Controlling Volunteer Canola as a Weed

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Final Report

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Steve Shirtliffe

Principal Investigator

Department of Plant Sciences

University of Saskatchewan

51 Campus Drive

Saskatoon, SK

S7N 5A8

1.0 Abstract

The objectives of these experiments were to determine the relative importance of genotype, seed size, time of windrowing, temperature, tillage system, and pre- and post-dissemination environment on the expression of secondary seed dormancy in spring *B. napus*. Volunteer canola establishes a seedbank through large harvest losses of viable seed (ca. 3000 seeds m^{-2}) which are usually equivalent to at least 10 times the normal seeding rate of canola. Secondary dormancy appears to be under genetic control and varies between canola cultivars. The environment that the canola is grown in has relatively little effect on its dormancy induction. Seed from high dormancy canola genotypes persists longer in the field because a small proportion of the seed becomes dormant following the high temperatures of summer. As shallow buried seed is less persistent producers should not deep till canola fields. Seeding canola with a low potential for secondary dormancy and not deep tilling should reduce subsequent weed problems with volunteer canola.

2.0 Executive Summary

Volunteer canola has become a common weed in western Canada. The aim of this project has been to determine why volunteer canola has become such a common weed and to suggest ways in which it can be managed. Large seed losses (3.3 – 10%) at harvest provide an ample source of seed to initiate a seedbank. Losses of 3000 viable seed m^{-2} are common. This amount of seed is 9-56 times the normal seeding rate of canola. These seed losses occur even when good management practices are followed and seem to be a result of the shattering nature of canola.

The length of time a seed can last in the seedbank is a function of the ability of the seed to develop secondary dormancy. Secondary dormancy is the ability of a seed to remain dormant (not germinate) when all of the conditions which would normally cause germination are present. It is advantageous as it allows a seed to not germinate at a time of year when it chances of successful reproduction are low. This mechanism is common in most summer annual weeds and causes the seed to germinate readily in spring but then to become dormant in summer and fall.

Using a lab test developed in Europe, we determined that many Canadian canola varieties do have the ability to develop secondary dormancy. This characteristic appears to be under genetic control as there are canola varieties that consistently show high potential to be induced into dormancy and a smaller proportion of varieties that show a low potential to be induced into dormancy.

Canola varieties observed in the lab test as having greater potential to be induced into dormancy also persist longer in the field. A small proportion of the seed of high dormancy potential canola varieties live past the non-dormant period in the spring and enter a dormant period in the summer and the fall. The higher soil temperatures of summer appear to induce dormancy in the seed and prevent germination late in the season that would result in the plant not having enough time to reproduce. Using a lab assay we have confirmed that high temperatures induce dormancy in canola varieties that are susceptible to it.

Producers should attempt to reduce seed loss at harvest in order to prevent canola seeds from being introduced into the weed seedbank. As early swathing does not increase dormancy, producers should swath at the recommended time and attempt to avoid seed shatter. Operating the combine properly will reduce seed loss somewhat and devices such as chaff collectors will

reduce separator losses. However these devices will have no effect on swathing or pickup seed losses.

Following harvest, producers should not deep till their fields as canola seed that remains near the soil surface does not persist as long. We think that suicidal germination and death from the wide temperature fluctuations kills much of the shallow buried seed. Volunteers should be controlled in crop to eliminate the chance of the seedbank being replenished. In our studies all of the volunteer canola always emerged before the timing of the in-crop herbicide application so there should be opportunity to control volunteer canola with herbicides. However, in some circumstances such as Clearfield® volunteer canola growing in peas, there will be no herbicide options. To avoid these situations, producers should carefully plan their crop rotations so that herbicide options exist for controlling volunteers.

It is recommended that the canola seed industry begin to screen new canola varieties for dormancy induction using the lab assay refined in this project. As this characteristic is stable in different years and locations we believe it to have a strong genetic control. By only releasing canola varieties with a low potential for induction into secondary dormancy, the persistence of volunteers should be drastically reduced. This step combined with good in-crop control of volunteers should reduce the prevalence of volunteer canola as a weed in western Canada.

3.0 Technical Report

3.1 Introduction

Annual canola acreage in western Canada has increased approximately 3 fold over the last 25 years (Statistics Canada, 1999). Based on relative abundance, an all encompassing measure calculated from the frequency, occurrence, and density of a weed species, volunteer canola has moved from ranking below 30th in the mid 1970's (Thomas, 1991; Thomas and Donaghy, 1991) to a rank of 12th during a 1995 summer survey conducted in Saskatchewan (Thomas et al., 1996). This outranks more common weeds such as kochia (*Kochia scoparia* [L.] Schrad.) and quack grass (*Agropyron repens* [L.] Beauv.). Recent survey (Thomas *et al*., 1999) and research plot (Derksen *et al*., 1999) data have shown that volunteer canola may persist for at least four years in rotation. Presently, it is not known whether long term persistence is the result of seed losses at the time of canola harvest or is primarily due to re-seeding by subsequent volunteers.

Research conducted in Europe has shown that *B. napus* can readily be induced into secondary dormancy by a combination of moisture stress and darkness (Pekrun, 1994). Field experiments have confirmed that although long term volunteer canola persistence is linked to a cultivar's potential for induction into secondary dormancy, the proportion of seed persisting via this mechanism is limited (Pekrun *et al.*, 1998).

It is important to determine the factors that affect seedbank persistence in canola, in order to devise management strategies which minimize the persistence of volunteer canola in western Canada.

3.2 Experiments

3.2.1 Lab Experiments

Dormancy assay

The following experiments were subjected to a secondary seed dormancy assay, as previously described by Pekrun *et al*. (1997). One hundred seeds were placed in each petri dish on two layers of filter paper. Each treatment was replicated four times and to induce secondary seed dormancy, the seeds were incubated in the dark at 20^{o}C in polyethylene glycol (PEG-8000) solution with an initial osmotic potential of -1.5 MPa. Plastic bags impervious to light were used to ensure no inadvertent exposure to light during these experiments. After 4 weeks, the seeds were transferred to new petri dishes containing distilled H_2O under a green safe light. After one week, the remaining ungerminated seeds were then again transferred to new petri dishes under green light. One week later, the remaining hard, non-germinated seeds were enumerated. Both, stratification (5 days at 2-4^{o}C) and tetrazolium (2,3,5 triphenyl tetrazolium chloride, 1% w/v) were used to confirm that all hard, non-germinated seeds were dormant. Dark germination of non-induced seed was also conducted using two to four replicates of 100 seeds of each genotype to determine seed viability as well as primary dormancy, if present.

3.2.1.1. Evaluation of genetic potential for development of secondary dormancy in canola.

Objectives

To evaluate the potential of induction into secondary dormancy of canola cultivars available in western Canada grown at two different locations in the Aspen Parkland ecoregion.

Materials and Methods

In 1999, seed from 16 commercially available *B. napus* genotypes grown in large-scale plot evaluation trials were obtained at the time of harvest from two Canola Production Centre locations in North Battleford and Grenfell, Saskatchewan (Canola Council 1999). Only six of these 16 genotypes were common in the 2000 variety evaluations. The locations, environmental parameters, and agronomic data are described in more detail in Canola Council (1999, 2000).

This study included genotypes with a wide range of quality traits. In 1999, 9 of the 16 genotypes were tolerant to herbicides (AC Excel, IMC107, IV2273, IV2463, IV2473, LG 32356, LG 3295, SW Rider), while 3 of 6 were herbicide tolerant (HT) in 2000. The dormancy assay was repeated four times in 1999 and two times in 2000 and the repetitions were blocked within each growth chamber. Unless otherwise indicated, seeds were stored at -15^{o}C during these experiments.

Data was initially analysed as a three-way factorial (genotype * location * year) using the MIXED procedure of SAS, however, significant interactions resulted the need for analysis within year and location. Treatment repetitions were nested within repetitions of the experiment. A single degree freedom estimate was conducted within each analysis comparing secondary dormancy potential between HT and non-HT genotypes. Fisher's protected LSD test was used to separate the means in all experiments.

Results and Discussion

A broad range in secondary seed dormancy potential was observed among the genotypes examined in this experiment (Table 1). Three distinct groups were observed; LG Dawn and Option 501 showed low levels (LD) for the expression of secondary seed dormancy, with a range of 15.2 to 31.4%. Quantum and IMC107 showed medium (MD) levels, ranging from 36.0 to 60.8%. The remaining 12 genotypes were classified as high (HD) expression of secondary dormancy. These genotypes displayed 49.0 to 90.3% potential for secondary dormancy expression. These observations were consistent between the two locations. In 1999, secondary seed dormancy expression was lower in all genotypes at Grenfell compared to North Battleford, except in Option 501. In the six genotypes examined in 2000, secondary seed dormancy expression was similar to that observed in 1999.

At North Battleford, contrasts revealed that the mean secondary dormancy potential of herbicide tolerant genotypes was significantly higher in both years (P > T, 0.0001). A similar, but not significant trend was observed at Grenfell among the 16 genotypes evaluated in 1999 (P > T, 0.6206), but not in 2000 (P > T, 0.1112). In all genotypes, dark germination of control treatments was greater than 94%.

TABLE 1. The effect of location and year on the potential for the development of secondary dormancy among *Brassica napus* genotypes. Analysis was conducted on square root transformed data. The standard errors are shown in parentheses.

	Potential for secondary seed dormancy expression			
	North Battleford		**Grenfell**	
Genotype	**1999**	**2000**	**1999**	**2000**
	----------%----------			
AC Excel	9.5 (0.06)	9.3 (0.21)	8.0 (0.71)	8.5 (0.15)
Exceed	8.9 (0.12)		7.2 (0.95)	
IMC107	7.8 (0.33)		6.5 (0.95)	
IV2273	9.4 (0.12)		7.7 (0.70)	
IV2463	9.3 (0.07)		7.7 (0.79)	
IV2473	9.4 (0.08)		8.3 (0.61)	
LG3235	9.1 (0.10)	8.0 (0.20)	7.3 (0.90)	8.5 (0.21)
LG3295	9.5 (0.11)		8.8 (0.33)	
LG Dawn	5.6 (0.25)	3.9 (0.33)	4.9 (0.96)	4.7 (0.49)
Magnum	9.0 (0.09)		8.3 (0.45)	
Millenium01	8.2 (0.33)		7.0 (0.89)	
Nexera500	8.6 (0.13)	7.3 (0.19)	8.2 (0.65)	7.4 (0.40)
Option501	4.0 (0.26)		5.2 (0.64)	
Quantum	6.7 (0.35)	7.1 (0.34)	6.0 (1.09)	7.0 (0.71)
SW Rider	9.3 (0.03)	8.2 (0.22)	7.6 (0.56)	8.4 (0.30)
Sentry	8.8 (0.13)		8.1 (0.56)	
$LSD_{0.05}$	0.5	0.7	0.8	0.9

Precipitation at Grenfell was 458 and 339mm throughout the entire growing season (May - Sept) and 104 and 100mm during the seed maturation period (Aug - Sept) in 1999 and 2000, respectively (Canola Council 1999, 2000). In North Battleford, accumulated precipitation throughout the growing season was 285 and 196mm and throughout the seed maturation period 62 and 113 in 1999 and 2000, respectively (Canola Council 1999, 2000).

3.2. 1.2 Effect of harvest method on dormancy in canola.

Objectives

To determine the effect of timing of windrowing and harvest method on the potential for development of secondary dormancy in *B. napus*.

Materials and methods

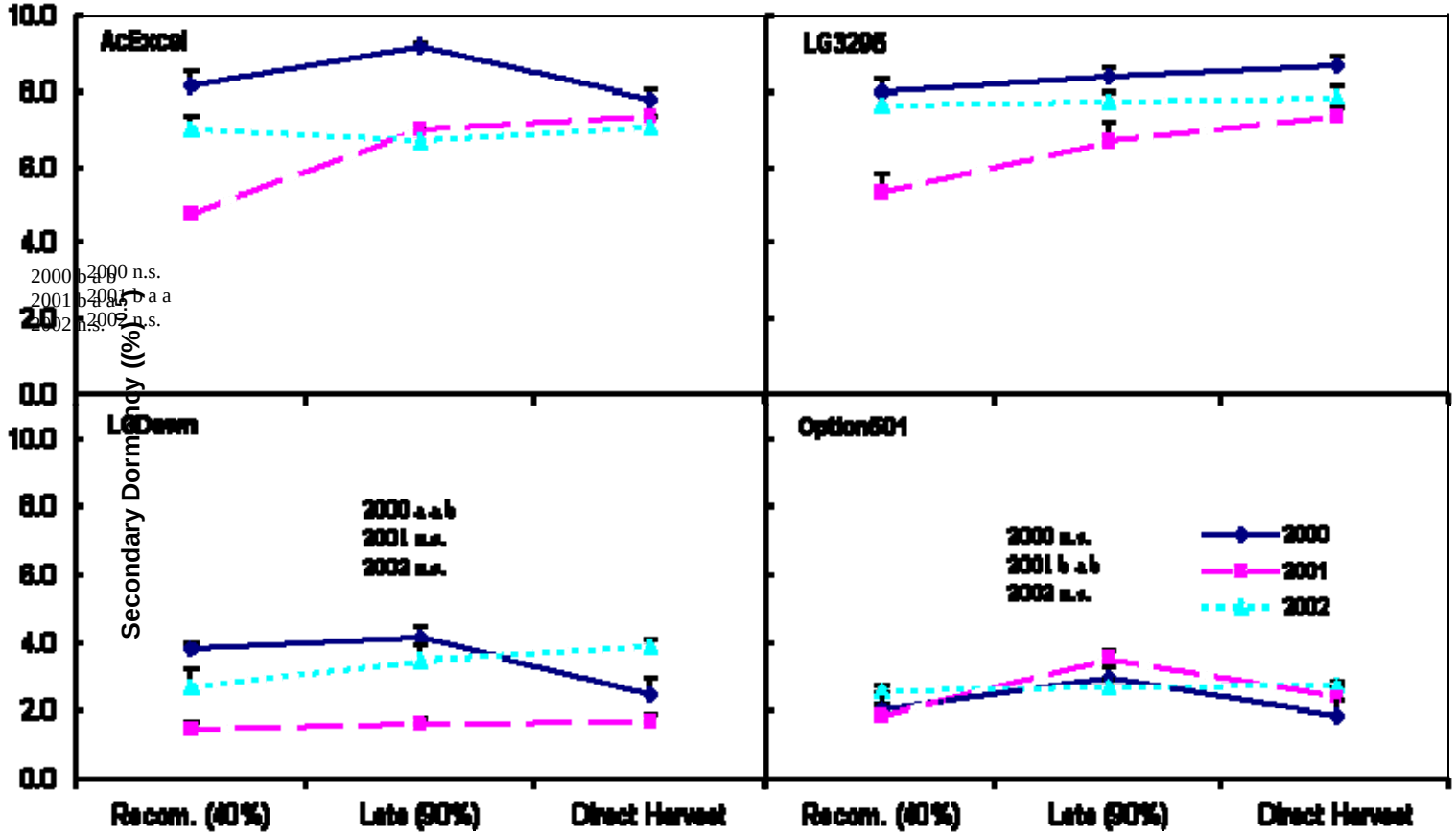
Two high dormancy (HD) (AC Excel and LG 3295) and two low dormancy (LD) genotypes (LG Dawn and Option 501) were used from the seedlots obtained from North Battleford in 1999. In the spring of 2000, 2001, and 2002, seed was planted at 5kg ha^{-1} in 8 x $8m^2$ areas isolated by at least 20m at the Kernen research farm. The plots were fertilized according to soil tests. Three different harvest regimes were employed. One-third of each plot was windrowed at the recommended time (30-40% of seed in siliques on the main rachis have turned colour), one-third was windrowed later then recommended (95-100% of the seeds in siliques on the main rachis had turned colour). The remaining third was not windrowed prior to harvest. All treatments were harvested at the same time (Oct 3, 2000; Sept 13, 2001; Oct 22, 2002). In 2000, the first windrowing date occurred during the last week of August in all genotypes. In 2001, it occurred one week earlier than 2000, and in 2002, the it occurred in early September. The late windrowing was conducted approximately two weeks after the first windrowing date in all years. Seed from each treatment was subjected to the dormancy assay immediately following harvest.

Due to excessively dry conditions, *ca.* 75 ml of supplemental irrigation was applied during August 2001 to ensure some progeny and also in May 2002 to aid germination and establishment.

Data was analysed using the GLM procedure, as a three-way factorial (treatment * genotype * year). Data were split as significant interactions demanded.

Results and Discussion

The influence of time of windrowing on the secondary seed dormancy expression was statistically significant in only 5 of 12 instances (Figure 1). When statistically significant, secondary seed dormancy expression was greatest in all genotypes at the late windrowing date, when 90% of the seed on the main rachis had turned colour. With the exception of LG Dawn, secondary seed dormancy expression was lower at the recommended time of windrowing when differences were observed. When plants were not windrowed, secondary seed dormancy expression was similar or lower to that observed at the late windrowing date.



Time of Windrowing (% black seed)

FIGURE 1. The influence of time of windrowing on the expression of secondary seed dormancy in two high (AC Excel, LG3295) and two low (LG Dawn, Option 501) dormancy genotypes. Standard error of the means and Fisher's protected LSD means separation for each year are indicated.

The relative contribution of different windrowing dates was negligible in comparison to other factors examined (Table 2). Nevertheless, the trend that early windrowing exhibited among the lowest potential for secondary seed dormancy expression relative to the remaining treatments in this experiment indicates that the recommended time of windrowing does not compromise the potential expression of secondary seed dormancy in western Canada. Inconsistencies observed in the windrowing study were likely the result of varying environmental conditions experienced during seed maturation in 2000, 2001, and 2002.

TABLE 2. The contribution of genotype and phenotype (pre-harvest components) to the total variation (sum squares) in the cultivar comparison, time of windrowing (TOW), seed size, and seed storage experiments. The number of genotypes examined is indicated in parentheses.

Experiment	**Environment**								
				Pre-dissemination		**Post-dissemination**			
	Genotype	Seed size	Maturity	Year	Location	Time	Temp	Θ_o	c.v.
	----------%----------								
Pre-harvest									
Cultivar comp. (16)	44.0			0.4	2.5	15.9			16.0
Cultivar comp. (4)	67.0			1.2	0.1	7.3			18.2
Seed size (4)	54.6	21.1		7.4					27.9
Harvest method (4)	82.4		1.5	4.8					18.0
Pre-dissem. Mean	68.8	21.1	1.5	4.5	0.1				
Post-dissemination									
Storage cond. (4)	75.8					5.9	3.0		25.2

3.2.1.3 Seed size effect on secondary dormancy in canola.

Objectives

To determine the potential of different seed size fractions from the same *B. napus* seed lots for induction into secondary dormancy.

Materials and Methods

In 2000, 2001, and 2002, seeds from all four genotypes from the recommended windrowing date of the harvest method study were passed through a stack of round-holed sieves and sorted according to size (large, 1.98 to 2.38 mm; medium, 1.59 to 1.98 mm; small < 1.59 mm). The proportion of each fraction relative to the total seedlot was determined gravimetrically and the dormancy assay was used to determine secondary seed dormancy expression among the different seed size fractions.

Data was analysed using the GLM procedure, as a three-way factorial (treatment * genotype * year). Data were split as significant interactions demanded.

Results and Discussion

A significant difference in seed viability among all three seed size classes was observed in the dark germination control. Seed viability in large seed (97.3%) was greater than in medium seed (95.5%) which was greater than in small seed (92.1%), irrespective of genotype (Table 3). The influence of seed size on secondary seed dormancy expression was analysed within year and genotype due to significant interactions. In all genotypes, a greater portion of the large seeds was induced into secondary seed dormancy than small seeds (Figure 2). Visual observations indicated that the majority of the small seeds did not survive the induction phase of the experiment. This was not observed in the medium and large seeds. In AC Excel, LG 3295, and LG Dawn, a more rapid decline in seed dormancy expression as seed size decreased was observed in 2001, compared to 2000 and 2002. This was not observed in Option 501.

TABLE 3. The proportion and viability of large, medium and small seeds of four *B. napus* genotypes grown from the same original seedlot in 2000, 2001, and 2002. The standard error of the mean is indicated in parentheses.

Genotype/Year	**Seed Size**					
	Large		**Medium**		**Small**	
	prop.	viability	prop.	viability	prop.	viability
	----------%----------					
AC Excel						
2000	8.2	97.0 (1.1)	81.3	97.0 (1.5)	10.4	91.8 (0.9)
2001	43.2	98.2 (0.6)	47.4	97.2 (1.3)	9.4	93.5 (0.6)
2002	25.8	98.0 (0.8)	70.6	96.0 (0.8)	3.6	90.0 (1.8)
LG3295						
2000	17.3	97.8 (1.9)	79.1	96.8 (1.7)	3.6	91.5 (1.7)
2001	69.5	98.2 (0.9)	28.7	95.0 (1.1)	1.8	90.8 (0.9)
2002	48.3	98.0 (1.7)	50.6	96.0 (0.9)	1.1	90.3 (1.0)
LG Dawn						
2000	16.9	97.0 (1.5)	72.1	94.0 (1.5)	10.9	94.8 (1.3)
2001	62.0	95.5 (1.8)	33.0	92.3 (1.1)	4.9	89.5 (1.7)
2002	37.6	95.3 (1.0)	58.5	94.8 (1.3)	3.9	92.3 (1.3)
Option 501						
2000	4.5	97.5 (1.3)	84.3	96.8 (1.4)	11.2	94.5 (1.2)
2001	47.9	98.3 (1.0)	44.1	95.5 (1.2)	8.0	94.2 (1.5)
2002	17.8	96.5 (1.9)	75.6	94.8 (1.5)	6.6	91.2(1.4)

The relative proportions of the large and medium seed size fractions of each genotype varied greatly among the three years (Table 3). In 2000, the large:medium seed size ratio was smallest among all genotypes, while in 2001, this ratio was greatest. The smallest seed size fraction consistently contributed very little to total seedlot composition.

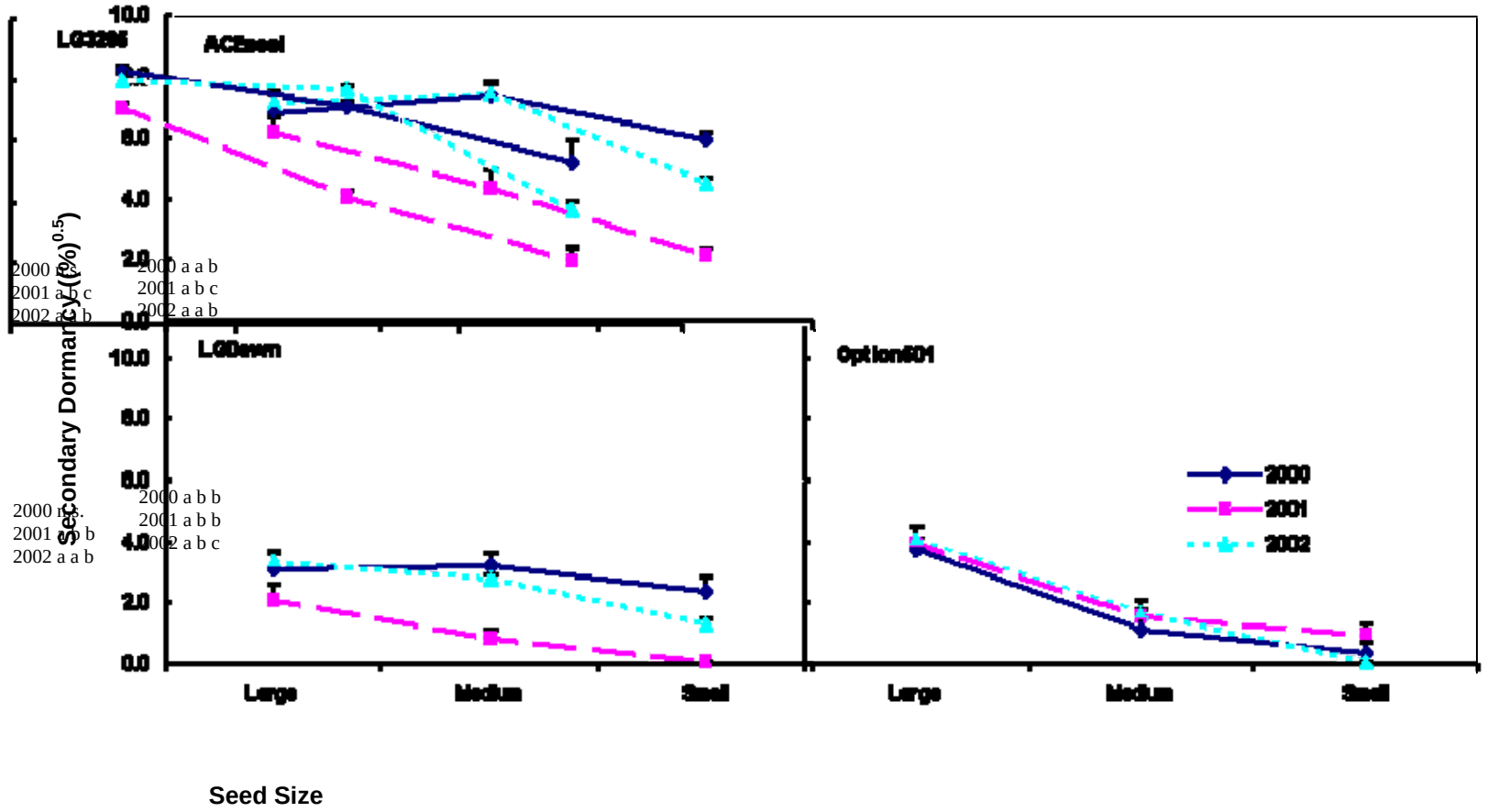


FIGURE 2. The influence of seed size on the expression of secondary seed dormancy in two high (AC Excel, LG3295) and two low (LG Dawn, Option 501) dormancy genotypes. Standard error of the means and Fisher's protected LSD means separation for each year are indicated.

Results showed that the importance of seed size to secondary seed dormancy expression in *B. napus* was second only to genotype (Table 2). The effect of seed size on seed germinability is relatively well understood in some species (Baskin and Baskin 1998); however, little is known of the effects of seed size on secondary seed dormancy expression. The lower seed germinability observed in smaller seed (Table 3) was primarily due to differences in seedlot viability as primary dormancy was small and not significantly different among seed size classes. Seed dormancy expression in *B. napus* was similar to that previously reported in *A. hymenoides* where the largest seeds exhibit the greatest degree of seed dormancy (Jones and Nielson 1999).

The high rate of seed death observed in the small seed fraction during the induction phase of the experiment suggests either a limited metabolic capacity to endure the imposed stresses, or an inability to switch the metabolism to a dormant state, or both. Little is known about the metabolic changes conferring secondary seed dormancy expression in *B. napus*. Small seed, however, only accounted for 1.1 to 11.2% by weight to the unsorted seedlot (Table 3) and therefore, contributed relatively little to seed dormancy observed in unsorted seedlots.

3.2.1.4 The effects of storage conditions on secondary dormancy in *B. napus*.

Objective

The objective of this experiment was to determine the effect of seed storage conditions on the induction of secondary dormancy in *B. napus*.

Materials and Methods

Immediately following harvest in 2000, samples from the recommended time of windrowing were stored at -15^{o}C, -70^{o}C, as well as ambient temperature in an uninsulated building where the annual temperature variations ranged between -12 and +35^{o}C. Every two months seeds from each treatment were subjected to the dormancy assay. This experiment was continued until October 2002.

The seed storage condition experiment data were analysed as a repeated measures two-way factorial (storage treatment * time) within each genotype using the MIXED procedure of SAS. After choosing the most accurate covariance structure, time was modeled as the regression variable with linear and quadratic components and a solution for the most appropriate regression equation for each storage treatment within each genotype was determined (Littell *et al.*, 1996).

To determine the contribution of each factor to total variance in each experiment, the proportion of the sums of squares (SS) of each factor in relation to the corrected total SS of the experiment was determined. One-way main effect analysis using the GLM procedure of SAS was used to obtain the SS. The variation among treatments in the harvest method study was considered to be primarily due to differences in seed maturity at the time of treatment implementation. Although there may have been an environmental component contributing to our observations, we assumed that the contribution was negligible as there was no possible means of testing this. Variation among successive repetitions of the same experiment was

considered as the post-dissemination time factor, while the variation between storage treatments was considered to be primarily the result of temperature differences among these treatments.

Results and Discussion

During storage, secondary seed dormancy expression decreased significantly at different rates in all genotypes, except Option 501 (Figure 3). Nevertheless, trends in Option 501 agree well with those observed in the remaining genotypes. In all genotypes, seed dormancy potential decreased most when stored at ambient temperatures and decreased least when stored at -70^{o}C over time. In the HD genotypes, the observed decrease in secondary seed dormancy potential was curvilinear over the two year duration of the experiment and differences among all storage treatments were significant. In the LD genotypes the relationship was linear over time and a significant difference was only observed between the -15^{o}C and ambient storage treatment in LG Dawn.

Seed storage temperature and duration also play an important role in secondary seed dormancy expression (Table 2). The rate of loss in secondary seed dormancy expression was linked to storage temperature and increased as mean storage temperature increased (Figure 3). In the HD genotypes significant differences in secondary seed dormancy rate loss were observed between the -70 and -15^{o}C storage treatments, indicating colder storage is better, if secondary seed dormancy expression is to be preserved. Our results did not indicate an internal dormancy/non-dormancy cycle previously reported in other species during seed storage (Froud-Williams *et al.*, 1986), even under ambient storage conditions. It is also unclear whether the high mean temperature or the annual temperature fluctuations in the ambient storage treatment contributed to the high loss of secondary seed dormancy expression.

A similar decrease in secondary seed dormancy expression during storage has been previously observed in *B. napus* (Schlink 1995), although not at the low storage temperatures examined in this experiment. This decrease in seed dormancy potential is similar to an after-ripening response associated with the release of primary seed dormancy in many species (Baskin and Baskin, 1998). At this time, it is unclear if the mechanisms regulating primary and secondary seed dormancy are similar (Bewley and Black, 1994). However, our results do suggest a significant degree of similarity between these seed dormancy classes, at the organism level.

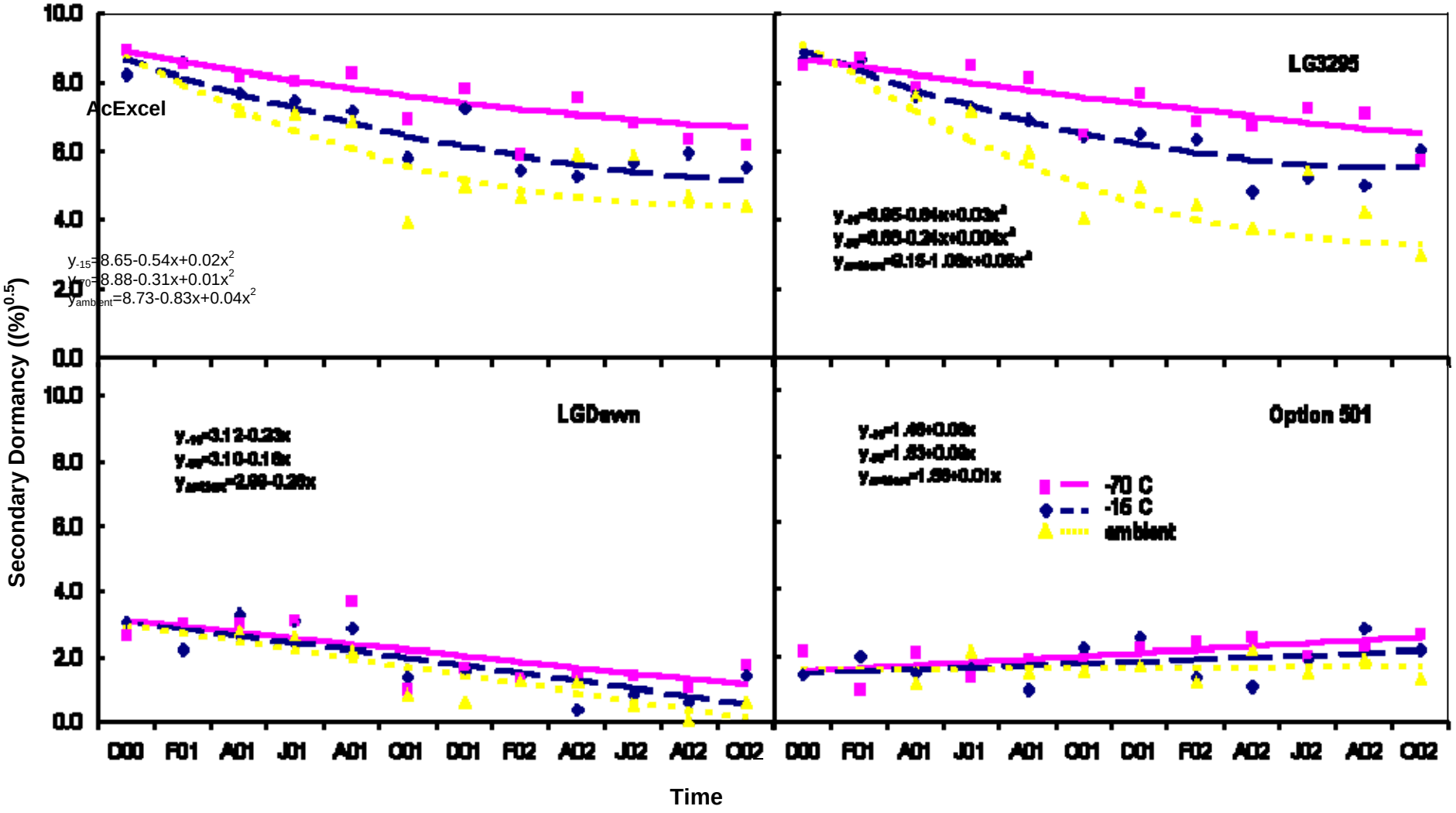


FIGURE 3. The influence of storage time and conditions (-15, -70, and ambient) on the expression of secondary seed dormancy in two high (AC Excel, LG3295) and two low (LG Dawn, Option 501) dormancy genotypes. The regression equations for each treatment are indicated.

3.2.2 Field Experiments

3.2.2.1 The influence of harvest operation losses on canola seedbank input.

Objective

To quantify the total canola seed losses incurred during the harvest process on commercial farms.

Materials and methods

Sample collection

In 1999 and 2000, fields were selected from producers located within a 150 km radius of Saskatoon. Where possible, two fields per producer were sampled in both years. A total of 17 and 19 fields were surveyed in 1999 and 2000, respectively. Fields were sampled within days after harvest to minimize the potential of seeds lost to germination. The harvest seasons of 1999 and 2000 were both very dry and seed germination prior to sampling was negligible. A producer management survey was completed in conjunction with each field.

Samples were collected at three random locations in each field. A measuring tape was laid perpendicular to two windrows. The location of swaths prior to harvest was easily determined due to the non-bleached (light green) appearance of stubble previously located under the windrow. Using a wet/dry vacuum cleaner, all remaining crop residue, lost seeds and some soil were removed from 25 x 25 cm^2 quadrants at one meter intervals along the transect. One meter intervals between sub-samples were chosen, as the width of most windrowers increases by 3 feet. The number of squares removed from each transect was noted and used to determine the quantity of seed lost per unit area. The bulked sample of each transect was placed in a paper bag and air dried at approximately 25^oC for further analysis.

Seed separation

Air dried samples were passed through a round 18/64" hand sieve (Cuthbert Co. Ltd., Winnipeg, Canada) to remove large crop residue particles. A Carter-Day XT3 dockage tester (Carter-Day Company, Minneapolis, USA) was then used to separate the remaining samples into fractions larger and smaller than the seeds of interest. A No. 6 riddle sieve and a wind speed setting at 7.5 provided the first separating steps. The sieves were comprised of a No. 20 (6/64") round sieve used in the top position, a No. 1 (2.5/64") round sieve placed in the middle position and a solid pan in the bottom position. This sieve combination was chosen after repeated trials with canola seed from various seed lots to ensure that all canola seeds passed through the top sieve, but were retained by the sieve in the middle location. The fraction retained by the middle sieve was then subjected to a wet sieving through a No. 16 (1.18mm) square brass sieve (Endecotts Ltd., London, UK). The gentle stream of water dissolved soil aggregates of a similar size as canola seeds, leaving only small stones, organic residue and seeds in the sieve. Upon air drying, the jagged stones were separated from canola seeds by rolling the seeds down a flat surface at a slight angle, followed by final hand sorting. The separated seeds were oven dried (1999) and weighed, and the thousand seed weight of each sample was determined.

To determine seed viability in 2000, 50 seeds were removed from each sample prior to wet sieving. Using the 1000 seed weights, the sample weights were adjusted for the removal of these seeds. Viability was determined by placing 50 seed samples into petri dishes containing two layers of filter paper and 8 ml of distilled water. Germination was monitored over two weeks at 20^{o}C and final germination percentages were tabulated.

Results and Discussion

Average yield losses equaled 107 kg ha^{-1} or 5.9%, amounting to seedbank additions of approximately 3600 seeds m^{-2} (Table 4). Germination tests revealed a mean viability of 82%, indicating seedbank additions of 3000 viable seeds m^{-2}.

TABLE 4**.** Total yield, yield loss, percent yield loss, thousand seed weight, and seedbank addition of Brassica napus during on-farm harvest as influenced year. Standard errors are indicated in parentheses as are LSD values where the model indicated significance at alpha = 0.05.

Year	**Yield**	**Yield loss**		**1000 Seed weight**	**Seedbank additions**
	(kg ha^{-1})	**(kg ha^{-1})**	**(%)**	**(g)**	**(seeds m^{-2})**
1999	1980 (131)	110 (16)	5.9 (0.8)	3.15 (0.07)	3570 (518)
2000	1890(115)	106 (14)	5.6 (0.7)	2.83 (0.07)	3610 (473)
LSD	n.s.	n.s.	n.s.	0.2	n.s.
Mean	1930 (123)	107 (15)	5.8 (0.8)		3590 (496)

Producer yield losses ranged from 3.3 to 9.9% (Table 5) or 9 to 56 times the normal seeding rate of canola. Harvest losses were consistent within producers, indicating that management practices play a significant role in seedbank additions. These observations suggest that seedbank additions may be reduced by more careful harvest management by producers. Nonetheless, even with relatively small persistence rates, seedbanks of this magnitude could result in significant volunteer populations for several years without further seedbank additions from escaped volunteers.

TABLE 5. Yield loss and seedbank additions summarized by producers for which more than one field-year of data was available. Standard errors are indicated in parentheses. Means followed by different letters are significantly different as determined by LSD means separation.

Producer	**Yield loss**		**Seedbank additions**
	(kg ha^{-1})	**(%)**	**(seeds m^{-2})**
1	146 (29)bc	9.6 (1.7)b	5250 (994)bc
2	107 (29)ab	4.9 (1.7)a	3760 (994)ab
3	44 (23)a	3.5 (1.4)a	1530 (811)a
4	83 (20)ab	3.3 (1.2)a	2660 (703)ab
5	97 (28)ab	4.3 (1.7)a	3110 (994)ab
6	125 (23)b	6.8 (1.4)ab	4300 (811)b
7	134 (28)b	6.9 (1.7)ab	4480 (994)bc
8	78 (20)ab	5.4 (1.2)a	2580 (703)ab
9	73 (20)ab	3.3 (1.2)a	2430 (703)ab
10	226 (30)c	9.9 (1.7)b	7130 (994)c

3.2.2.2 Effects of tillage systems on volunteer canola persistence.

Objectives

To determine the longevity of an artificially created volunteer canola seedbank, and to study seed persistence of canola cultivars under two differing tillage management systems.

Materials and Methods

This experiment was established on canola stubble, which was seeded in the spring of 1999 at two locations near Saskatoon. At both locations, the canola crop was removed prior to maturity to eliminate the potential of natural seed shed causing contamination. The experiment was a two factor RCBD with four replicates. Factors included tillage (conventional; zero-till) and genotype (six *B. napus*; two *B. rapa*). The *B. napus* seed was obtained from the Canola Production Center located near North Battleford (Canola Council 1999), while the *B rapa* seed was sourced from the regional variety trial location at Canora. The selected *B. napus* genotypes had a broad range of breeding systems, oil quality, and herbicides tolerance characteristics and included: Quantum; Nexera 500; 46A73; InVigor 2273; LG 3235, and IMC106. AC Parkland and Hysyn 111 were the *B. rapa* genotypes selected for this experiment.

A laboratory assay (Pekrun, 1994) was used to classify the *B. napus* genotypes according to their potential for the development of secondary dormancy. This assay was repeated twice. Four genotypes (46A73, IV2273, LG 3235, and Nex 500) had high (HD) potential for the development of secondary dormancy, ranging from 72 - 88%. The remaining two genotypes (Quantum and IMC106) had medium (MD) potential, ranging from 46 and 49% (Gulden *et al.*, 2000). Genotypes were grouped according to this seed dormancy classification system for data analysis.

Dormancy induction in *B. rapa* seed could not be achieved using the described assay conditions, and as a result these genotypes could not be classified according to seed dormancy potential.

Canola seeds were distributed at a density of 2000 seeds m^{-2} using a Fabro cone seeder, with double disc openers. The tubes delivering the seeds were removed from the openers and held in place approximately 30 cm above the soil surface. The openers were not allowed to disturb the soil surface.

Conventional tillage plots were tilled twice each spring and fall for the duration of the study. The zero-till treatments remained undisturbed. Wheat was seeded (100 kg ha^{-1}) between May 10^{th} and 18^{th} of 2000, 2001, and 2002. Fertilizer was also applied at the time of seeding and was based on soil test recommendations.

In late April of 2001, a pre-seeding glyphosate burn-off was applied to all treatments at both sites to control winter-annuals. The wheat crop was harvested at maturity and the crop residue was returned to the experimental units.

Soil temperatures were measured for the duration of the experiment, with the exception of May 2000 to Oct 2000. Daily mean, minimum and maximum temperatures at 1 and 10 cm depths were recorded for each tillage system. At each location, cumulative monthly precipitation.

The soil seedbank was sampled every spring (mid to late April) prior to any field operations. Ten soil cores per experimental unit were removed to a depth of 15 cm using a hydraulic soil probe, equipped with a 7.5 cm diameter coring tube. The cores were loosely broken up and arranged into flats. Germination was conducted under ambient temperatures (10-

15°C) and artificial light conditions. The readily germinable seeds were quantified by irrigating the flats as necessary and recording seedling recruitment on a weekly basis. Immediately after quantification, the emerged seedlings were removed and each sample was stirred. This method also ensured the germination of readily germinable and conditionally dormant seeds. After three weeks, the soil was allowed to air dry and stored for dormancy determination.

After one to six months, the remaining seeds were elutriated from the soil. The soil samples were coarsely broken up and placed into 20 mesh sprayer strainers that were capped at each end. The soil was washed from these strainers using an elutriator (as described by Wiles *et al.*, 1996). Immediately after washing, canola seed was manually removed from the samples and was tested for viability. Firm, healthy seeds were presumed to be viable and dormant.

If one viable seed or emerged seedling were found among all soil cores taken from one experimental unit, this would equate to a minimum seedbank detection of 22 seeds m^{-2}.

Field emergence of volunteer seedlings was monitored during the growing season in 1999, and at monthly intervals from April to October in 2000, 2001 and 2002. Spring seedling recruitment counts were conducted prior to seeding. Counts in early June were also conducted just to in-crop weed control. These counts were conducted in six randomly placed 0.25 m^2 quadrats in each experimental unit. In 2002, whole plot counts were conducted as seedling recruitment densities were too low to quantify using quadrats.

All seedling and seed counts were pooled for each experimental unit. To meet the assumptions of ANOVA, all data were transformed using the square root method. Prior to transformation, 0.001 was added to each value, to enable transformation of zero values. This resulted in transformed zero values equating to 0.03. Means and standard errors of the mean were calculated for genotype groups.

The GLM procedure of SAS was used to analyse the data for each location separately due to the strong influence of location on seedbank persistence. To determine differences among the genotype groups (HD, MD and *B. rapa*) four single degree freedom estimates were conducted within each ANOVA. This enabled the estimation of differences between HD and MD *B. napus* genotypes without the influence of the unclassified *B. rapa* genotypes. When the two-way interaction was significant ($p < 0.05$), differences among genotype groups were estimated within tillage systems.

The relationship between spring seed dormancy in 2000 was regressed against seedbank persistence of individual *B. napus* genotypes using the GLM procedure of SAS. In addition, total seedling recruitment in 2000 and 2001 was regressed against spring seedbank persistence of that year. These comparisons were conducted at both locations within tillage systems and on the combined data. Regression analysis was conducted on transformed treatment means.

Results and Discussion

Spring seedbank persistence was higher in HD genotypes than in MD genotypes in 2001, irrespective of tillage system and location. These results confirm trends observed in Europe where high dormancy genotypes also exhibit greater seedbank persistence (Pekrun and Lutman 1998, Pekrun *et al.* 1997). The mean persistence of HD genotypes was 6 and 12 fold higher than that of MD genotypes at Kernen and Dundurn in 2001, respectively. In 2002, few persisting seeds were detected in the seedbank. This was primarily due to persistence levels that were lower than our level of seedbank detection. Nevertheless, more persisting seeds of HD *B. napus* genotypes were found than those of other genotype groups at both locations. In 2002, the highest seedbank persistence was found in LG 3295 (HD) in CT (11 seeds m^{-2}) at Kernen.

IV 2273 (HD) in ZT and Quantum (MD) in CT followed with 6 seeds m^{-2}. At Dundurn, 11 seeds m^{-2} were found in IV 2273 (HD) in CT, while 6 seeds m^{-2} were recorded in AC Parkland (*B. rapa*) in CT. This indicates that long-term seedbank persistence of *B. napus* can be reduced by growing genotypes with low potential for secondary seed dormancy development in western Canada.

In the spring of 2000, mean seedbank persistence was lower in conventional tillage (CT) compared to zero tillage (ZT) at Kernen . A similar trend was observed at Dundurn, although the difference was not significant (Table 6). This suggests that short-term seedbank persistence may be greater under ZT compared to CT. These findings are in contrast to the observations in the UK where seed burial by tillage strongly contributes to seedbank persistence in *B. napus* (Pekrun *et al.* 1998). Higher persistence in ZT after one winter may in part have contributed to observations in a Manitoba weed survey where higher volunteer canola seedling recruitment was found in ZT compared to CT (Thomas *et al.* 1997). In Alaska, greater seed survival of *B. rapa* was attributed to increased snow cover in ZT (Sparrow *et al*. 1990). Low fall precipitation may have contributed to the higher levels of seedbank persistence in ZT after one winter in this study. In western Canada, low fall precipitation has recently been linked to higher volunteer canola seedling recruitment during the following spring (Légère *et al.* 2001). Low fall precipitation reduces the possibility of fall germination as well as the loss of desiccation-tolerance in seed, thereby increasing seedbank persistence.

In the spring of 2001, the tillage system effect on seedbank persistence at Kernen was opposite to that observed in 2000. Although low in comparison to 2000, the seedbank persistence was approximately an order of magnitude higher under CT compared to ZT. This equated to approximately 1% and 0.1% of the untransformed original seedbank additions in CT and ZT, respectively. Similar trends in all genotype groups were observed. This indicates that *Brassica* spp. seedbank losses were higher under ZT throughout the first year than in CT. A similar trend was not observed at Dundurn at this time where persistence in both tillage systems was similar to that observed under ZT at Kernen after two winters. The low persistence recorded in Dundurn in 2001 may be related to the sandy soil texture at this location. Similar observations were reported in one experiment conducted on winter *B. napus* in the UK (Lutman and López-Granados 1998).

In 2001, the seedbank persistence of *B. rapa* genotypes was substantially higher in CT than ZT, at both locations. The significance of seed burial on overwintering of this species has been reported by Sparrow *et al.* (1990), but has not previously been documented over two seasons.

In 2001, the seedbank persistence of *B. rapa* genotypes was substantially higher in CT than ZT, at both locations. The significance of seed burial on overwintering of this species has been reported by Sparrow *et al.* (1990), but has not previously been documented over two seasons.

Although few persisting seeds were found in 2002, the tillage system trends were similar to those observed in 2001. Given maximum persistence of 0.2% of the untransformed original seedbank additions in HD *B. napus* in CT at Kernen and mean on-farm seedbank additions of 3000 viable seeds m^{-2} using current production systems (Gulden *et al*. 2003), a maximum of 6 seeds m^{-2} could be expected in fine textured CT fields three years after the last canola crop.

TABLE 6. Seedbank persistence of two groups of *B. napus* (MD, HD) and *B. rapa* genotypes in conventional (CT) and zero tillage (ZT) at two locations in 2000 and 2001.

	2000			2001		
Genotype	**CT**	**ZT**	**Mean**	**CT**	**ZT**	**Mean**
Kernen						
HD B. napus[a]	23.3 (2.89)	27.3 (3.47)	25.3 (3.30)	5.23 (2.19)	2.60 (1.36)	3.91 (1.91)
MD *B. napus*	19.5 (3.10)	29.7 (7.57)	24.6 (4.76)	2.26 (2.22)	0.86 (1.65)	1.56 (1.38)
B. rapa	20.3 (4.75)	29.2 (5.20)	24.8 (3.97)	4.59 (2.88)	0.61 (1.16)	2.60 (1.82)
Tillage mean[b]	21.6 b	28.4 a		4.33 a	1.67 b	
Estimates						
napus vs *rapa*[c]			0.26			0.52
HD vs MD			0.67			2.35 **
HD vs *rapa*			0.49			1.31
MD vs *rapa*			-0.19			-1.05
Dundurn						
HD *B. napus*	27.2 (3.98)	27.2 (4.18)	27.2 (4.01)	1.19 (1.04)	3.07 (1.92)	2.13 (1.59)
MD *B. napus*	20.1 (2.69)	28.3 (3.91)	24.2 (3.13)	0.61 (1.16)	0.61 (1.16)	0.61 (0.79)
B. rapa	25.6 (3.70)	23.2 (5.97)	24.4 (3.45)	2.84 (2.19)	0.61 (1.16)	1.73 (1.33)
Tillage mean	25.0	26.4		1.46	1.84	
Estimates						
napus vs *rapa*			1.77			-0.10
HD vs MD			2.98			1.52 *
HD vs *rapa*			2.77			0.40
MD vs *rapa*			-0.21			-1.11

[a] Data are square root transformed seeds m^{-2}. Standard errors of the means are indicated in parenthesises.
[b] Means followed by different letters are significantly different and were separated using Fisher's protected LSD where appropriate.
[c] Estimated differences and significance of estimated differences is indicated where appropriate (*** $p<0.01$; ** $p<0.01$ to <0.05, * $p<0.05$ to <0.10).

3.2.2.3 Secondary dormancy and temperature regulate seedbank dynamics in *B. napus*.

Objectives

To determine the influence of storage conditions on the potential for the development of secondary dormancy in two *B. napus* genotypes [LG3295 (high), Option 501 (low)] as influenced by tillage system and depth of burial over time.

To determine development of secondary dormancy in remaining *B. napus* seeds throughout the growing season as influenced by field conditions at two depths and under two tillage systems.

Materials and Methods

Laboratory experiments

Seed was obtained at harvest (1999) from one of the large plot variety trials located in Delmas, SK (Canola Council 1999). Secondary seed dormancy expression among genotypes at 20°C was determined (Pekrun et al. 1997). This experiment was repeated twice. The influence of temperature (5, 10, 15, 20°C), initial osmotic potential (-0.5, -1.0, -1.5, -2.0 MPa) on the

development of seed dormancy in two high dormancy genotypes was investigated (LG 3295, AC Excel). Treatments were sampled at 1,2, 3, and 4 weeks of dormancy induction. After the induction phase, the non-dormant seeds were removed in a two week dark germination test at 15^{o}C (Pekrun et al 1997b). The initial solution osmotic potentials were adjusted for temperature (Michel 1983) and the experiment was repeated twice.

Field study establishment

The experiments were established at two sites located in the Moist Mixed Grassland ecoregion (Acton et al. 1998) in Saskatchewan, in 2000 and 2001. The two locations differed in soil type (Kernen with a clay texture; Dundurn with a loam texture). The role tillage, genotype (LG 3295 - HD and Option 501- LD), and burial depth (1, 10 cm) on seedbank dynamics was examined. Tillage systems were maintained prior to the establishment of the experiment, and consisted of conventional tillage (2 cultivations each spring and fall) and zero tillage (soil disturbance at seeding only). Four rows of plastic pots that were modified to facilitate drainage and contained 200 viable seeds each, were buried level to the soil surface on Oct 8 to 10, 2000 (8 pots per row) and Sept 25 and 26, 2001 (12 pots per row). In the zero-tillage system, the pots were placed between rows of standing stubble to maintain the snow trapping ability. Soil disturbance within the plastic pots did not occur after establishment. In 2000, 10 nylon-mesh pouches per treatment were also buried at these depths. Each pouch contained 600 viable seed and air-dried soil from each respective location. Only freshly harvested canola seed was buried and secondary dormancy potential was determined in the lab (2000 HD = 64.5% , LD = 4.8%; 2001 HD = 29.3%, LD = 3.8%). Wheat was seeded (100 kg ha^{-1}) between the rows of pots in 2001 and 2002.

In each experiment, 32 samples were exhumed from each location at each sampling time. Sampling occurred mid-month and the intervals are indicated in Figures 5 and 6. Following removal from the field, the plastic pots were placed in a dark growth cabinet at 15^{o}C and irrigated as necessary. Seedling recruitment was monitored for two weeks (germinable portion of the seedbank), after which the remaining seeds (ungerminable portion of the seedbank) were elutriated as previously described by Gulden et al. (200x). All elutriated seeds were transferred to petri plates that were irrigated and placed in a dark cabinet (15^{o}C) for one week where germination was evaluated. All presumably dormant seeds were then subjected to stratification (1 week at 3^{o}C), followed by another week of dark germination to determine their viability. All dormant, but viable seeds were considered part of the ungerminable seedbank. Elutriation was conducted in a shed at ambient temperatures and under fluorescent lighting. In the 2002 experiment established in the fall of 2001, the top 7 to 8 cm of the soil was removed from two repetitions of the 10 cm burial depth samples immediately prior to placing the plastic pots into the growth cabinet. This was done in lieu of the nylon-mesh pouches to determine the readily germinable portion of the seedbank.

Soil temperatures were measured for the duration of the experiments. Daily mean, minimum and maximum temperatures at 1 and 10 cm were recorded in one repetition of each tillage system using a CR10 data logger (Campbell Scientific, AB, Canada) with four thermocouples per treatment connected in series. Gravimetric soil moisture (*S.M.*) was determined at each sampling date. Soil water potential was determined by generating standard curves for each soil ranging from 6 to 30% gravimetric soil moisture content using a W4P PotentiaMeter (Decagon devices Inc.,WA, USA). Water potential was converted to absolute

values before both, the independent and dependent variables were log transformed. Linear regression analysis was conducted and water potentials were determined from mean soil moisture contents

($\Psi_{Clay} = -10^{(3.78-3.22*\log(\%S.M.))}$, r^2 = 0.97, 3df; $\Psi_{Loam} = -10^{(5.17-4.84*\log(\%S.M.))}$, r^2 = 0.94, 3df).

In the genotype comparison study, secondary seed dormancy among genotypes was expressed as a percentage of viable seed. No differences in seed viability and primary dormancy were observed among the genotypes. In the second laboratory experiment, seed dormancy induction rates were determined by linear regression analysis of square root transformed dormancy percentages of each replicate of each temperature and initial osmotic potential combination over time (3 df) and standard error of the means were determined. In the field experiment, aall seedling and seed counts were converted to percent of original seedbank. The appropriate standard errors of the means were calculated.

Results and Discussion

Lab Experiments

In the first laboratory experiment, we observed a wide range of secondary seed dormancy expression among commercially available Canadian spring *B. napus* genotypes (Table 7). Nevertheless, most genotypes, including those tolerant to herbicides, tended to display high potential for secondary seed dormancy expression, while few genotypes exhibited low expression of secondary seed dormancy immediately following harvest. In general, seed dormancy levels observed here were higher than those previously reported (Momoh et al. 2002; Pekrun et al. 1997b).

The rates of dormancy induction in two *B. napus* genotypes were then compared with high (HD) inherent potential for seed dormancy expression using a range of temperatures and water potentials that approximate the range of those that might be experienced in the field during the growing season. As the treatment temperature increased, an increase in seed dormancy induction rate was observed, irrespective of the difference between the induction temperature and germination test temperature (15^{o}C) (Figure 4). Low dormancy induction rates at 5^{o}C were more likely due to this temperature's proximity to the ideal stratification temperature (2 to 4^{o}C) rather than a function of the increase in absolute temperature difference between the induction and germination temperatures. As previously reported (Pekrun et al. 1997), decreasing osmotic potential to values approaching the permanent wilting point in soils (*ca.* –1.5 MPa) also increased seed dormancy induction rates. When examining the variance components in this study, temperature (48%) contributed 2.7-fold more to the total variation in the rate of seed dormancy expression than osmotic potential (18%). Temperature principally controls seed dormancy in species that exhibit annual dormancy cycles (Baskin and Baskin 1977; Baskin and Baskin 1985; Baskin and Baskin 1988). Although in *B. napus*, darkness and osmotic stress are obligatory for high levels of secondary seed dormancy expression, temperature is of great importance in regulating the dormancy phenotype.

TABLE 7. Secondary seed dormancy expression in 21 *B. napus* genotypes. The standard errors are shown in parentheses.

Genotype	Secondary Seed Dormancy
	----------%----------
AC Excel	90.9 (0.9)
LG 3295 *	90.0 (5.0)
InVigor 2473 *	88.4 (2.4)
InVigor 2273 *	88.0 (3.3)
SW Rider *	87.1 (0.4)
InVigor 2463 *	86.1 (0.1)
LG3235 *	82.1 (2.1)
Magnum	80.8 (0.8)
Exceed *	79.6 (1.4)
Sentry	77.9 (1.4)
IMC 105	76.3 (1.5)
Nexera 500	74.4 (3.1)
46A73 *	72.1 (6.4)
Millennium 01	68.8 (2.8)
45A71 *	68.3 (4.0)
IMC 107 *	61.8 (2.3)
Hylite 201	60.6 (0.9)
IMC 106 *	48.6 (9.9)
Quantum	45.8 (8.8)
LG Dawn *	31.3 (1.8)
Option 501	16.6 (0.4)

* Denotes herbicide tolerant genotype with one of four different modes of action.

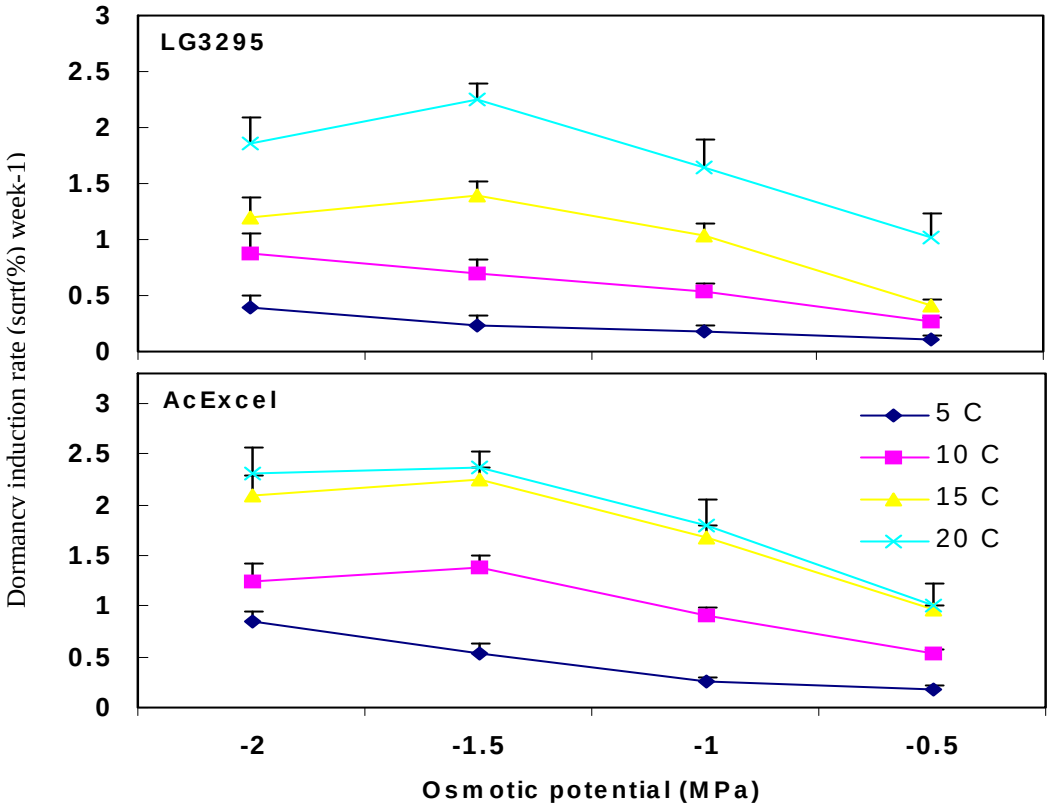


FIGURE 4. Rate of secondary dormancy induction as influenced by temperature and osmotic potential in two high dormancy *Brassica napus* genotypes. Error bar = 1 s.e.m.

Field Experiments

In the deep seedbank, higher levels of ungerminable seed (i.e. all seeds that did not germinate in the soil during 2 weeks at 15^{o}C) were observed in the HD genotype compared to the LD genotype throughout the growing season (Figures 5 and 6). In 3 of 4 site-years, we observed an increase in the ungerminable portion of the deep seedbank of the HD genotype as soil temperatures increased to those identified as ideal for dormancy expression in the previous experiment (Figure 4). This did not occur in the LD genotype (Figures 5 and 6). In contrast to previous reports (Pekrun et al. 1997a), we found no correlation between the ungerminable seedbank and the temperature difference between the mean soil temperature at the time of sampling and the germination test temperature (15^{o}C). In both genotypes, the total deep seedbank (germinable + all ungerminable) population had shifted entirely to an ungerminable state between June and July 2002. A measure of the total deep seedbank in the 2001 experiment was not available as an invasion of predatory insects into the buried nylon pouches that were intended for this purpose, destroyed all samples.

Although these experiments were not designed to provide evidence of an annual dormancy cycle *sensu stricto* (Baskin and Baskin 1985, Baskin et al. 1996; Bouwmeester and Karssen, 1992), our seedbank observations in the semi-arid environment of western Canada, indicated elements of such a cycle in the HD genotype (Figures 5 and 6). The ungerminable portion of the seedbank increased as soil temperatures increased and the total seedbank remaining was ungerminable throughout summer and fall. The increase in the ungerminable fraction was observed in the same cohort over two consecutive seasons at the clay soil location (Figure 5) and is typical of a dormancy/non-dormancy cycle in summer annuals (Baskin and Baskin 1985).

Similar deep seedbank dynamics were not observed in the HD genotype in the loam soil in 2001 (Figure 6). In the fall of 2000, the soil water potential at the 10 cm depth was high (–0.5 MPa) in the loam soil. This increased the potential for fall germination as well as seed death via desiccation throughout the winter. High survivorship over winter (Legere et al 2001) and the subsequent increase in ungerminability as soil temperatures increased was only observed in the HD genotype when soil water potentials were lower than –1.5 MPa prior to freeze up (Figures 5 and 6). These low fall soil water potentials appear to have preconditioned seeds of the HD genotype so that germination in the spring was largely prohibited, despite soil water potentials that would otherwise have been adequate for germination (> -1.0 MPa) (Rao and Dao, 1987).

At the shallow burial depth, seedbank dynamics differed from the buried seedbank. Despite inherent genetic differences in seed dormancy potential, total seedbank levels were negligible after June at all times (Figures 5 and 6). We believe these observations were primarily a function of the high diurnal temperature variations near the soil surface causing seed death. Lower seedbank persistence at shallow burial depths is typical in *B. napus* (Schlink 1995; Pekrun and Lutman 1998) and closely related species (Sparrow et al. 1990). From this depth, seedling recruitment was observed only in the months of May and June and was low (0.1 to 1.5% of original seedbank additions) due to low precipitation (data not shown).

The dormancy status of the ungerminable seedbank is less clear. Virtually all elutriated seeds (i.e. those washed from the soil) germinated immediately following this procedure and thus, provided little evidence of secondary innate dormancy (where germination is inhibited under all conditions) (Baskin and Baskin 1985). Similarly, seed dormancy induced in *B. napus* in the laboratory is also not deep in nature as only three days of stratification are required for the

release of dormancy (Momoh et al 2002; Pekrun et al. 1997a). Regardless, we established a clear link between seed dormancy as determined in the laboratory and seedbank dynamics and persistence under field conditions in this species.

These experiments have shown that the observed seasonal recruitment behaviour of *B. napus* in western Canada was the result of two fates. In the shallow seedbank, the lack of seedling recruitment was the result of high seed mortality during winter and early spring. When buried, however, a shift in the seedbank population from a germinable to an ungerminable state was the primary mechanism preventing germination, particularly in the HD genotype. Although germination may have been an important means of seed loss from the deep seedbank, it was lethal in all cases as the deep seedbank was buried below the biological maximum depth of recruitment of this species (max. 8-9 cm) (Lutman 1993). The seedbank dynamics of *B. napus* documented here are characteristic of small seeded annual weeds in temperate regions (Baskin and Baskin 1988) and clearly indicate that canola does possess weedy characteristics that may influence management strategies for feral populations.

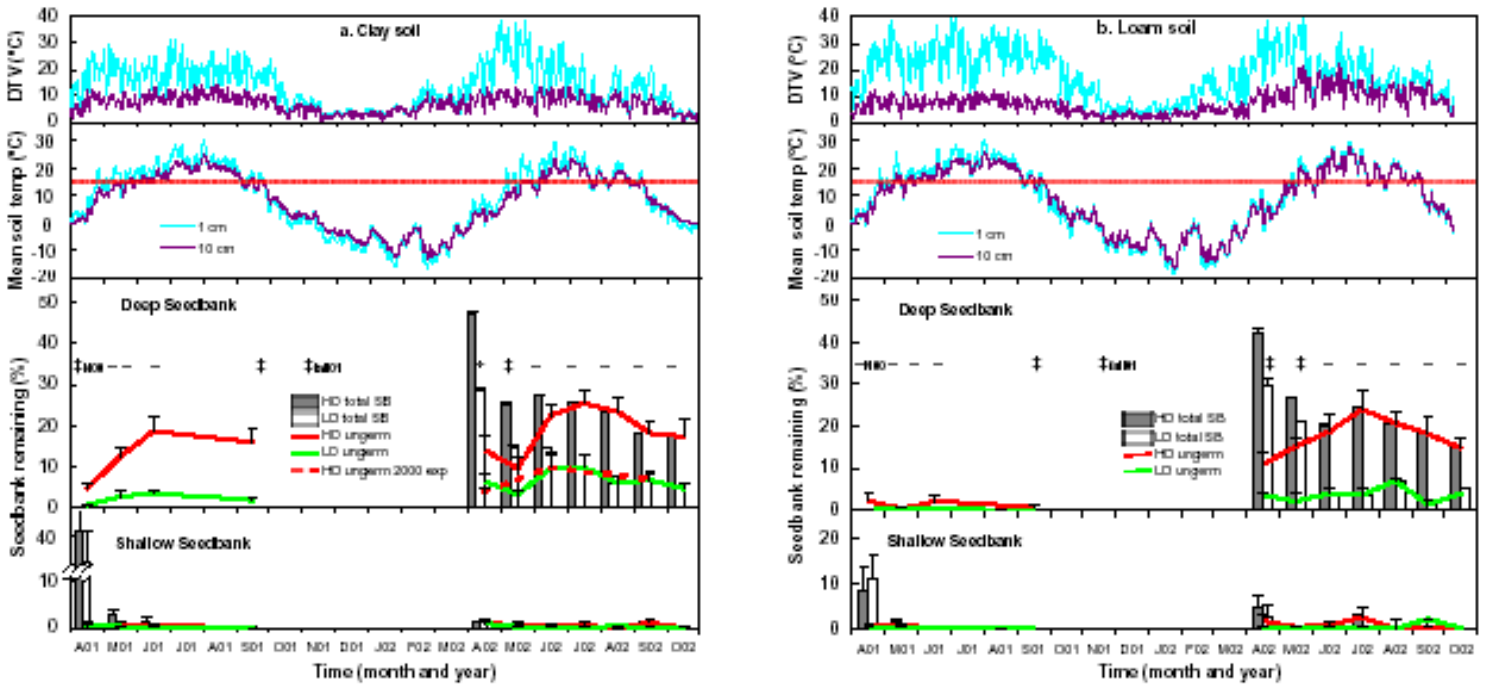


FIGURE 5. Mean and diurnal temperature variations (CTV=max-min) at two depths in clay (a; Kernen) and loam (b; Dundurn) soils. Ungerminated and total seedbank of two *Brassica napus* genotypes with divergent seed dormancy potentials (HD=high, LD=low) at 10 cm (deep) and 1 cm (shallow) burial depths. Symbols in deep seedbank indicate soil water potential at the time of sampling as well as fall 2000 (- > -0.5 MPa, + -0.5 to –1.0 MPa, ‡ < -1.0 MPa). Error bar = 1 s.e.m.

3.3 Conclusions

Data showed that secondary seed dormancy expression was primarily controlled by genotype. The small influence of pre- and post-dissemination environment, in comparison to genotype, suggests that these findings are applicable over a wide geographic area. Findings also suggest that producers windrow their crop as close to the recommended date of windrowing as possible, as late windrowing (two weeks) may increase the potential for secondary seed dormancy expression (Figure 1) in addition to increasing the likelihood of seed shatter. If volunteer canola persistence is to be minimized, however, a low dormancy genotype should be grown (Gulden et al. 2003) as factors other than genotype contribute relatively little to secondary seed dormancy expression in Canadian spring *B. napus* genotypes.

Seedbank persistence differences among tillage systems were less pronounced compared to results previously reported in winter canola in the UK (Pekrun and Lutman, 1998). This may, in part, be due to climatic differences as well as the more shallow tillage operations in western Canada, that leave the bulk of the seedbank closer to the soil surface relative to the UK (Clements *et al.* 1996). The proportion of persisting seeds tended to be higher in the CT than ZT due to lower seedbank mortality, but no clear distinction in seedbank persistence in terms of absolute time could be made between these two tillage systems. The results agree with previous observations in western Canada that have indicated no clear advantage of ZT over CT in reducing the longevity of the volunteer canola seedbank (Légère *et al*. 2001). In *B. napus*, secondary seed dormancy potential contributed to higher seedbank persistence and volunteer seedling recruitment over time. Both observations were a result of lower seedbank mortality in HD genotypes. As a result, it is recommended that low dormancy genotypes be grown if the potential for volunteer populations is to be minimized. Unfortunately, information with respect to the seed dormancy potential of individual genotypes is currently not readily available to producers. In this study, initial seedbank additions were lower than on-farm harvest losses (Gulden *et al.* 2003). Nevertheless, some persistent seeds as well as volunteer seedling recruitment were observed 3 years after seedbank initiation, even at low initial seedbank levels and when seedbank replenishment was not allowed. Adequate temporal separation (at least 4 years) between subsequent canola crops of different quality and herbicide tolerance characteristics is therefore essential in fields where pollen-mediated gene flow and direct seed contamination from volunteers are to be minimized. With regards to this study, all volunteer canola seedling recruitment occurred prior to the typical time of in-crop weed control. Therefore, it would have been possible to control volunteer canola populations using in-crop herbicides.

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3.4 Further Research

This study did not examine the contribution of reseeding volunteers to the volunteer canola seedbank. Similarly it did not examine any effect of out-crossing or multiple resistance on the population dynamics of volunteer canola.

3.5 Information of Benefit to Producers. Processors, or Goverment

Producers should attempt to reduce seed loss at harvest to prevent canola seeds from introduced to the weed seedbank. As early swathing does not increase dormancy, producers should swath at the recommended time and attempt to avoid seed shatter. Operating the combine properly will reduce seed loss somewhat and devices such as chaff collectors will reduce separator losses. However these devices will have no effect on swathing or pickup seed losses.

Following harvest, producers should not deep till their fields as canola seed that remains near the soil surface does not persist as long. We think that suicidal germination and death from the wide temperature fluctuations kills much of this shallowly buried seed. Volunteers should be controlled in crop to eliminate the chance of the seedbank being replenished. In our studies all of the volunteer canola always emerged before the timing of the in-crop herbicide application so there should be opportunity to control volunteer canola with herbicides. However, in some circumstances such as Clearfield® volunteer canola growing in peas, there will be no herbicide options. To avoid these situations, producers should carefully plan their crop rotations so that herbicide options exist for controlling volunteers.

It is recommended that the canola seed industry begin to screen new canola varieties for dormancy induction using the lab assay refined in this project. As this characteristic is stable in different years and locations we believe it to have a strong genetic control. By only releasing canola varieties with a low potential for induction into secondary dormancy, the persistence of volunteers should be drastically reduced. This step combined with good in-crop control of volunteers should reduce the prevalence of volunteer canola as a weed in western Canada.

4.0 Personnel

A personnel report will be supplied.

5.0 Equipment

No equipment was purchased.

6.0 Project Developed Materials

Gulden, R.H., S.J. Shirtliffe and A. G. Thomas. 2003. Harvest losses of canola (*Brasica napus*) cause large seedbank inputs. Weed Sci. 51: 83-86.

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Credit to ADFRR and SPG is included in all of these publications.

7.0 Project Photos

Several digital images and PowerPoint presentations of the project are available on a CD-ROM from the author.

8.0 Acknowledgements

Support for this project was described at the following :

Gulden, R.H., Shirtliffe, S.J., and Thomas, A.G. 2003. Volunteer Canola: The Weed We Seed. Pioneer Co-op Cabri Farm Center Agronomy day. Mar 5, 2003. Presentation.

Shirtliffe, S. J., R.H. Gulden and A. G. Thomas. 2002. Volunteer Canola: The Weed We Seed. *Canadian Association of Agri-Retailers meetings.* Nov 28, 2002. Presentation.

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Gulden, R. H., Shirtliffe, S. J., and Thomas, A. G. 2002. Volunteer canola (*B. napus*) in western Canada. *Soils and Crops 2002*. Feb. 21-22, 2002, Saskatoon SK. Presentation and Paper.

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Gulden, R.H. and S.J. Shirtliffe. 2000. Differences in the secondary dormancy of canola varieties. *Weed Science Society of America, Abstract. Toronto, ON.* February 5-10. Abstract of Poster Presentation.

9.0 Expense Statement

An expense statement will be supplied by the U of S business office.