Clearfield™ Crops in Your Crop Rotation

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Introduction

Crops that have been bred to be tolerant to imidazolinone herbicides have been available in Western Canada for about a decade. The first "imi" tolerant crop, known as Smart canola, was introduced in 1995 and later renamed to Clearfield™ canola. Clearfield™ spring wheat was introduced into the marketplace in 2004 while Clearfield™ sunflower received regulatory approval in Canada in 2005. Clearfield™ lentil has also received regulatory approval with breeder seed of a small red lentil type being available in 2006.

The Clearfield™ crops have been bred to be resistant to the herbicides imazamox (Solo®), imazethapyr (Pursuit®), or a combination of the two (Odyssey®). These herbicides provide broad-spectrum grass and broadleaf weed control in both Clearfield™ crops and crops with inherent tolerance such as field peas and dry beans.

These crops are not considered a GM (genetically modified) crop because they were bred through traditional breeding methods such as mutagenesis and selection. Therefore, they have general market acceptance and have not received the same opposition that has arisen when attempts to introduce GM crops such glyphosate resistant wheat or glufosinate resistant rice in the marketplace (Tan et al. 2005). However, the Clearfield™ trait is considered "novel" and is subject to the same regulatory approvals as GM crops. Canada is the only country in the world that requires this regulatory approval (Tan et al. 2005).

Clearfield™ crops and can offer a number of advantages in your crop rotation. The herbicides used in these crops provide excellent one-pass weed control with good to excellent crop tolerance. They are effective at low application rates, have low mammalian toxicity, and possess a favorable environmental profile (Tan et al. 2005). As with any technology, there can be disadvantages which include: increased potential for weed resistance evolution; control of volunteer crops; and potential accumulation of herbicide residues in the soil. However, all of these disadvantages can be overcome with some careful planning and following stewardship guidelines.

Weed Resistance

This topic will be covered in detail by other speakers so it will only be covered briefly in this paper. Clearfield™ crops can influence weed resistance evolution through out-crossing or increased selection pressure. The latter would be the primary concern as the majority of the crops have very low out-crossing frequencies, and in the case of lentils and spring wheat, very few weedy relatives. The imidazolinone herbicides inhibit the ALS (acetolactate synthase) enzyme that is necessary for the biosynthesis of branched-chain amino acids. They belong to the Group 2 herbicide class, which include sulfonylurea herbicides (Refine Extra, Express, Muster, Sundance) and other Group 2 herbicides such as Frontline and Everest.

Resistance to Group 2 herbicides is the fastest growing class of herbicide resistant weeds in the world (Heap 2005). Repeated use of this (or any) herbicide group will lead to selection of resistant species and remove competition from susceptible species. It should be pointed out that many growers (and some agronomists) feel that using reduced rates of herbicides will speed up the evolution of resistant weeds. In the majority of cases, the use of reduced rates will have no impact on the rate of weed resistance evolution. The resistant gene(s) is present at a low frequency in some weed species and controlling susceptible weeds will reduce competition for resources, allowing the resistant biotype to multiply and produce resistant offspring. For a number of reasons, the development of resistance occurs much quicker in Group 1 and 2 herbicides than herbicide groups such as 4 and 9 (Beckie et al. 2001). Good crop and herbicide rotation, as well as integration of other agronomic strategies can reduce the onset of herbicide resistance. A rotation of canola-barley-field pea-wheat-lentil-wheat-sunflower-barley-canola would be considered a good rotation; however, if the canola, wheat, sunflower and lentil were Clearfield™ types, one could conceivably use an imidazolinone herbicide 9 out of the 9 years (if Assert were applied to the barley).

In discussing weed resistance, it is important to note the role that these products play in managing herbicide resistance. With the popularity of Roundup Ready canola, and the frequent use of glyphosate in zero-till production, glyphosate resistance has evolved in some species in other parts of the world (Heap 2005). The intermittent use of Group 2 herbicides can play a role in delaying the onset of resistance to other herbicide groups.

The concern of outcrossing to weedy relatives has arisen with the introduction of herbicide tolerant canolas (Johnson et al. 2004). The frequency of pollen-mediated gene flow and subsequent cross-fertilization of Argentine canola with wild relatives such as wild mustard, wild radish, and dog mustard is extremely low. In extensive greenhouse and field studies, only one Argentine canola/wild radish hybrid was detected in over 50,000 samples. No Argentine canola/wild mustard or Argentine canola/dog mustard hybrids were detected among 43,000 and 22,000 seedlings tested, respectively (Warwick et al. 2003a). Argentine canola can cross-pollinate with Polish canola or bird's rape. The degree to which hybrids will form will depend on the varieties and the distance between the two species. In field studies conducted in Saskatchewan where Polish canola was grown beside an herbicide-resistant Argentine canola field, hybrids were detected at frequencies of 0.11% at 40 m and dropped below 0.01% at distances of 60 to 250 m from the edge of the Argentine canola field (Warwick et al. 2003b). Since Polish canola acreage is low in Western Canada (< 2% of canola grown) and the weedy bird's rape is not present on the Prairies, the risk of gene transfer between these two species is currently low.

Pollen flow between varieties is quite common and there are reports of volunteer canola with resistance to two or three herbicide groups. The risk of multiple herbicide resistance developing depends on a number of factors: the distance between and the relative size of the pollen donor and recipient fields; environmental conditions such as wind speed and direction, relative humidity and temperature; and the presence of insect pollinators (Beckie et al. 2003a). While multiple herbicide-resistant canola volunteers can occur, these volunteers are susceptible to herbicides with other modes of action (2,4-D, MCPA, Buctril-M and Sencor) (Beckie et al. 2003b).

The potential risk for pollen flow from Clearfield™ wheat to weedy relatives is non-existent presently in Canada (Canadian Food Inspection Agency 2004a). They only related species in Canada is quackgrass and there are no known naturally occurring hybrids between the two species. In the United States, there is a related weedy relative known as jointed goatgrass (*Aegilops cylindrical*). Jointed goatgrass can hybridize with winter wheat; however, the hybrid does not readily produce viable seed (Canadian Food Inspection Agency 2004a). In spite of the low frequency of jointed goatgrass / wheat hybrids, specific management strategies have been developed to minimize any potential risk (Rainbolt et al. 2004).

Lentils have less than a 1% outcrossing rate and there are no wild or weedy relatives in Canada that can hybridize with them (Canadian Food Inspection Agency 2004b). Transfer of the Clearfield™ gene from cultivated to wild sunflower does occur (Canadian Food Inspection Agency 2005). However, the imidazolinone tolerant trait is already present in the wild population (the wild population was the original gene source for breeding the tolerant cultivars) so it is not expected that the crosses will result in increased weediness of the wild type.

Volunteer Crops

Clearfield™ crops as volunteer weeds should be marginally more problematic relative to their conventional counterparts. While sulfonylurea herbicides such as Refine Extra or Express can not be safely applied to Clearfield™ canola or lentil, they will not provide adequate control of volunteers. However, there are a number of herbicides options available for controlling volunteer Clearfield™ canola and lentils.

Studies on the persistence of canola conducted across the Prairies indicate that most of the volunteer canola germinated and emerged the year after seeding (Harker et al. 2006a). If adequate control of volunteer canola is achieved and the volunteers are not allowed to produce viable seed, the number remaining after 2 years is negligible (Fig. 1). The data also illustrates the importance of good in-crop weed control as most of the emergence occurred after the pre-seed burnoff but prior to in-crop spraying. Broadleaf herbicides belonging to groups 4, 5, and 6 can be used to control volunteer Clearfield™ canola in cereal crops.

Similar studies conducted on the persistence of wheat found that volunteer densities two to three years after seed dispersal were close to zero; however, there was always some plants detectable at most locations (Harker et al. 2006b). The majority of wheat seedlings emerged the year following seed dispersal at the in-crop, pre-spray interval (Fig. 2). Group 1 graminicides such as Assure, Poast, or Select will control volunteer Clearfield™ wheat in broadleaf crops.

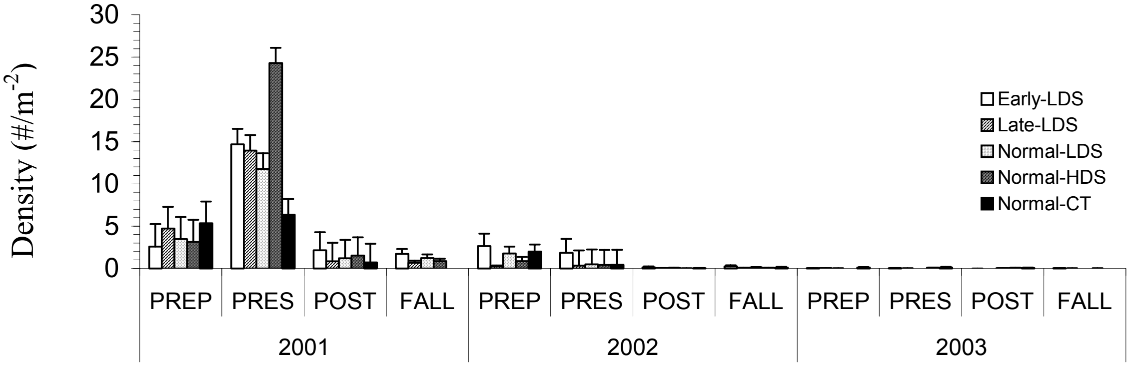

Figure 1: Volunteer glyphosate-resistant canola mean densities and standard errors in experiments conducted at seven locations on the Canadian Prairies from 2001 to 2003. Canola was spread in the late fall of 2000 and plots were seeded to a wheat-field pea-barley cropping sequence beginning in 2001. There were five seeding system combinations: early, normal and late seeding in low-disturbance, direct seeding (LDS), and high-disturbance direct seeding (HDS) and conventional tillage (CT) at normal seeding dates. Densities were determined at four intervals each year; pre-planting (PREP), in-crop pre-spray (PRES), in-crop post-spray (POST) (3 to 4 wk after herbicide application), and fall (FALL) (October) Adapted from Harker et al. 2006a.

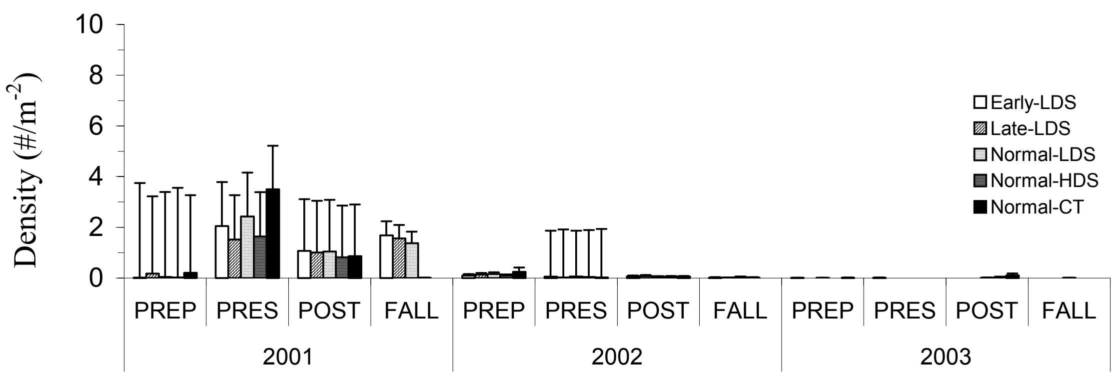

Figure 2:. Volunteer glyphosate-resistant wheat mean densities and standard errors in experiments conducted at seven locations on the Canadian Prairies from 2001 to 2003. Wheat was spread in the late fall of 2000 and plots were seeded to a Liberty Link canola-barley-field pea cropping sequence beginning in 2001. There were five seeding system combinations: early, normal and late seeding in low-disturbance, direct seeding (LDS), and high-disturbance direct seeding (HDS) and conventional tillage (CT) at normal seeding dates. Densities were determined at four intervals each year; pre-planting (PREP), in-crop pre-spray (PRES), in-crop post-spray (POST) (3 to 4 wk after herbicide application), and fall (FALL) (October) Adapted from Harker et al. 2006b.

Very little research has been conducted on the persistence of lentil seed in the soil. Volunteer lentils are not normally a problem in successive crops; however, there is anecdotal evidence of problems with red lentil contamination in green lentil seed even when there has been a 3-4 year interval between crops. It is speculated that this may be due to the severe droughts in the past few years, with a high percentage of the lentil crop experiencing high harvest losses. Lentil growers should be aware of potential admixtures and be aware that the imidazolinone herbicides will not adequately control and prevent contamination of a non-Clearfield™ red lentil in a Clearfield™ green lentil.

Accumulation of Soil Residues

Pursuit® and Odyssey® both contain the active ingredient imazethapyr which has the potential to carryover and injure susceptible rotational crops. Solo® contains the active ingredient imazamox which has some residual properties but its half-life in the soil is much shorter than imazethapyr (Shaner and Hornford, 2005). In addition, imazethapyr is more readily adsorbed by plant roots and translocated than imazamox; thus it has greater soil activity and is much likely to cause carryover injury to residual crops (Shaner and Hornford, 2005). Recropping experiments conducted at Scott support this (Fig. 3).

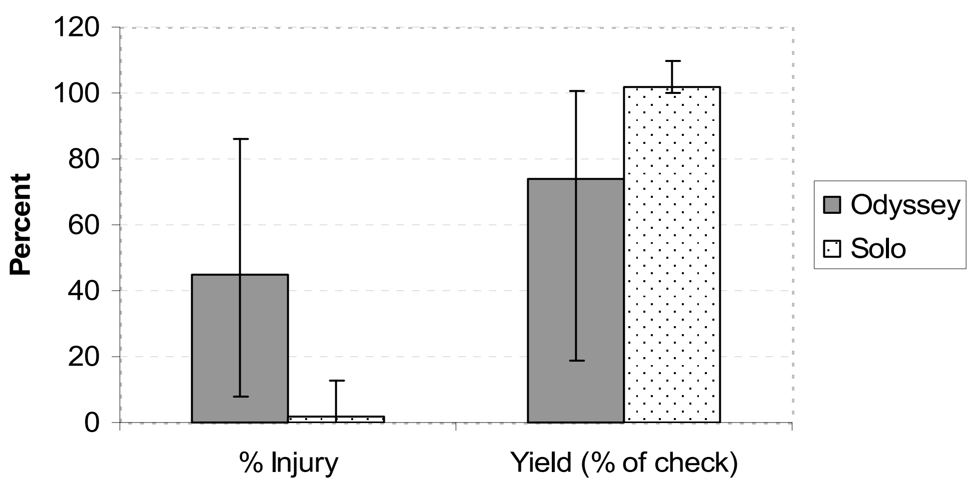

Fig 3: Effect of imidazolinone herbicide residues on Roundup ready canola grown 2 years after herbicide application. Means of 6 recropping experiments conducted at Scott, SK. from 1992-2000 (Johnson and Kirkland, unpublished data). Bars represent the range of injury and yield percentages from the six experiments.

During the droughts experienced in the early part of this decade, there was concern about the accumulation of herbicide residues from repeated application of residual Group 2 herbicides like Odyssey®, Sundance®, Everest®, and Assert®. The concern was colloquially termed "herbicide stacking" and experiments were conducted across Saskatchewan and Alberta to determine the impact of repeat applications. Herbicide stacking is defined as the repeated application of different residual herbicides which results in additive or synergistic phytotoxicity to rotational crops (Johnson et al. 2005). To explain the concept, herbicide A is applied in year 1 to 2/3 of a field and herbicide B is applied in year 2 to 1/3 of the field that received herbicide A and the remaining 1/3 of the untreated field. In other words, 1/3 of the field has received herbicide A, 1/3 has received herbicide B, and 1/3 received both herbicides A+B over the two years. Like all good farmers, an untreated check strip was left in the field for comparison. In year three, a susceptible crop is grown. In year 3, herbicide A caused a 20% yield reduction by itself, and herbicide B caused a 30% yield reduction. If the combined injury of A and B is >50%, then the effect would be considered additive or synergistic so this would be considered stacking.

Research results indicate that stacking did occur on some soils and environments. Sequences of the herbicides Odyssey®, Assert®, and Sundance® were most likely to result in stacking (Johnson et al. 2005). Stacking was more likely to occur in low organic matter soils located in the dark brown soil zones. Stacking occurred in about 20 % of the experiments conducted (Johnson, unpublished data). Therefore, the problem is not widespread and can be easily avoided by following stewardship guidelines for the management of Clearfield™ crops (covered by Bertholet in these proceedings).

CLEARFIELD™ CROPS IN ROTATION

Clearfield™ canola

The percentage of canola acreages devoted to Clearfield™ production has dropped from about 20% in 2000 to about 15% in 2005 (Beckie, personal communication). This is likely due to the high productivity of competitive hybrids and problems with residual herbicide carryover in the drought years. There could be a resurgence in Clearfield™ canola acres with the introduction of Clearfield™ hybrids and the growing popularity of specialty canola oil types such as Nexera that carry the Clearfield™ trait. Also, the introduction of the less residual Solo® herbicide will reduce concerns with herbicide carryover. However, if a grower wants to prevent overuse of Odyssey or Solo, they may want to save these herbicides for use on field peas, which have limited herbicide options.

Clearfield™ wheat

The introduction of Clearfield™ wheat in parts of the United States was a clear winner. The Clearfield™ trait in winter wheat has allowed for the control of a number of troublesome grass weeds such as downy brome, jointed goatgrass, and feral rye. However, its benefit in Western Canada cropping systems is a little harder to quantify. It does allow for the control of volunteer barley which could be problematic in some situations. Clearfield™ wheat may be a good choice following an Odyssey® or Pursuit® application if carryover risk is high (low soil pH, drought). However, it would prudent to use other herbicide groups for weed control if the crop was used for this purpose.

Clearfield™ lentil and sunflower

These are two clear winners due to the lack of alternative herbicides in both of these crops. The introduction of Clearfield™ lentil will reduce the application of unregistered imidazolinone herbicides which can cause subtle injury but still result in yield reductions (Wall 1996). The major concern for lentil growers is kochia. Odyssey® and Solo® can provide satisfactory to good control of kochia; however, growers will have to deal with increasing numbers of Group 2 resistant kochia. Sunflowers have few broadleaf herbicide options and the introduction of the Clearfield ™ trait will benefit sunflower production.

Conclusion

Clearfield™ crops can be used in a crop rotation to manage weeds and as a tool for resistance management. In order to retain the long-term sustainability of the Clearfield™ production system, producers will have to pay close attention to and follow the guidelines outlined in the BASF Clearfield™ stewardship plan.

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