultural production in Canada. Direct seeding (conservation tillage) practices are now the norm; 70–80% of the land is direct seeded in western Canada. Farmers have adopted this technology to maintain soil quality and conserve soil moisture but more importantly to improve farm profitability. Greater moisture conservation has facilitated a 70% reduction in fallow and has allowed production of crops that require more water (Table 1).

Table 1. Agriculture production changes over the last decade in Canada.

	2005 (million ha)	change from 1995
Wheat	10	−20%
Canola	5.5	+55%
Barley	5	−5%
Oat	2	−3%
Field pea	1.4	+250%
Corn	1.3	+3%
Soybean	1.1	+35%
Lentil	1	+190%
Linseed	0.8	+40%
Canaryseed	0.4	+45%
Mustard	0.25	−10%
Dry bean	0.2	+110%
Sunflower	0.1	+155%
Tame hay	7.5	+20%
Direct seeding	20	+100%
Fallow	4	−70%
Organic	0.5	+500%
	Million animals	
Beef cattle	16	+20%
Hogs	15	+30%
Sheep	1.3	+45%

Wheat (*Triticum aestivum* L.) continues to be the main crop but has decreased 20% in the past decade due to low commodity prices (Table 1). Production area of other cereals has changed little over the last decade but a greater proportion is consumed domestically (as opposed to exported). This is due to a marked increase in livestock production (Table 1); again an attempt to increase farm profits as crop commodity prices decline. Farmers have diversified into oilseeds and pulses as net returns are often greater with these crops than with cereals.

ON-FARM CHANGES IN WEED MANAGEMENT

Conservation tillage The widespread adoption of conservation tillage and increased crop diversification has facilitated (and necessitated) changes in how farmers manage weeds. Conservation tillage can lead to shifts in weed species with an increase in some winter annual, biennial and perennial weeds being noted in western Canada (Blackshaw 2005). However, farmers report lower overall weed populations after being in direct seeding systems for five to ten years. Weed seed mortality tends to be greater when weed seeds are left on the soil surface compared to when buried in the soil with tillage. Additionally, crop residues on the soil surface may inhibit weed germination and growth through physical suppression and/or allelopathic interactions.

Pre-seed glyphosate is widely utilised for weed control in direct seeding systems because it is highly efficacious and economical. Farmers have moved from applying glyphosate 1–2 weeks before seeding to applying it 3–5 days after seeding (shortly before crop emergence) to better enable crops to get a competitive advantage over weeds. Florasulam is being used as a tank mix with pre-seed glyphosate in recent years to provide a few weeks of residual control of broadleaved weeds. However, it can only be used where cereals are to be seeded, as it will injure many dicot crops. Effective weed control with these pre-seed herbicides sometimes allows farmers to reduce in-crop herbicide use (fewer applications or reduced doses).

Crop rotation As outlined in Table 1, a greater variety of crops are now grown in Canada. Diverse crop rotations are the cornerstone of all sustainable pest management and crop production systems. Monoculture cropping facilitates an increase in weed species that are able to effectively compete with that crop or that are able to overcome competition through some avoidance mechanism. Thus, crop rotation tends to limit the build up of any single problem weed species and indeed has been recognised as an important factor mitigating development of potential problematic weed species in conservation tillage systems (Blackshaw 2005).

Crop diversification encourages operational diversity that in turn can lead to better weed control. Different crops are naturally planted and harvested at different times of the year. If sufficient differences exist between crop and weed in their germination requirements then seeding date can be manipulated to benefit the crop. Early sown spring crops may outcompete weeds requiring warmer soil temperatures for germination. For example, densities of the C_4 species green foxtail (*Setaria viridis* (L.) P.Beauv.) have markedly declined with early planted crops in conservation tillage systems that often having lower soil temperatures (Blackshaw 2005). Conversely, delayed seeding can be used to manage early germinating weeds such as kochia (*Kochia scoparia* (L.) Schrad.). Alternating seed dates over years is a desired weed management practice.

Manipulating seed date also can be accomplished with winter cereals. A novel approach to altering crop seed date is to plant spring canola (*Brassica napus* L.) cultivars in late fall when the ground is nearly frozen so that germination does not occur until the following spring (Johnson *et al.* 2004). Most spring-germinating weeds emerge after canopy closure of these fall-planted crops and are non-competitive. Inclusion of forages such as lucerne (*Medicago sativa* L.) for two to three years in rotation with annual crops, with the main goal of managing weeds, is gaining acceptance in areas where forage demand is high.

Herbicide timing Research has documented the importance of early weed removal to protect crop yield (Harker *et al.* 2001). Farmers previously preferred to delay in-crop post emergence herbicide applications until all weeds had emerged. Crops visibly looked cleaner but some of the yield potential had already been lost. Much extension effort occurred to demonstrate this concept and now farmers routinely apply in-crop post emergence herbicides at the 2–4 rather than at the 6–8 leaf stage of crops. Farmers now tolerate a few late emerging weed escapes knowing that crop yield (and profits) will be higher. They also quickly realised that herbicides are often more effective on smaller weeds and successful use of reduced herbicide doses could be improved.

Herbicide resistant crops Herbicide resistant canola was introduced into Canada in 1996 and now occupies 5 million ha annually (95% of production). Herbicide resistant soybean (*Glycine max* (L.) Merr.) and corn (*Zea mays* L.) are grown on an additional

1 million ha. Herbicide resistant canola consists of RR (55%), LL (28%), and Clearfield (12%) cultivars. The Canola Council of Canada has documented that rapid farmer adoption of this technology was primarily due to increased economic return, and secondarily to better weed control (www.canola-council.org). The lack of effective and economical herbicides to control broadleaved weeds in conventional canola meant that farmers tried to only plant canola on land relatively free of weeds. Now canola is seen as a clean-up crop in terms of weed management. Another huge benefit (but difficult to measure) of RR and LL canola is management of Group A and B resistant weeds. Many progressive farmers choose LL canola in a deliberate attempt to reduce selection pressure for glyphosate resistant weed populations (none in Canada yet!).

Few technologies are 100% positive. Farmers incur additional costs to apply 2,4-D, bromoxynil or tribenuron/thifensuluron for control of volunteer RR canola. Perhaps the biggest surprise to growers was gene flow between herbicide resistant canola types (e.g. RR to LL) with the result that glyphosate no longer gave complete control of volunteer LL canola. The majority (>95%) of volunteer canola emerges in the year after production (Harker *et al.* 2006) and farmers have few problems managing it. Concerns about development of 'superweeds' (gene flow to related weed species) have thankfully been largely unfounded.

Industry involvement in herbicide resistant canola has fuelled development of hybrid cultivars. These hybrid canola cultivars were developed because of their yield potential (>30% higher yield) but they have the added benefit of being more competitive with weeds due to rapid growth and early canopy closure that shades weeds. Hybrid canola is now considered to be more competitive than spring wheat and may rival barley (*Hordeum vulgare* L.). Research is underway to answer this question. Adoption of hybrid canola has increased from 15 to 70% in the past five years and canola hectares have increased 55% in the last decade. Use of hybrid and herbicide resistant canola has resulted in excellent weed control in the canola production year.

Crop seed rate The establishment of a crop with a more uniform and dense plant distribution will increase its ability to suppress weeds. One of the easiest and most consistent methods to accomplish this goal is to simply increase crop seeding rates (Blackshaw *et al.* 2006). However, farmers in the semi-arid regions of western Canada have been reluctant to adopt this practice. A certain amount of folklore exists about excessive vegetative growth and crops running out of water before grain fill if crop density is too high. We have rarely been able to document this result in our research and only at cereal densities above 450 plants m^{-2}; much higher than the 225–275 plants m^{-2} that are being advocated. The tillering ability of cereals is thought to compensate for low seed rates but in fact these tillers are the first to die with drought stress. Farmers experienced severe drought in western Canada in 2001 and 2002 and found that crop yields were similar or greater with higher than with standard seed rates. In addition to weed suppression, higher crop seed rates result in earlier and more uniform maturity, decreased green seed content in canola, and more uniform kernel size in cereals. Smith *et al.* (in press) documented the positive economic return from higher seed rates of wheat, barley and canola, but not field pea (*Pisum sativum* L.), in western Canada. Most farmers have increased crop seed rate by about 1/3 in the past five years and it is paying dividends in terms of crop productivity and long-term weed management. It is noteworthy that the majority of organic farmers have doubled crop seed as a weed management tool.

Crop fertilisation Many agricultural weeds are high consumers of nutrients and therefore are capable of reducing available nutrients for crop growth. Additionally, growth of many weed species is enhanced by higher soil nutrient levels (Blackshaw *et al.* 2003).

Much research has gone into manipulating fertiliser timing and placement to reduce weed interference in crops. Spring compared with fall-applied fertiliser often reduced weed biomass and increased yield of spring-planted wheat, barley, canola and field pea (Blackshaw *et al.* 2004, 2005a, 2005b). Nitrogen fertiliser placed as narrow in-soil bands, rather than surface broadcast, has been found to reduce the competitive ability of several weed species (Blackshaw *et al.* 2004). A field study utilising ^{15}N-enriched liquid nitrogen fertiliser clearly documented greater nitrogen uptake by wheat, and often lower nitrogen uptake by weeds, when nitrogen was placed 10 cm below the soil surface (away from surface germinating weeds) compared to when surface broadcast (Blackshaw *et al.* 2002). Weed seedbank data indicate that nitrogen fertiliser application method can be an important component of long-term weed management (Figure 1).

Fertiliser use data indicate a 40% reduction in the amount of fall-applied fertiliser and a 50% reduction in the amount of broadcast nitrogen fertiliser, in favour of sub-surface placement, in the past five years in Canada.

Silage, green manure and cover crops Silage crops are often harvested before weeds produce mature seed, thus limiting seed return to the soil seedbank. Barley

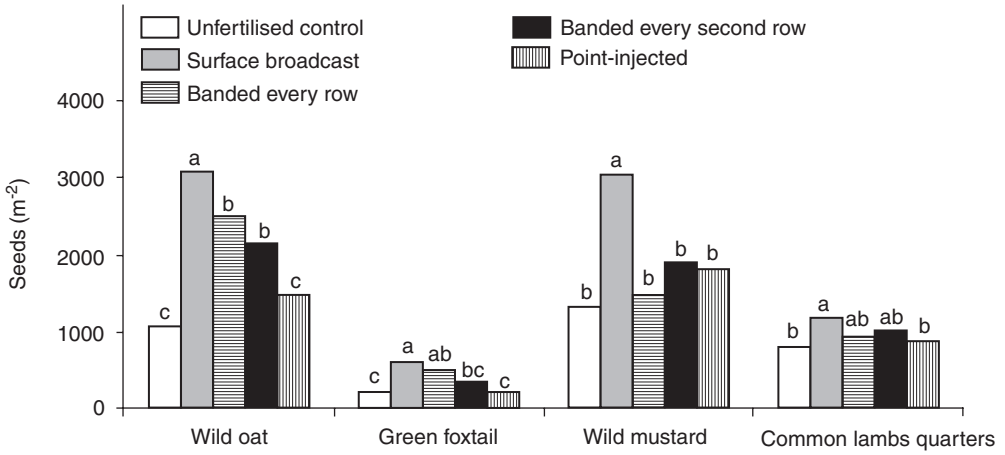

Figure 1. Effect of nitrogen fertiliser application method in four consecutive years on the weed seedbank for four weeds: wild oat (*Avena fatua* L.); green foxtail (*Setaria viridis*); wild mustard (*Sinapis arvensis* L.); and common lambsquarters (*Chenopodium album* L.), at the conclusion of the four-year experiment. Bars on the graph within a weed species with the same letter are not significantly different according to Fisher's Protected LSD test at the 5% probability level. (Adapted from Blackshaw *et al*. 2004).

and corn silage have been popular for many years in Canada, but silage production has increased in recent years, especially where herbicide resistant weed populations are prevalent. Silage production for 2–4 years can dramatically reduce the weed seedbank and allow growers to return to annual cash crops.

Green manure and cover crops are widely used by organic farmers, but adoption by conventional farmers is only just beginning. Sweetclover (*Melilotus officinalis* (L.) Lam.) in the drier regions and red clover (*Trifolium pratense* L.) in the wetter regions are the green manure crops of choice in organic production. In addition to their nitrogen fixing ability, both species are competitive with weeds and decaying residues of sweetclover are known to release allelochemicals that inhibit weeds (Blackshaw *et al.* 2005c). Winter rye is the main cover crop utilised in Canada. Organic farmers use it for weed suppression but conventional farmers are more interested in providing ground cover after production of low residue crops such as potato (*Solanum tuberosum* L.) or sugar beet (*Beta vulgaris* L.), with weed suppression seen largely as a bonus.

Crop advisors and decision support systems Crop agronomists working directly with growers are becoming ever more numerous as governments reduce extension efforts and farm size becomes larger. Some are employed by agriculture retailers hoping to increase sales and others are hired directly by the farmer. They are often involved in planning crop selection, scouting of fields during the growing season and crop marketing. Additionally, they provide invaluable information on integrated crop and weed management practices.

Multi-year studies in farmer's fields developed and verified economic threshold models for wild oat (*Avena fatua*) control in wheat, barley, and canola (O'Donovan *et al.* 2005). The models have been incorporated into decision support software (AgroManager on Weeds2™, Westco, Calgary AB) and are being used to aid in the decision to apply a wild oat herbicide. Wild oat herbicide use has declined about 15% ($45 million) in the last five years and this reduction has been partially attributed to these decision aids.

Merits of combining weed management practices A multi-site study conducted at several locations (23 site-years of data) assessed the merits of combining several crop production practices to manage weeds in the context of full or reduced herbicide doses in major field crops of western Canada (Blackshaw *et al.* 2005a,b). Factors included in the study were crop rotation, seed date, seed rate, fertiliser timing, and herbicide dose. There was a significant interaction between crop seed rate and herbicide dose; higher seed rates usually improved the efficacy of reduced herbicide doses in all crops. It is notable that the weed seedbank was not greater after four continuous years of using 50% herbicide doses within a competitive cropping system (early seed date, higher crop seed rate, spring-applied banded fertiliser) at two of three sites.

In another study, use of a competitive canola cultivar, higher seed rates and early weed removal resulted in superior weed control and a 41% increase in canola yield compared with standard agronomic production practices (Harker *et al.* 2003).

SUMMARY

Much research is being conducted and progress is being made on developing biologically and economically robust integrated weed management systems. The key to widespread adoption of alternative weed management methods is putting the various practices together into workable systems at the farm level. Farmer interest in these systems is high but they are understandably reluctant to accept greater risk of crop failure or to accept reduced cash flow in one year even it means increased income in subsequent years. Nevertheless, adoption of conservation tillage, diversified crop rotations, higher crop seed rates, competitive crop cultivars, and subsurface banded fertiliser indicate that much progressive change is occurring at the farm level.

Despite these successes there is no room for complacency. There remains much work to be done by all members of the agricultural community to develop, refine, and facilitate adoption of these improved weed management and crop production systems. Collectively, we can meet the challenge.

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